Alaska Exclusive Economic Zone: Ocean Exploration and Research

Bibliography

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Background

In preparation for future work in the Alaska region, the NOAA Office of Ocean Exploration and Research (OER) in collaboration with the NOAA Central Library conducted a literature review of the current state of science and management priorities in Alaskan waters. OER plans to use this literature review to identify unexplored and under-described areas in the Alaska region and to narrow the focus for more information regarding exploration priorities in the region.

OER is the only federal program dedicated to exploring our deep ocean. By leading national efforts to explore our ocean and making ocean exploration more accessible, OER is filling gaps in the basic understanding of U.S. deep waters and seafloor and providing the critical deep-ocean data, information, and awareness needed to strengthen the economy, health, and security of our nation.

Scope

This literature review focuses on peer-reviewed publications and government, Alaskan native, IARPC (Interagency Arctic Research Policy Committee), and other technical reports within the last twenty years (2000 to present) by U.S. and international scientists. Its scope is focused on Alaskan waters deeper than 200 meters within the U.S. Exclusive Economic Zone (EEZ), as well as high-priority areas in the high seas. It is not an exhaustive review, but provides an overview of previously conducted research. Six disciplines of interest are identified in this annotated bibliography: 1) biology and ecology of benthic and pelagic taxa (from microbes to megafauna), 2) chemistry, 3) physical oceanography, 4) geology, 5) marine cultural heritage, and 6) management. Recurring topics are summarized within each discipline:

Biology and ecology of benthic and pelagic taxa (from microbes to megafauna) - A major topic identified by this bibliography for biological studies in Alaska is *fisheries*. There are significant commercial and subsistence fishing activities in Alaska. Studies generally focus on target species and their distributions (e.g., Sohn et al., 2010), life histories (e.g., Abookire, 2006), and growth rates (e.g., Ainsley et al., 2011; Matta et al., 2017). There is also interest in identifying essential fish habitat for spatial protections and management (e.g., Laman et al., 2018), especially in the face of climate change impacts such as ocean acidification (Ekstrom et al., 2015; Mathis et al., 2015). Also of great interest is the sustainable management of Alaskan fisheries, including holistic approaches (Moffit et al., 2016; MacLean et al., 2017) and resilience to shifting baselines (Jeffers, 2010; Hollowed et al., 2020). Geographically, the majority of studies are focused on the Gulf of Alaska and the eastern Bering Sea.

Additionally, *corals and sponges* are widely distributed throughout Alaskan waters (Heifetz et al., 2005; Miller et al., 2015) with hotspots along the Gulf of Alaska continental margin (Rooper et al., 2017), Aleutian Islands chain (Heifetz et al., 2005), and Bering Sea submarine canyons (Miller et al., 2015). Development and validation of habitat models for these taxa are of great interest to the scientific community (e.g., Bryan & Metaxas, 2007; Masuda & Stone, 2015). Model validation has been conducted for the Aleutian Islands (Rooper et al., 2018) and Bering Sea (Rooper et al., 2016), but are still needed for the Gulf of Alaska. Corals and sponges are ecosystem engineers that form habitat structure for other organisms (Krieger & Wing, 2002; Etnoyer & Morgan, 2005), such as commercially important fish (Miller et al., 2012). As a result, they can be vulnerable to fishing impacts (Hourigan, 2015; Malecha & Heifetz, 2017; Wilborn et al., 2018) from which they can be slow to recover (Andrews et al., 2002; Heifetz et al., 2009).

Chemistry - Alaskan waters play an important role in the *global carbon cycle* (Bates & Mathis, 2009), encompassing both highly productive and high-nutrient, low-chlorophyll areas (Aguilar-Islas et al., 2016). Nutrient and primary production can be highly dynamic in space and time (Coyle et al., 2019). Additionally, climate change impacts on the carbon cycle, both regionally and globally, are actively being studied. At high latitudes, sea ice is a significant driver of vertical mixing and stratification, driving nutrient distributions and subsequent primary production (Druckenmiller et al., 2009). Changes in the timing and magnitude of sea ice cover and loss have downstream effects on primary production, the food webs they support, and the overall carbon cycle (Dupont, 2012). Higher latitude areas (i.e., Chukchi Sea, Beaufort Sea, and Arctic Ocean) seem to be the geographic focus for this theme.

Also related to carbon, *ocean acidification* and resulting changes in marine carbonate chemistry have significant downstream effects on chemical (Biastoch et al., 2011; Mathis et al., 2011) and biological processes (Long et al., 2013; Mostofa et al., 2016). High latitudes, which already experience seasonal carbonate undersaturation (Bates et al., 2013), can be especially vulnerable due to their high carbon dioxide solubility and ocean mixing patterns (Fabry et al., 2009). Carbonate dynamics are not only determined by atmosphere-sea gas exchange (Evans et al., 2015) but also by currents and circulation (Zhong et al., 2019). In Alaskan waters, there are many studies related to ocean acidification impacts on fisheries and related taxa (e.g., Sigler, 2008; Punt et al., 2014), as well as other ecological impacts (e.g., Reum et al., 2020). Other chemistry topics of interest include other element and nutrient cycling, trace metals, methane seeps, and hydrothermal vents.

Physical oceanography - The *currents and circulation* in Alaskan waters are highly dynamic with several water masses merging and dividing over complex bathymetry (Kelly et al., 2019; Lin et al., 2019; Pickart et al., 2019). There seems to be great scientific interest in modeling these flow regimes (e.g., Li et al., 2019; Shroyer & Pickart, 2019), especially in the Gulf of Alaska (e.g., Jarosz et al., 2017; Hristova et al. 2019), as well as identifying *transport of sediment and nutrients* between water masses (e.g., Stabeno et al., 2002; Halverson et al., 2013; Spall et al., 2018). Other topics covered include mesoscale features, coastal influence, and climate change impacts.

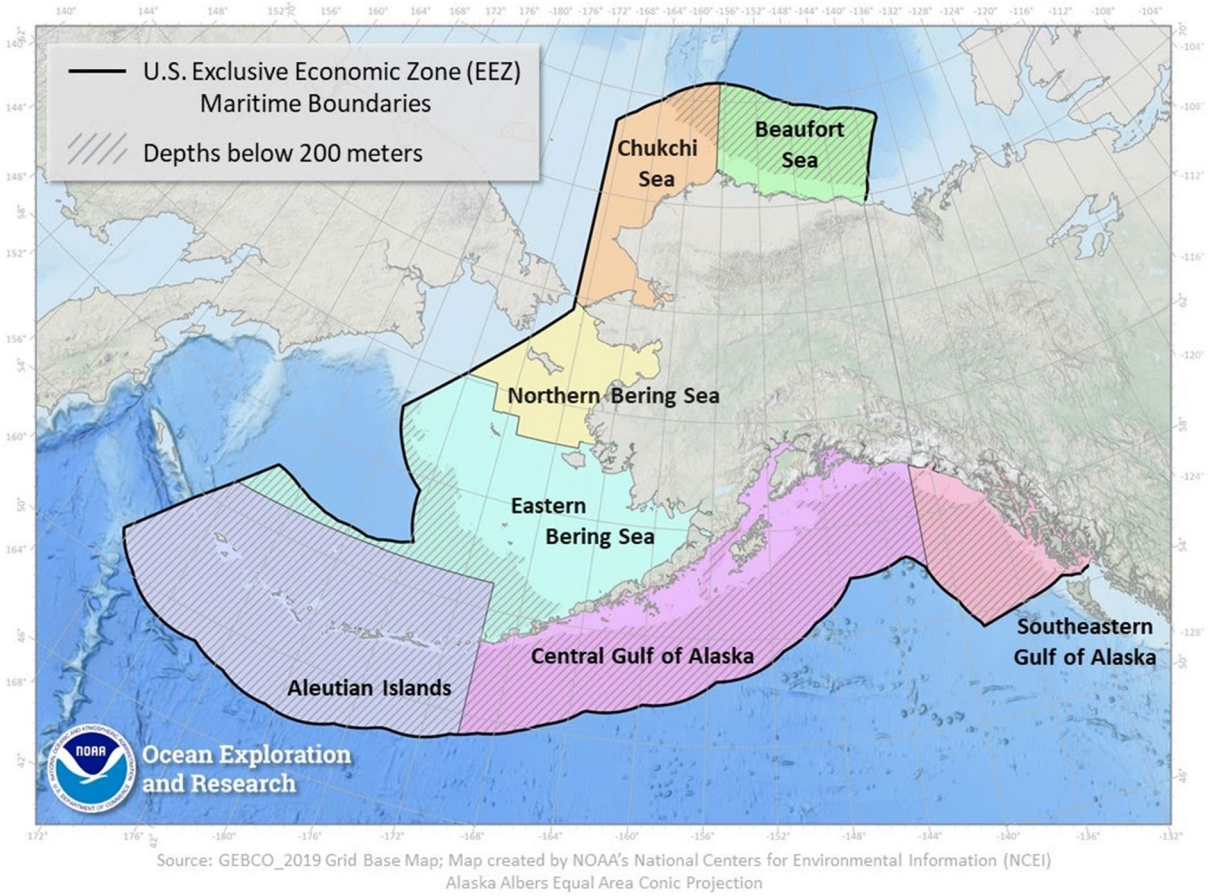
Geology - The literature listed depicts *past geological and oceanographic environments* for several Alaskan regions that are inferred from Late Paleozoic (e.g., Kossovaya et al., 2018), early Mesozoic (e.g., Taylor et al., 2008), and Quaternary (e.g., Brothers et al., 2019) paleontological and geomorphological evidence. Other papers are focused on Alaska's complex, and active, geological and tectonic structures and processes. The complex bathymetry and geomorphology of the Alaska region have inspired scientific interest in *mapping and characterizing geological features* (e.g., Rathburn et al., 2009; Swartz et al., 2015; Zimmerman et al., 2019). The Queen Charlotte-Fairweather Fault system, which is a transform boundary between the Pacific and North American plates characterized by frequent seismic events (e.g., Barrie et al., 2013; Greene et al., 2019; Brothers et al., 2020), is of particular interest in the southeastern Gulf of Alaska. The geological history of the Alaska region is also of interest in light of its possible role providing stepping stones for biotic dispersal, including humans, between the present-day North American and Eurasian continents (Carrara et al., 2007; Caruthers et al., 2008; Fedorowski et al., 2014).

Alaskan natural resources can potentially contribute to the development of the blue economy, relative to *critical minerals, oil, and gas*. Rare earth elements and other commercially valuable minerals have been identified in the Bering (Zhou et al., 2007) and Chukchi Seas (Chen et al., 2003). The terrestrial North Slope of Alaska is of both scientific and commercial interest as a potential source of gas hydrates and other hydrocarbons (Collett et al., 2011; Spencer et al., 2011; Pan et al., 2020). In 2007, the U.S.

Geological Survey drilled the Mount Elbert Gas Hydrate Stratigraphic Test Well on the North Slope to assess the viability of gas hydrates as a commercial energy source (Hunter et al., 2011). The U.S. Bureau of Ocean Energy Management (BOEM) is also interested in oil and gas development in the Beaufort Sea (Durell & Neff, 2019). Although outside of our 20-year scope, BOEM and its predecessor, the Minerals Management Service, have done extensive bathymetric surveys in the Alaska region related to potential targets for the energy industry (e.g., BOEM 2014, 2016); these reports are included. Also of interest are volcanism, geo-hazards, the Aleutian Trench, methane seeps, and hydrothermal vents.

Marine cultural heritage - The Alaska region is rich in marine cultural heritage as a result of its long history related to *human communities that are dependent on marine resources and commercial whaling*. The Bering Land Bridge provided a migration passage for humans and their settlement on the North American continent (McGillivary, 2005; Falk, 2011). Study of these early coastal communities is difficult due to their submergence underwater, but advances in technology have aided research efforts (McGillivary, 2005). Additionally, the mid-1800s to early 1900s saw the rise and fall of commercial whaling in the Arctic Ocean for oil and baleen. The intensive hunt for mainly bowhead whales led to their decline in numbers to the detriment of indigenous communities who depend on that resource. The shipwrecks associated with historic whaling represent a significant part of the Alaskan marine cultural history and heritage (Barr & Delgado, 2016). Other topics covered include paleoshorelines, plate reconstruction, extractive industries, and World War II Aleutian foreign occupation.

Management - *Current and future climate change impacts* are a pervasive theme in many studies (e.g., Auad, 2008; Logerwell et al., 2018; Cornish et al., 2020; Hollowed et al., 2020), both explicitly and implicitly. In addition to ocean acidification, ocean warming is changing physical processes (Donohue & Stacey, 2016), chemical processes (Biastoch et al., 2011), and biological processes (Reum et al., 2020). Ocean warming is also changing sea ice dynamics with significant chemical and biological impacts (Meier et al., 2014; Moore et al., 2018). Perhaps most importantly, these changes are increasing the *vulnerability of Alaskan human communities* that depend on sea ice for their survival and cultural heritage (Sakakibara, 2009; Ford & Pearce, 2010; Cozzetto et al., 2013). Other management topics of interest include spatial protection designations (marine protected areas, vulnerable marine ecosystems, ecologically or biologically significant areas), essential fish habitat, historic and current commercial activities, management needs, co-management of marine resources, traditional ecological knowledge, and subsistence use.



Map of the bibliography regional delineations in Alaskan waters. Regional delineations were made according to the identified science priorities within the bibliography and the NOAA Alaska Fisheries Science Center[1] survey and management areas. The northern Bering Sea is included as an emerging management interest due to loss of sea ice, shifting biological distributions, and general lack of commercial fishing activities. The southeastern Gulf of Alaska is also separated because it is regularly referenced in the literature, which often focuses on the local fault system and its downstream effects. Additionally, the "eastern" Beaufort Sea lies entirely outside of the U.S. EEZ, so is not depicted on the map but is included as a region in the bibliography. Regional sections of the bibliography that are listed without a cardinal direction, e.g., "Gulf of Alaska," are inclusive of all portions of the area, e.g., central and southeastern Gulf of Alaska. These delineations do not reflect OER operational or exploration priorities or any intention to fund future work in these regions.

[1]To date, the NOAA National Marine Fisheries Service has funded a significant amount of research conducted in Alaskan waters (https://www.fisheries.noaa.gov/region/alaska).

Sources Reviewed

The following databases were used to identify sources: Clarivate Analytics' Web of Science: Science Citation Index Expanded and Social Science Index; ProQuest's Science and Technology database, including Aquatic Science Fisheries Abstracts; Elsevier's Science Direct; JSTOR; EBSCO's Academic Search Complete and Environment Complete; NOAA's Institutional Repository; BioOneComplete; and Google Scholar.

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Section I: Aleutian Islands

Biology

Bond, A. L., Jones, I. L., Sydeman, W. J., Major, H. L., Minobe, S., Williams, J. C., & Byrd, G. V. (2011). Reproductive Success of Planktivorous Seabirds in the North Pacific Is Related to Ocean Climate on Decadal Scales. *Marine Ecology Progress Series,* 424, 205-U218. https://doi.org/10.3354/meps08975

Growing evidence indicates relationships between seabird demography and both large- and small-scale variation in climate and oceanography, yet few studies have examined multiple species and locations simultaneously. As secondary consumers, least, whiskered, and crested auklets (Aethia pusilla, A. pygmaea, and A. cristatella, respectively), congeneric planktivorous seabirds endemic to the Bering and Okhotsk seas, are expected to respond to changes in ocean climate due to their low trophic positioning. From 1990 to 2008, we measured reproductive success (productivity) and breeding phenology (mean hatching date) of auklets on Buldir, Kiska, and Kasatochi, 3 islands spanning 585 km across the Aleutian Islands, Alaska, USA. A model including Island, Species, and Winter Aleutian Low Pressure Index (ALPI) best explained productivity, with reproductive success decreasing among all species with increasing ALPI (beta = -0.273 +/- 0.0263 [SE]), likely through control of water temperature and prey (zooplankton) availability. Auklet productivity also increased with increasing winter sea surface temperature (SST) in the western North Pacific and western Bering Sea (and correspondingly decreased with increasing SST in the Gulf of Alaska), and was correlated negatively with spring sea-level air pressure in the North Pacific. These responses are reflective of positive values of the Aleutian low pressure system. Though our datasets cover only 19 yr or less, we found similar correlations between climate and auklet productivity among all species and islands. Together, our results suggest that ocean climatic conditions and reproductive success of planktivorous auklets are significantly related.

Bond, A. L., Jones, I. L., Williams, J. C., & Byrd, G. V. (2012). Diet of Auklet Chicks in the Aleutian Islands, Alaska: Similarity among Islands, Interspecies Overlap, and Relationships to Ocean Climate. *Journal of Ornithology,* 153(1), 115-129. https://doi.org/10.1007/s10336-011-0704-3

Seabirds are effective samplers of the marine environment, and can be used to measure resource partitioning among species and sites via food loads destined for chicks. We examined the composition, overlap, and relationships to changing climate and oceanography of 3,216 food loads from Least, Crested, and Whiskered Auklets (Aethia pusilla, A. cristatella, A. pygmaea) breeding in Alaska during 1994-2006. Meals comprised calanoid copepods (Neocalanus spp.) and euphausiids (Thysanoessa spp.) that reflect secondary marine productivity, with no difference among Buldir, Kiska, and Kasatochi islands across 585 km of the Aleutian Islands. Meals were very similar among species (mean Least-Crested Auklet overlap C = 0.68; Least-Whiskered Auklet overlap C = 0.96) and among sites, indicating limited partitioning of prey resources for auklets feeding chicks. The biomass of copepods and euphausiids in Least and Crested Auklet food loads was related negatively to the summer (June-July-August) North Pacific Gyre Oscillation, while in Whiskered Auklet food loads, this was negatively related to the winter (December-January-February) Pacific Decadal Oscillation, both of which track basin-wide sea-surface temperature (SST) anomalies. We found a significant quadratic relationship between the biomass of

calanoid copepods in Least Auklet food loads at all three study sites and summer (June-July) SST, with maximal copepod biomass between 3-6A degrees C (r (2) = 0.71). Outside this temperature range, zooplankton becomes less available to auklets through delayed development. Overall, our results suggest that auklets are able to buffer climate-mediated bottom-up forcing of demographic parameters like productivity, as the composition of chick meals has remained constant over the course of our study.

Bond, M. H., Miller, J. A., & Quinn, T. P. (2015). Beyond Dichotomous Life Histories in Partially Migrating Populations: Cessation of Anadromy in a Long-Lived Fish. *Ecology,* 96(7), 1899-1910. https://doi.org/10.1890/14-1551.1

Across animal taxa, migration allows individuals to exploit habitats and resources that predictably vary seasonally in suitability. Theory predicts that the decision to migrate or not is shaped by the relative fitness costs and benefits of exhibiting a given life history. Adoption of a migratory strategy is widely thought to reflect a dichotomous outcome; individuals are either resident or migratory, and continue to exhibit this life history until death. In fishes, anadromy and freshwater residency represents a well-studied life history dichotomy. Resident individuals may adopt a migratory life history later in life, but migratory individuals are not known to abandon this pattern. Here, we investigated the fitness benefits, as measured by body size, of residency and anadromy in a salmonid fish, Dolly Varden, Salvelinus malma, in Alaska, and reveal a novel life history: cessation of migration by older, larger individuals. Otolith microchemical analysis of Dolly Varden showed that while most fish migrated to sea at least once in their lives, lifelong resident fish exist in streams with close proximity to the ocean. Moreover, the probability of seaward migration in any year of life decreased annually after an individual's fourth year, and no fish migrated after their eighth year, while the oldest fish were captured in their 11th year. Migration conferred a size advantage in young fish, but the size benefits of marine foraging declined in older fish, at which time fish increasingly retired from anadromy. Additionally, measurement of both natal otolith chemistry and the gonadosomatic index indicated a continued contribution to lifetime fitness, rather than senescence, in retired individuals. We suggest that the novel life history of reversion to residency by older fish is viable because foraging opportunities are subsidized by the predictable annual supply of energy-rich eggs and carcasses of spawning Pacific salmon.

Brewer, R. S., Norcross, B. L., & Chenoweth, E. (2017). Temperature- and Size-Dependent Growth and Movement of the North Pacific Giant Octopus (Enteroctopus dofleini) in the Bering Sea. *Marine Biology Research,* 13(8), 909-918. https://doi.org/10.1080/17451000.2017.1309436

Octopus growth and movement occurs during all life stages and have implications for survival, food web dynamics and reproduction. From 2009 to 2011, 1714 North Pacific giant octopus (Enteroctopus dofleini) were tagged and recaptured in the eastern Bering Sea with visible implant elastomers to better understand the ecology of this data-poor species. Over this period, 246 of the tagged individuals were recaptured. In autumn, when temperatures were warmest, E. dofleini had higher growth rates and moved more than in the colder winter months. For both short-and long-term recaptures, small octopus grew faster than large octopus. Movement of octopus over short-and long-term periods was low for very small and very large octopus and high for median-sized octopus, which is likely to be a function of maturity status and reproductive activities. Approximately 80% of recaptures moved less than 2 km from the initial tagging location for time periods up to a year, suggesting long-term site fidelity. As

temperature and size may be tightly linked to growth and movement rates for E. dofleini in the eastern Bering Sea, predicted climate warming will likely alter ecological processes for the species and impact their distribution.

Brooke, S., & Stone, R. (2007). Reproduction of Deep-Water Hydrocorals (Family Stylasteridae) from the Aleutian Islands, Alaska. *Bulletin of Marine Science,* 81(3), 519-532. Retrieved from https://www.ingentaconnect.com/contentone/umrsmas/bullmar/2007/00000081/00000003/art00016

Previous studies in the Aleutian islands have found dense coral "gardens" dominated by hydrocorals, gorgonians, and sponges between 117 and 338 m depth, These structurally complex habitats supported a high taxonomic diversity of corals and associated fauna, but disturbance from fishing activities was observed at many of the sites. In 2003 and 2004, the submersible DELTA was used to collect samples of 11 different species of hydrocorals from deep-water sites along the Aleutian Island Archipelago. Samples of three species were also collected from shallow water (< 27 m) in 2003 using SCUBA. All samples were processed according to standard histological techniques and used to describe the reproductive traits of each species. All species studied were gonochoristic brooders with the majority of gonophores containing mature embryos or planulae. The developmental stage of gametes within a single specimen was not highly synchronized; females contained eggs as well as planulae, and males exhibited a range of gamete development. These reproductive traits indicate that hydrocorals have limited potential to recolonize disturbed areas in the Aleutian Islands.

Cairns, S. D., & Bayer, F. M. (2005). A Review of the Genus Primnoa (Octocorallia : Gorgonacea : Primnoidae), with the Description of Two New Species. *Bulletin of Marine Science,* 77(2), 225-256. Retrieved from https://www.ingentaconnect.com/content/umrsmas/bullmar/2005/00000077/00000002/art00006

The four species and one additional variety of the genus Primnoa are revised, including descriptions and illustrations of all taxa. Two new species are described, Primnoa wingi from the Aleutian Islands and Primnoa notialis from the Subantarctic. Primnoa willeyi Hickson, 1915 is considered to be a variety of Primnoa pacifica Kinoshita, 1907. Primnoa is known to occur in the northern boreal Atlantic and Pacific and Subantarctic South Pacific at depths of 9-1029 m. It is particularly common throughout the Aleutian Islands, where it is often a bycatch of fishery trawling and sometimes made into jewelry.

Cairns, S. D., & Lindner, A. (2011). A Revision of the Stylasteridae (Cnidaria, Hydrozoa, Filifera) from Alaska and Adjacent Waters. *Zookeys*(158), 1-88. https://doi.org/10.3897/zookeys.158.1910

The stylasterid fauna of Alaska is revised, consisting of the description or redescription and illustration of 21 species, one additional subspecies, and a geographically adjacent species: Stylaster venustus. Six new species and one new subspecies are described: Errinopora fisheri, E. undulata, E. disticha, E. dichotoma, Stylaster crassiseptum, S. repandus, and Stylaster parageus columbiensis. Four subspecies are raised to

species rank: Stylaster leptostylus, S. trachystomus, S. parageus, and Distichopora japonica, and five species and one subspecies were synonymized. A dichotomous key to the Errinopora species and tabular keys to the Errinopora and Alaskan Stylaster species are provided. The focus of the study was on the stylasterids from Alaska, primarily those from the diverse Aleutian Islands, but also including records from British Columbia. This is the first revisionary work on this fauna since the seminal report by Fisher in 1938.

Chilton, E. A. (2010). Maturity and Growth of Female Dusky Rockfish (Sebastes variabilis) in the Central Gulf of Alaska. *Fishery Bulletin,* 108(1), 70-78. Retrieved from https://spo.nmfs.noaa.gov/content/maturity-and-growth-female-dusky-rockfish-sebastes-variabilis-central-gulf-alaska

The dusky rockfish (Sebastes variabilis) has recently been resurrected as a distinct species in the genus Sebastes. Reproductive biology and growth were examined for this redescribed species in the central Gulf of Alaska. Age and length at 50% maturity were 9.2 years and 365 mm fork length, respectively, which are lower than previously reported. Fertilized ova and eyed embryos were observed in April and evidence of postparturition was not observed until May. The gonadosomatic index decreased with the onset of postparturition in May. Von Bertalanffy growth parameters for female dusky rockfish, estimated from the maturity samples, were significantly different from growth parameters derived from Gulf of Alaska fishery-independent survey data.

Drew, G., Piatt, J. F., & Williams, J. (2018). Biological Responses of Crested and Least Auklets to Volcanic Destruction of Nesting Habitat in the Aleutian Islands, Alaska. *Auk,* 135(3), 477-485. https://doi.org/10.1642/auk-17-180.1

Crested Auklets (Aethia cristatella) and Least Auklets (A. pusilla) are crevice-nesting birds that breed in large mixed colonies at relatively few sites in the Aleutian Island archipelago, Bering Sea, Gulf of Alaska, and Sea of Okhotsk. Many of these colonies are located on active volcanic islands. The eruption of Kasatochi volcano, in the central Aleutians, on August 7, 2008, completely buried all crevice-nesting seabird habitat on the island. This provided an opportunity to examine the response of a large, mixed auklet colony to a major geological disturbance. Time-lapse imagery of nesting habitat indicated that both species returned to the largest pre-eruption colony site for several years, but subsequently abandoned it within 5 yr after the eruption. In 2010, a rockfall site in a cove north of the old colony site began to accumulate talus, and groups of auklets were observed using the site in 2011. Use of the new colony appeared to coincide with the abandonment of the old colony site by both species, though surface counts suggested that Least Auklets shifted to the new colony sooner than Crested Auklets. At-sea surveys of seabirds before and after the eruption indicated that both Crested and Least auklets shifted their at-sea distributions from the waters around Kasatochi Island to nearby Koniuji Island. In combination, at-sea counts and colony time-lapse imagery indicated that Crested and Least auklets using Kasatochi responded to the volcanic disturbance and complete loss of nesting habitat at the main colony on Kasatochi with dispersal either to newly created habitat on Kasatochi or to an alternate colony on a nearby island.

Goddard, P., Wilborn, R., Rooper, C. N., Williams, K., & Towler, R. (2017). Results of the 2012 and 2014 Underwater Camera Surveys of the Aleutian Islands. In *NOAA Technical Memorandum NMFS-AFSC-351*. https://doi.org/ 10.7289/V5/TM-AFSC-351

The 2012 and 2014 Underwater Camera Surveys of the Aleutian Islands conducted by NOAA Fisheries were the first comprehensive underwater camera surveys of corals and sponges in the Aleutian Islands. Two-hundred sixteen transects were successfully completed in an area which extended west from Akutan Island to Near Pass and north from Amchitka Island to the top of Bowers Bank. Each randomly selected transect was assigned to one of six geographical regions. Demersal populations of corals, sponges, hydrocorals, sea pens, sea whips, fishes, and crabs were sampled by drifting a stereo drop camera for 15 minutes at each transect. Survey results presented in this report include fish and crab composition and density, coral, sponge, sea pens, and sea whip density and height, and substrate composition for each transect. The Appendix lists survey region, start position, distance towed, swath, mean depth, and mean temperature for each transect completed.

Heifetz, J., Stone, R. P., & Shotwell, S. K. (2009). Damage and Disturbance to Coral and Sponge Habitat of the Aleutian Archipelago. *Marine Ecology Progress Series,* 397, 295-303. https://doi.org/10.3354/meps08304

Video imagery was examined to quantify seafloor disturbance and damage to corals and sponges relative to fishing practices in the central Aleutian Islands of Alaska. Corals and sponges were classified as damaged if they had broken skeletons, missing or broken branches, were torn (i.e. sponges) or detached from the seafloor, or were attached but lying on the seafloor. Disturbance was defined as any alteration to the seafloor or biota caused by fishing gear or natural events. Overall, 14% of corals and 21% of sponges were damaged, and disturbance was widespread and evident on most video transects. The proportion of damaged corals was significantly less ($p = 0.003$) in areas with little or no bottom trawl fishing versus areas with medium and high intensity bottom trawl fishing. For other gear types, damage was not significantly different among fishing levels. Damage for all corals was 7% in untrawled areas, 7% in low-intensity areas, 14% in medium-intensity areas, and 49% in high-intensity areas. For gorgonians, 5% were damaged in untrawled areas and 23% were damaged in high-intensity areas. For hydrocorals, damage was 10% in untrawled areas and 53% in medium-intensity areas. Hydrocorals were absent from high-intensity areas. About 40% of sea whips were damaged in high-intensity areas versus 1%, in other areas. While some protective measures have been implemented to halt the expansion of bottom trawl fishing to unfished areas, the conservation of coral and sponge habitat in fished areas is still of primary concern.

Heifetz, J., Wing, B. L., Stone, R. P., Malecha, P. W., & Courtney, D. L. (2005). Corals of the Aleutian Islands. *Fisheries Oceanography,* 14, 131-138. https://doi.org/10.1111/j.1365-2419.2005.00371.x

A unique feature of the benthic habitat in the Aleutian Islands is the presence of a highly diverse and abundant coral and sponge community. These communities likely provide important habitat for a variety of fish and invertebrate species. Summaries of historical data and recent direct observations with a submersible indicate that the Aleutian Islands may harbour the highest diversity and abundance of coldwater corals in the world. There are 69 documented taxa (species and subspecies) of coral in the

Aleutians of which 25 are endemic. Within the Aleutian Islands, there is an increase in diversity of corals west of about longitude 169 degrees W. This shift in diversity is consistent with the hypothesis of an ecological boundary in the vicinity of Samalga Pass. Given the endemism and high diversity and abundance of corals in the Aleutians, there is evidence that this region is the evolutionary centre of origin for some taxa of coldwater corals.

Hoff, G. R. (2009). Embryo Developmental Events and the Egg Case of the Aleutian Skate *Bathyraja aleutica* (Gilbert) and the Alaska Skate *Bathyraja parmifera* (Bean). *Journal of Fish Biology,* 74(3), 483-501. https://doi.org/10.1111/j.1095-8649.2008.02138.x

Embryo development events were correlated with egg-case changes for the Aleutian skate Bathyraja aleutica and the Alaska skate Bathyraja parmifera. Yolk absorption underwent two phases: that of steady absorption during early development and that of rapid yolk absorption during the final development stages. Total length (L(T)) for 50% of the pre-hatching embryos egg-case jelly disappearance was 92.04 mm (range 81-102 mm) and 99.36 mm (range 81-100 mm) for B. aleutica and B. parmifera, respectively, allowing the inner chamber to open to seawater flow. The tail filament underwent three phases of growth: rapid elongation during early development (< 100 mm embryo L(T)), stasis of tail filament length during the remainder of embryo development and rapid absorption soon after hatching. Complete tail filament development coincided with the disappearance of egg-case jelly. Clasper buds first developed at embryos > 70 mm L(T) for both species and the sex ratio was 1:1 well before hatching. Egg cases that were devoid of an ova or developing embryo were c. 5.0 and 6.5% of the egg cases examined for B. aleutica and B. parmifera, respectively. Measurements showed that egg cases containing only egg jelly were smaller in both width and length than those possessing an ova. Embryo stages were punctuated with distinct events that correlated with egg case changes controlling the internal environment of the developing embryo.

Horvath, E. A., & Stone, R. P. (2018). Another Unusual New Gorgonian (Anthozoa: Octocorallia: Plexauridae) from the Aleutian Islands of Alaska. *Zootaxa,* 4524(1), 112-120. https://doi.org/10.11646/zootaxa.4524.1.8

An unusual new species of plexaurid octocoral, Alaskagorgia splendicitrina, is described from a specimen collected in the far west Aleutian Island Archipelago, Alaska, USA. Unusual features that separate it from its only congener include: the vibrant yellow color of the live colony and an arborescent growth form with numerous coiling and twisting branches, the pale yellow color of the sclerites and the lack of small and densely warted double-headed sclerites. The new species is represented by only a single specimen despite extensive sampling in the region during the past several decades; the speculation is that it radiated from the much less explored region to the west.

Hunt, G. L., & Stabeno, P. J. (2005). Oceanography and Ecology of the Aleutian Archipelago: Spatial and Temporal Variation. *Fisheries Oceanography,* 14, 292-306. https://doi.org/10.1111/j.1365-2419.2005.00378.x

This compilation of new information and summaries of earlier work emphasizes variability within marine waters of the Aleutian Archipelago. From the Alaska Peninsula to Near Strait, net flow through the passes is northward, with four passes (Amukta, Amchitka, Buldir, and Near Strait) contributing most of the flow. East of Samalga Pass (169 degrees W), waters derived from the Alaska Coastal Current predominate, whereas west of Samalga Pass, waters of the Alaskan Stream predominate. The pattern of storm tracks creates a climatological (interannual and long term) transition zone in weather features (e.g. surface air temperature) near 170 degrees W. The marine ecosystem of the Aleutian Archipelago also has a strong discontinuity at Samalga Pass, where cold-water corals, zooplankton, fish, marine mammals and foraging seabirds show a step change in species composition. Diets of ground fish, Steller sea lions (Eumetopias jubatus) and some seabirds also change there. Lower growth rates of some fish species and stable isotope data indicate that productivity declines westward along the archipelago. The available data demonstrate considerable ecosystem variability over time scales of decades to millennia. Abrupt changes in composition of fish communities at several of the major passes suggest that Samalga Pass may mark only one of several ecological divisions of Aleutian waters. This spatial and temporal heterogeneity provides an important context within which to view recent declines in populations of Steller sea lions and other species, and has important implications for the management of regional marine resources. We conclude that the marine waters of the Aleutian Archipelago are divided into at least two different ecological regions, with potential for a concomitant separation of some fishery resources.

Laman, E. A., Kotwicki, S., & Rooper, C. N. (2015). Correlating Environmental and Biogenic Factors with Abundance and Distribution of Pacific Ocean Perch (Sebastes alutus) in the Aleutian Islands, Alaska. *Fishery Bulletin,* 113(3), 270-289. https://doi.org/10.7755/fb.113.3.4

In the Aleutian Islands, patterns of distribution and abundance of Pacific ocean perch (Sebastes alutus) are influenced by oceanographic processes and biogenic structures. We used generalized additive modeling (GAM) to examine relationships between these predictors and patterns of settled juvenile and adult distribution and abundance from bottom trawl surveys conducted from 1997 through 2010. Depth, temperature, and location had the greatest influence, and biogenic structures co-occurring with this species improved predictions. Model results confirmed previously reported depth- and temperature-dependent patterns of Pacific ocean perch and revealed the elevated presence and abundance of this fish in proximity to Aleutian passes. Adults were more common and abundant in deeper (similar to 225 m) water than were juveniles (similar to 150 m), and the probability of encountering either life stage increased in the presence of fan- and ball-shaped sponges over moderate slopes and decreased with increasing tidal velocities. The GAMs accounted for one-quarter of the deviance for juvenile presence-absence (24.9%) and conditional abundance (25.0%) and accounted for 38.7% and 42.5% of the deviance for the same adult response variables. Although depth, temperature, and location were the dominant predictor variables of both juvenile presence and abundance, our results indicate that biogenic structures that provide vertical structure in otherwise low-relief, trawlable habitats may represent refugia for Pacific ocean perch juveniles and adults.

Lehnert, H., & Stone, R. P. (2015). New Species of Sponges (Porifera, Demospongiae) from the Aleutian Islands and Gulf of Alaska. *Zootaxa,* 4033(4), 451-483. Retrieved from https://www.biotaxa.org/Zootaxa/article/view/zootaxa.4033.4.1

Ten new species of demosponges, assigned to the orders Poecilosclerida, Axinellida and Dictyoceratida, discovered in the Gulf of Alaska and along the Aleutian Island Archipelago are described and compared to relevant congeners. Poecilosclerida include Cornulum globosum n. sp., Megaciella lobata n. sp., M. triangulata n. sp., Artemisina clavata n. sp., A. flabellata n. sp., Coelosphaera (Histodermion) kigushimkada n. sp., Stelodoryx mucosa n. sp. and S. siphofuscus n. sp. Axinellida is represented by Raspailia (Hymeraphiopsis) fruticosa n. sp. and Dictyoceratida is represented by Dysidea kenkriegeri n. sp. The genus Cornulum is modified to allow for smooth tylotes. We report several noteworthy biogeographical observations. We describe only the third species within the subgenus Histodermion and the first from the Indo-Pacific Region. Additionally, the subgenus Hymerhaphiopsis was previously represented by only a single species from Antarctica. We also report the first record of a dictyoceratid species from Alaska. The new collections further highlight the richness of the sponge fauna from the region, particularly for the Poecilosclerida.

Renner, M., Nelson, E., Watson, J., Haynie, A., Poe, A., Robards, M., & Hess, S. C. (2018). The Risk of Rodent Introductions from Shipwrecks to Seabirds on Aleutian and Bering Sea Islands. *Biological Invasions,* 20(9), 2679-2690. https://doi.org/10.1007/s10530-018-1726-z

Accidental introductions of rodents present one of the greatest threats to indigenous island biota, especially seabirds. On uninhabited remote islands, such introductions are likely to come from shipwrecks. Here we use a comprehensive database of shipwrecks in Western Alaska to model the frequency of shipwrecks per Aleutian and Bering Sea island, taken as a proxy for the threat of rodent introductions, using physical variables, and the intensity of nearby fishing traffic and activity as predictors. Using data spanning from 1950 to 2013, we found that shipwrecks were particularly common in the 1980s to early 2000s, with a major peak in wrecks during the late 1980s. Amount of fishing activity within 5 km of an island was the strongest predictor of shipwrecks, followed by the strength of tidal currents and density of large-vessel traffic. Islands with the highest frequency of shipwrecks are all in the eastern Aleutians, including Unimak, Unalaska, and Akun Islands. By contrast, the largest seabird colonies are in the western Aleutian and Pribilof Islands, including Buldir, Kiska, and Saint George islands. Multiplying the frequency of a shipwreck by the number of seabirds breeding per island provides a measure of risk. The risk of rodent introductions from shipwrecks to seabirds was then greatest for Saint George (Bering Sea), Buldir (Western Aleutians) and Saint Matthew islands (Bering Sea). Keeping these high-risk islands rodent free would maintain their high a conservation value. Most islands with a high predicted frequency of shipwrecks already have established rodent populations and therefore few remaining seabirds. Of those islands with established rodent populations, Attu and Kiska Islands would make suitable targets for eradication, given their relatively low expected frequency of shipwrecks for their size. Further improvements in rat prevention on vessels and shipping safety would benefit the economy, human health and safety, and to the long-term conservation of island ecosystems.

Rieser, A., Watling, L., & Guinotte, J. (2013). Trawl Fisheries, Catch Shares and the Protection of Benthic Marine Ecosystems: Has Ownership Generated Incentives for Seafloor Stewardship? *Marine Policy,* 40, 75-83. https://doi.org/10.1016/j.marpol.2012.12.028

Proponents of catch share-based fisheries have claimed ecological stewardship can result from the assignment of individual catch quotas. This claim is examined by analyzing the distribution of benthic habitat protection measures adopted by quota-owning industry sectors within the exclusive economic zones (EEZs) of the U.S. (Alaska), New Zealand, and high seas seamounts within the Southern Indian Ocean Deepsea Fishers Association (SIODFA) competence area. Results suggest the protection of both benthic ecosystems and essential fish habitat (EFH) are marginal at best when quota owners have primacy in determining the boundaries of bottom trawl closures. The majority of the areas in these three regions that are closed to trawling are too deep to fish, may not contain vulnerable marine ecosystems, and do not have high abundances of commercially important species. "Freezing the footprint" of bottom trawling is not the best method for benthic habitat protection in areas where the fishing industry is actively fishing vulnerable habitats. Analytical methods should be applied to help determine boundaries of future bottom trawl closures rather than allowing the fishing industry to place benthic protection areas (BPAs) in areas where they are not interested in fishing.

Rooper, C. N., Boldt, J. L., & Zimmermann, M. (2007). An Assessment of Juvenile Pacific Ocean Perch (Sebastes alutus) Habitat Use in a Deepwater Nursery. *Estuarine Coastal and Shelf Science,* 75(3), 371-380. https://doi.org/10.1016/j.ecss.2007.05.006

It is believed that juvenile habitats are important to determining recruitment to adult fish populations through density dependence that occurs in nursery areas. For deepwater marine fishes, the characteristics of nursery areas are generally unknown. The objectives of this study were to examine a potential nursery area for juvenile Pacific ocean perch (POP, Sebastes alutus), determine the specific microhabitats used by juvenile POP, and compare the distribution of juvenile POP to adults. Juvenile POP habitat use was examined at three sites near Samalga Pass in the Aleutian Islands. Presence or absence and density estimates of juvenile POP were made from underwater video collected at I I transects and from 6 bottom tows at the study sites. Juvenile POP were found predominantly in mixed sand and boulder substrata to the exclusion of most other habitat types. Juvenile POP were found within one body length of complex structure such as boulders, upright coral or sponges. There were higher densities of juvenile POP at the site south of Samalga Pass than at the other sites, while adult POP were found in highest abundance at the site north of Samalga Pass. An examination of large-scale patterns of juvenile and adult POP distribution indicates that juveniles use shallower depth zones on the continental shelf. Combined with the geographic separation we observed in this study, this suggests juvenile POP use nursery habitats that are different from adult POP. Conservation and management of this species should address the habitat requirements of juveniles to maintain the goal of healthy adult populations.

Rooper, C. N., Wilborn, R., Goddard, P., Williams, K., Towler, R., & Hoff, G. R. (2018). Validation of Deep-Sea Coral and Sponge Distribution Models in the Aleutian Islands, Alaska. *ICES Journal of Marine Science,* 75(1), 199-209. https://doi.org/10.1093/icesjms/fsx087

Spatial management of vulnerable benthic ecosystem components such as deep-sea corals and sponges requires adequate maps of their distribution. These maps are often based on statistical models of survey data. The objective of this project was to validate the predictions of existing presence or absence and abundance models of deep-sea corals and sponges in the Aleutian Islands that were based on bottom trawl survey data. Model validation was conducted by comparing bottom trawl survey model predictions to the observations of an in situ camera survey conducted at randomly selected locations. The measures of goodness of fit (area-under-the-receiver-operator-curve, AUC) for the bottom trawl survey model predictions of camera survey observations ranged from 0.59 to 0.77 (for sponges and coral, respectively) and indicated that the bottom trawl survey models predicted the probability of presence for corals accurately across the Aleutian Islands. The bottom trawl survey models explained as little as 3% of the variability in Stylasteridae density and up to 17% of the variability in coral density. These results indicate that models of deep-sea coral distributions based on presence and absence data from bottom trawl surveys can be accurate and can provide useful information for spatial management of these vulnerable taxa. However, for some other taxa, such as sponges, care should be taken interpreting the results of bottom trawl survey models. An interesting finding of this study was that the residuals from the bottom trawl survey model-camera density relationships were negative in areas that remained open to fishing after 2005, possibly indicating an effect of continued bottom trawling on the abundance of corals in these areas. This study highlights the importance of validating models of species distribution using independent surveys, so that the results can be used with confidence to support decision-making processes.

Rooper, C. N., Wilkins, M. E., Rose, C. S., & Coon, C. (2011). Modeling the Impacts of Bottom Trawling and the Subsequent Recovery Rates of Sponges and Corals in the Aleutian Islands, Alaska. *Continental Shelf Research,* 31(17), 1827-1834. https://doi.org/10.1016/j.csr.2011.08.003

The abundance of some marine fish species are correlated to the abundance of habitat-forming benthic organisms such as sponges and corals. A concern for fisheries management agencies is the recovery of these benthic invertebrates from removal or mortality from bottom trawling and other commercial fisheries activities. Using a logistic model, observations of available substrate and data from bottom trawl surveys of the Aleutian Islands, Alaska, we estimated recovery rates of sponges and corals following removal. The model predicted the observed sponge and coral catch in bottom trawl surveys relatively accurately (R-2=0.38 and 0.46). For sponges, the results show that intrinsic growth rates were slow (r=0.107 yr(-1)). Results show that intrinsic growth rates of corals were also slow (r=0.062 yr(-1)). The best models for corals and sponges were models that did not include the impacts of commercial fishing removals. Subsequent recovery times for both taxa were also predicted to be slow. Mortality of 67% of the initial sponge biomass would recover to 80% of the original biomass after 20 years, while mortality of 67% of the coral biomass would recover to 80% of the original biomass after 34 years. The modeled recovery times were consistent with previous studies in estimating that recovery times were of the order of decades, however improved data from directed studies would no doubt improve parameter estimates and reduce the uncertainty in the model results. Given their role as a major ecosystem component and potential habitat for marine fish, damage and removal of sponges and corals must be considered when estimating the impacts of commercial bottom trawling on the seafloor.

Rooper, C. N., Zimmermann, M., Prescott, M. M., & Hermann, A. J. (2014). Predictive Models of Coral and Sponge Distribution, Abundance and Diversity in Bottom Trawl Surveys of the Aleutian Islands, Alaska. *Marine Ecology Progress Series,* 503, 157-176. https://doi.org/10.3354/meps10710

Ecosystem management requires information to determine and mitigate adverse impacts of fishing on all ecosystem components. Deep-sea coral and sponge ecosystems often co-occur with fishing activities, and there is considerable research documenting the vulnerability and slow recovery of deep-sea coral and sponge communities to damage. The objective of the present analysis was to construct models that could predict the distribution, abundance and diversity of deep sea corals and sponges in the Aleutian Islands. Generalized additive models were constructed based on bottom trawl survey data collected from 1991 to 2011 and tested on data from 2012. The results showed that deep-sea coral and sponge distributions were strongly influenced by the maximum tidal currents at bottom trawl locations, possibly indicative of reduced sedimentation or increased food-delivery processes near the seafloor in areas of moderate to high current. Depth and location were also important factors affecting the distribution of deep-sea sponges and corals. The analysis resulted in acceptable models of presence or absence for all taxonomic groups and similar fits when models were applied to test data. The best-fitting models of abundance explained between 20 and 25% of the deviance in the abundance data. Current management protects similar to 50% of the coral and sponge habitat in the Aleutian Islands at depths to 500 m. The models constructed here will allow managers to evaluate ecological versus economic benefits between protecting coral and sponge habitat and allowing commercial fishing by examining the effect of spatial closures on the amount of coral and sponge habitat that is protected.

Spencer, M. L., Stoner, A. W., Ryer, C. H., & Munk, J. E. (2005). A Towed Camera Sled for Estimating Abundance of Juvenile Flatfishes and Habitat Characteristics: Comparison with Beam Trawls and Divers. *Estuarine Coastal and Shelf Science,* 64(2-3), 497-503. https://doi.org/10.1016/j.ecss.2005.03.012

An inexpensive towed video camera sled was developed to provide abundance estimates for juvenile flatfishes and other benthic taxa, and to characterize habitat features. The camera sled was compared with beam trawls and diver survey methods in Yaquina Bay, Oregon, and in bays of Kodiak Island, Alaska. In Yaquina Bay the camera sled with a tickler chain (to induce flatfish movement) yielded density estimates for juvenile flatfish (English sole, Pleuronectes vetulus) that were equivalent to those of the divers, but greater than with a I in beam trawl or the camera sled without a tickler chain. Crab (Cancer magister) density estimates were similar between the divers and the camera sled (with or without the tickler chain), but were underestimated with the beam trawl. In Kodiak, densities of juvenile flatfish (northern rock sole, Lepidopsetta polyxystra) were similar between the camera sled with a tickler chain, divers, and a 2 in beam trawl. Density estimates from the camera sled were obtainable for flatfish as small as 20 mm. Habitat features, such as empty bivalve shells, were underestimated with the beam trawl compared with the divers and the camera sled. These results demonstrate the effectiveness of an inexpensive, simple to operate, towed camera sled in surveying abundance and habitat associations of juvenile flatfishes, crabs, and other taxa.

Stone, R. P. (2006). Coral Habitat in the Aleutian Islands of Alaska: Depth Distribution, Fine-Scale Species Associations, and Fisheries Interactions. *Coral Reefs,* 25(2), 229-238. https://doi.org/10.1007/s00338-006-0091-z

The first in situ exploration of Aleutian Island coral habitat was completed in 2002 to determine the distribution of corals, to examine fine-scale associations between targeted fish species and corals, and to investigate the interaction between the areas' diverse fisheries and coral habitat. Corals, mostly gorgonians and hydrocorals, were present on all 25 seafloor transects and at depths between 27 and 363 m, but were most abundant between 100 and 200 m depth. Mean coral abundance (1.23 colonies m(-2)) far exceeded that reported for other high-latitude ecosystems and high-density coral gardens (3.85 colonies m(-2)) were observed at seven locations. Slope and offshore pinnacle habitats characterized by exposed bedrock, boulders, and cobbles generally supported the highest abundances of coral and fish. Overall, 85% of the economically important fish species observed on transects were associated with corals and other emergent epifauna. Disturbance to the seafloor from bottom-contact fishing gear was evident on 88% of the transects, and approximately 39% of the total area of the seafloor observed had been disturbed. Since cold-water corals appear to be a ubiquitous feature of seafloor habitats in the Aleutian Islands, fisheries managers face clear challenges integrating coral conservation into an ecosystem approach to fisheries management.

TenBrink, T. T., & Spencer, P. D. (2013). Reproductive Biology of Pacific Ocean Perch and Northern Rockfish in the Aleutian Islands. *North American Journal of Fisheries Management,* 33(2), 373-383. https://doi.org/10.1080/02755947.2012.760505

Estimates of maturity (i.e., the proportion of mature individuals at age) play an important role in assessing stock productivity; however, this information has not been published for rockfishes in the Aleutian Islands. Ovary and otolith samples were collected from Pacific Ocean Perch Sebastes alutus and Northern Rockfish S. polyspinis during both fishery-independent and fishery-dependent cruises in 2010 to investigate maturity and other aspects of reproductive biology. Histological examination of ovaries indicated that both species exhibited general parturition in April, while specimens caught in the summer and fall were maturing and generally exhibited progressive stages of vitellogenesis. Histological analysis was more reliable when characterizing ovary condition than were macroscopic or visual assessments during the developing period. Estimates of natural mortality, based on a relationship with the gonadosomatic index, were 0.040 for Pacific Ocean Perch and 0.042 for Northern Rockfish. Mean fecundity estimates calculated for Northern Rockfish (89,320 oocytes) were correlated more with length and weight than age. Estimates of age and length at 50% maturity were 9.1years at 32.4cm for Pacific Ocean Perch and 7.6years at 27.7cm for Northern Rockfish and indicate maturation at younger ages than do previous studies from the Gulf of Alaska. This information on reproductive biology will improve estimation of fishing mortality reference points and management of these commercially important species in the Aleutian Islands.

Turner, K., Rooper, C. N., Laman, E. A., Rooney, S., Cooper, D. W., & Zimmerman, M. (2017). *Model-Based Essential Fish Habitat Definitions for Aleutian Island Groundfish Species.* https://doi.org/10.7289/V5/TM-AFSC-360

The 1996 reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) mandates NOAA Fisheries to identify habitats essential for managed fish and invertebrate species and conserve habitats from adverse effects of fishing and other anthropogenic activities. Essential Fish Habitat (EFH) is defined under the act as 'those waters and substrates necessary to fish for spawning, breeding, feeding or growth to maturity'. As part of this mandate, EFH descriptions for all species listed under a Fisheries Management Plan in Alaska waters are needed. In addition, these descriptions are routinely revisited under a 5-year cycle that reviews and updates EFH information (including species descriptions) with new data and research.

Wilborn, R., Rooper, C. N., Goddard, P., Li, L. B., Williams, K., & Towler, R. (2018). The Potential Effects of Substrate Type, Currents, Depth and Fishing Pressure on Distribution, Abundance, Diversity, and Height of Cold-Water Corals and Sponges in Temperate, Marine Waters. *Hydrobiologia,* 811(1), 251-268. https://doi.org/10.1007/s10750-017-3492-9

Deep-sea benthic environments can be home to diverse communities of corals and sponges which are important habitat for marine fishes and invertebrates. From 2010 to 2014, underwater camera surveys in the Aleutian Islands were completed with the objective of evaluating potential effects of substrate type, tidal currents, depth, and fishing pressure on distribution, abundance, diversity, and size of structure-forming invertebrate (SFI) communities. The presence of rocky substrates was associated with higher probability of presence, higher density, and taller SFI. Multivariate analyses showed community structure changed over gradients of substrate, tidal currents, and longitude, with sea whips typically occupying deeper depths and mostly unconsolidated substrates, while other corals were largely found in rocky, shallower areas. These patterns were also reflected in co-occurrence analyses indicating sea whips were negatively associated with other SFI taxa. Most SFI occupied areas of swift tidal currents; however, heights of individual SFI decreased with increasing tidal currents. Coral and sponge densities at some sites in this study exceeded densities reported from other global coral and sponge habitats. Identifying the environmental conditions leading to high-density and high-diversity SFI communities is important for management of fisheries and evaluating potential impacts of climate change in benthic marine ecosystems.

Geology

Horowitz, W. L., Steffy, D. A., & Hoose, P. J. (1989). *Geologic Report for the Shumagin Planning Area, Western Gulf of Alaska.* Retrieved from https://www.boem.gov/sites/default/files/boem-newsroom/Library/Publications/1989/89_0097.pdf

The 130,000-square-mile Shumagin Planning Area encompasses portions of the continental shelf and slope, the Aleutian Trench, and the Aleutian Abyssal Plain. The planning area lies southeast of the Alaska Peninsula and extends 375 miles from Chirikof Island to Unimak Pass. Water depths range from less than 165 feet nearshore to over 21,300 feet in the Aluetian Trench. The Shumagin Oil and Gas Lease Sale 129 was scheduled for January 1992 on the Minerals Management Service 5-year lease sale schedule

announced in 1987; at this writing, the sale has been deferred. The Shumagin continental shelf constains five strcuturally distinct sedimentary basins that formed on an evolving forcarc accretionary prism. These basins are, from northeast to southwest, the Shumagin basin, the East and West Sanak basins, the East Sanak slope basin, and the Unimak basin. Geophysical and geological interpretations suggest the presence of a Neogene Oligocene sedimentary section (sequence C), and Eocene (sequence B), and a basement of Cretaceous and early Paleocene Age (sequence A).

Rathburn, A. E., Levin, L. A., Tryon, M., Gieskes, J. M., Martin, J. M., Perez, M. E., . . . Ziebis, W. (2009). Geological and Biological Heterogeneity of the Aleutian Margin (1965-4822 M). *Progress in Oceanography,* 80(1-2), 22-50. https://doi.org/10.1016/j.pocean.2008.12.002

Geological, biological and biogeochemical characterization of the previously unexplored margin off Unimak Island, Alaska between 1965 and 4822 m water depth was conducted to examine: (1) the geological processes that shaped the margin, (2) the linkages between depth, geomorphology and environmental disturbance in structuring benthic communities of varying size classes and (3) the existence, composition and nutritional sources of methane seep biota on this margin. The study area was mapped and sampled using multibeam sonar, a remotely operated vehicle (ROV) and a towed camera system. Our results provide the first characterization of the Aleutian margin mid and lower slope benthic communities (micro-biota, foraminifera, macrofauna and megafauna), recognizing diverse habitats in a variety of settings. Our investigations also revealed that the geologic feature known as the "Ugamak Slide" is not a slide at all, and could not have resulted from a large 1946 earthquake. However, sediment disturbance appears to be a pervasive feature of this margin. We speculate that the deep-sea occurrence of high densities of Elphidium, typically a shallow-water foraminiferan, results from the influence of sediment redeposition from shallower habitats. Strong representation of cumacean, amphipod and tanaid crustaceans among the Unimak macrofauna may also reflect sediment instability. Although some faunal abundances decline with depth, habitat heterogeneity and disturbance generated by canyons and methane seepage appear to influence abundances of biota in ways that supercede any clear depth gradient in organic matter input. Measures of sediment organic matter and pigment content as well as C and N isotopic signatures were highly heterogeneous, although the availability of organic matter and the abundance of microorganisms in the upper sediment (1-5 cm) were positively correlated. We report the first methane seep on the Aleutian slope in the Unimak region (3263-3285 m), comprised of clam bed, pogonophoran field and carbonate habitats. Seep foraminiferal assemblages were dominated by agglutinated taxa, except for habitats above the seafloor on pogonophoran tubes. Numerous infaunal taxa in clam bed and pogonophoran field sediments and deep-sea "reef' cnidarians (e.g., corals and hydroids) residing on rocks near seepage sites exhibited light organic delta C-13 signatures indicative of chemosynthetic nutritional sources. The extensive geological, biogeochemical and biological heterogeneity as well as disturbance features observed on the Aleutian slope provide an attractive explanation for the exceptionally high biodiversity characteristic of the world's continental margins.

Shillington, D. J., Van Avendonk, H. J. A., Holbrook, W. S., Kelemen, P. B., & Hornbach, M. J. (2004). Composition and Structure of the Central Aleutian Island Arc from Arc-Parallel Wide-Angle Seismic Data. *Geochemistry Geophysics Geosystems,* 5. https://doi.org/10.1029/2004gc000715

New results from wide-angle seismic data collected parallel to the central Aleutian island arc require an intermediate to mafic composition for the middle crust and a mafic to ultramafic composition for the lower crust and yield lateral velocity variations that correspond to arc segmentation and trends in major element geochemistry. The 3-D ray tracing/2.5-D inversion of this sparse wide-angle data set, which incorporates independent phase interpretations and new constraints on shallow velocity structure, produces a faster and smoother result than a previously published velocity model. Middle-crustal velocities of 6.5 - 7.3 km/s over depths of similar to 10 - 20 km indicate an andesitic to basaltic composition. High lower-crustal velocities of 7.3 - 7.7 km/s over depths of similar to 20 - 35 km are interpreted as ultramafic-mafic cumulates and/or garnet granulites. The total crustal thickness is 35 - 37 km. This result indicates that the Aleutian island arc has higher velocities, and thus more mafic compositions, than average continental crust, implying that significant modifications would be required for this arc to be a suitable building block for continental crust. Lateral variations in average crustal velocity (below 10 km) roughly correspond to trends in major element geochemistry of primitive (Mg # > 0.6) lavas. The highest lower-crustal velocities (and presumably most mafic material) are detected in the center of an arc segment, between Unmak and Unalaska Islands, implying that arc segmentation exerts control over crustal composition.

Thurston, D. K. (2009). *Environmental Geology of the Northern Aleutian Shelf for the Darft Environmental Impact Statement for Northern Aleutian Basin Ocs Oil and Gas Lease Sale 214 Sale (Canceled)*. Retrieved from [No URL available]

No abstract available.

von Huene, R., Miller, J. J., & Krabbenhoeft, A. (2019). The Shumagin Seismic Gap Structure and Associated Tsunami Hazards, Alaska Convergent Margin. *Geosphere,* 15(2), 324-341. https://doi.org/10.1130/ges01657.1

The potential for a major earthquake in the Shumagin seismic gap, and the tsunami it could generate, was reported in 1971. However, while potentially tsunamigenic splay faults in the adjacent Unimak and Semidi earthquake segments are known, such features along the Shumagin segment were undocumented until recently. To investigate margin structure and search for splay faults, we reprocessed six legacy seismic records and also processed seismic data acquired by RV Langseth during the ALEUT project (cf. Becel et al., 2017). All records show splay faults separating the frontal prism from the margin framework. A ridge uplifted by the splay fault hanging wall extends along the entire segment. At the plate interface, the splay fault cuts across subducted sediment strata in some images, whereas in others, the plate interface sediment cuts across the fault. Splay fault zones are commonly associated with subducting lower-plate relief. Along the upper slope, beneath a sediment cover, major normal faults dipping landward and seaward border a ridge of basement rock. The faults displace a regional unconformity that elsewhere received Oligocene-Miocene sediment. Low seafloor scarps above some normal faults indicate recent tectonism. The buried ridge is a continuation of the Unimak Ridge structure that extends NE of the Unimak/Shumagin segment boundary. Some geological characteristics

of the Shumagin segment differ from those of other Alaskan earthquake segments, but a causal link to the proposed Shumagin creeping seismic behavior is equivocal.

Management

Ritchie, L. A., & Gill, D. A. (2008). The Selendang Ayu Shipwreck and Oil Spill: Considering Threats and Fears of a Worst-Case Scenario. *Sociological Inquiry,* 78(2), 184-206. https://doi.org/10.1111/j.1475-682X.2008.00234.x

On December 8, 2004, the Selendang Ayu, a Malaysian-flagged freighter, ran aground off Unalaska Island in Alaska's Aleutian chain. Despite rescue efforts by the United States Coast Guard, six of the Selendang Ayu's crew members died. In addition to the deaths, more than 300,000 gallons of heavy bulk fuel oil spilled into the sea. Much of the oil washed onto the island's shores, into areas providing cultural, recreational, subsistence, and commercial fishing resources for residents of the renewable resource community of Dutch Harbor/Unalaska. The purpose of this article is to identify and examine different dimensions of risk, based on qualitative research conducted in 2005. We use a contextual constructionist approach to understand risk, which conceptualizes risk as an objective hazard, threat, or danger that is mediated through social and cultural processes. Research methods included 31 personal interviews, participatory observation, and a review of media coverage. Findings revealed several dimensions of risk perceived by residents: the incident in relation to Dutch Harbor/Unalaska as a high-risk community and more general current events; threats to the community's annual $1 billion seafood industry; threats to Alaska Native subsistence culture; and issues of future risk and uncertainty. Interviews and observations support our conclusion that the Selendang Ayu incident represented a "shot across the bow" that could have been a "worst case" if oil had contaminated commercial fish processing. Residents believe that it is only a matter of time before another, more damaging accident occurs. Given this general perception, it is important to more clearly assess risk in Dutch Harbor/Unalaska and help the community increase resilience to the multiple hazards it faces. More broadly, Dutch Harbor/Unalaska serves as an example-all communities could benefit from better risk assessments and increased attention to resiliency.

Shester, G., & Ayers, J. (2005). A Cost Effective Approach to Protecting Deep-Sea Coral and Sponge Ecosystems with an Application to Alaska's Aleutian Islands Region. In *Cold-Water Corals and Ecosystems.* A. Freiwald & J. M. Roberts (Eds.), (pp. 1151-1169) https://doi.org/10.1007/3-540-27673-4_59

There is much debate about how to protect deep-sea coral and sponge ecosystems using the data currently available. The Aleutian Islands in Alaska contain some of the most abundant, diverse, and pristine deep-sea coral and sponge ecosystems on Earth. From 1990 to 2002, U.S. federal fishery observer data indicates approximately 2,176,648 kg of coral and sponge bycatch occurred in the Aleutian Islands, equaling 52 % of all coral and sponge bycatch in Alaska. Coral and sponge bycatch rates in the Aleutians were over 12 times the rate in the Bering Sea or Gulf of Alaska. The National Marine Fisheries Service (NMFS) estimates that 87 % of coral bycatch and 91 % of sponge bycatch is caused by bottom trawling in the Bering Sea/Aleutian Islands management areas. The conservation organization Oceana developed an interdisciplinary fishery management approach to mitigating adverse impacts of

fishing on deep-sea coral and sponge ecosystems, which has been used by NMFS to formulate a habitat protection alternative for the Aleutian Islands that is being considered in an Environmental Impact Statement. The Oceana Approach is offered as a cost effective model for reducing the adverse effects of fishing on deep-sea coral and sponge ecosystems. The approach uses observer data to identify areas of high coral and sponge bycatch rates to develop a comprehensive management policy that allows bottom trawling only in specific designated areas with high fish harvest and low habitat impacts. All areas not specified as open would be closed to bottom trawling. To prevent effort displacement, bottom trawl effort is reduced by the amount that historically occurred in areas that would become closed. The Oceana Approach also includes coral and sponge bycatch limits and a plan for comprehensive seafloor research, mapping, and monitoring. An enforcement strategy for these management measures is developed based on agency capabilities, and includes increased observer coverage, vessel monitoring systems, and electronic logbooks. This approach allows for continued catch of target species with minimal adverse impacts on coral and sponge habitat. Successful implementation of the Oceana Approach will protect areas of high known trawl impacts to deep-sea coral and sponge ecosystems and prevent trawl effort from moving into new, unexplored areas. The methodology is recommended for application to other regions and should be adjusted based on the available fishery and biological data for each region.

Marine Culture Heritage

Broderick, F., & Burwell, M. (2014). The S. S. Northwestern: Sailing Sheltered Seas - an Illustrated History. *Aleutian Voices,* 1 (1). Retrieved from https://www.nps.gov/aleu/learn/historyculture/upload/3-SHELTERED-SEAS-508-final.pdf

During World War II the remote Aleutian Islands, home to the Unanga{ (Aleut) people for over 8,000 years, became one of the fiercely contested battlegrounds of the Pacific. This thousand-mile-long archipelago saw the first invasion of American soil since the War of 1812, a mass internment of American civilians, a 15-month air war, and one of the deadliest

battles in the Pacific Theatre. In 1996 Congress designated the Aleutian World War II National Historic Area to interpret, educate, and inspire present and future generations about the history of the Unanga{ and the Aleutian Islands in the defense of the United States in World War II. In a unique arrangement, the Aleutian World War II National Historic Area and visitor center are owned and managed by the Ounalashka Corporation (the village corporation for Unalaska) and the National Park Service provides them with technical assistance. Through this cooperative partnership, the Unanga{ are the keepers of their history and invite the public to learn more about their past and present. This project was funded by the National Park Service, Affiliated Areas Program in support of the Aleutian World War II National Historic Area, in cooperation with the Aleutian Pribilof Heritage Group.

Dixon, E. J., Sharma, G., & Stoker, S. (1978). *Western Gulf of Alaska Cultural Resource Study Final Report.* Retrieved from https://espis.boem.gov/finalreports/1799.pdf

The following text consists of three major sections. In section one, Sharma briefly reviews the glacial and geological history of the study area. He also discusses his interpretation of submerged sills which he believes record six individual periods of sea level stability during periods of marine transgression. He

presents data on the individual sills in an appendix to the text. Included in his chapter are paleographic maps based on his interpretation of sea level rise and bathymetric features. Stoker discusses terrestrial and marine faunal distributions for the study area and delineates the factors upon which he based their projection to the study area in section two. Through the use of symbols, he has depicted the projected distributions on the paleographic maps prepared by Sharma. In section three, Dixon reviews the Pleistocene/Holocene prehistory of the study area and the model for archeological site prediction developed for the Bering Land Bridge Cultural Resource Study. Based on Stoker's projection of faunal distributions for the study area and Sharma's paleographic maps, he delineates regions of high, medium, and low archeological probability and has transferred this data to BLM/OCS protraction diagrams. This chapter is followed by a short section which identifies data gaps for the study area and a bibliography of cited literature from all sections of the report.

Physics

Stabeno, P. J., Reed, R. K., & Napp, J. M. (2002). Transport through Unimak Pass, Alaska. *Deep-Sea Research Part Ii-Topical Studies in Oceanography,* 49(26), 5919-5930. https://doi.org/10.1016/S0967-0645(02)00326-0

We examined inflow through Unimak Pass (< 200 m deep), which is the only major connection between the shelves of the North Pacific Ocean and the eastern Bering Sea. Geostrophic transport was generally northward from the Gulf of Alaska into the Bering Sea. The flow through the pass appeared to be modulated by the seasonal cycle of freshwater discharge. On shorter time scales, transport also was affected by semi-daily variations in tidal mixing. This effect was significant and not anticipated. Near-bottom currents, measured from moorings, were maximum during winter, and significantly correlated (r = 0.7) with the alongshore winds. Although the flow through Unimak Pass transported some nutrients from the North Pacific Ocean, the Gulf of Alaska shelf is not the major source of nutrients to the Bering Sea shelf.

Section II: Aleutian Islands, Beaufort Sea, Bering Sea, Chukchi Sea, Gulf of Alaska

Geology

Albert, N. R. D., & Hudson, T. (1981). *The United States Geological Survey in Alaska: Accomplishments During 1979.* Retrieved from https://pubs.er.usgs.gov/publication/cir823B

This circular describes the 1980 programs of the U.S. Geological Survey in Alaska. A brief description of the Alaskan operations of each major division of the Survey is followed by project descriptions arranged by geographic regions in which the work takes place. The mission of the Geological Survey is to identify the Nation 's land, water, energy, and mineral resources; to classify federally-owned mineral lands and waterpower sites; to resolve the exploration and development of energy and natural resources on Federal and Indian lands; and to explore and appraise the petroleum potential of the National Petroleum Reserve in Alaska. Alaska is at once the largest, the least populated, the least explored, and the least developed State in the Nation. More than half of the Nation 's 600 million acres of Outer Continental Shelf lies off Alaska 's coast. The land area of Alaska contains 375 million acres, 16 percent of the onshore land of the Nation. Its resources of all kinds present an opportunity to demonstrate how the needs of both conservation and development can be met for the benefit of the American people.

Bureau of Ocean Energy Management (2011). *Shipwreck Inventory.* Retrieved from [No URL available]

No abstract available.

Pewe, T. L. (1975). *Quaternary Geology of Alaska.* https://doi.org/10.3133/pp835

No abstract available.

Marine Culture Heritage

Burwell, M. (2005). Alaska's Worst All Time Shipping Losses. Retrieved from https://www.boem.gov/about-boem/alaskas-worst-all-time-shipping-losses

No abstract available.

Section III: Aleutian Islands, Bering Sea, Gulf of Alaska

Biology

Heifetz, J. (2002). Coral in Alaska: Distribution, Abundance, and Species Associations. *Hydrobiologia,* 471, 19-28. https://doi.org/10.1023/a:1016528631593

To help identify fishery management actions that minimize the adverse impacts of fishing activities on corals in Alaska, the distribution and abundance of corals were analyzed based on trawl survey data collected during 1975-1998. We also examined the species of commercially managed fish that are associated with coral. Soft corals, primarily Gersemia sp. (=Eunephthya sp.), were the most frequently encountered corals in the Bering Sea. In the Aleutian Islands gorgonian corals, primarily in the genera Callogorgia, Primnoa, Paragorgia, Thouarella, and Arthrogorgia were the most common corals. In the Gulf of Alaska, gorgonian corals, primarily in the genera Callogorgia and Primnoa, and cup corals, primarily 'Scleractinia unidentified', occurred most frequently. The Aleutian Islands area appears to have the highest abundance and diversity of corals. Some fish groups are associated with particular types of coral. Rockfish (Sebastes spp. and Sebastolobus alascanus) and Atka mackerel (Pleurogrammus monopterygius) were the most common fish captured with gorgonian, cup, and hydrocorals, whereas flatfish and gadids were the most common fish captured with soft corals.

Holsman, K. K., & Aydin, K. (2015). Comparative Methods for Evaluating Climate Change Impacts on the Foraging Ecology of Alaskan Groundfish. *Marine Ecology Progress Series,* 521, 217-235. https://doi.org/10.3354/meps11102

Climate change is expected to strongly impact Alaskan (USA) marine ecosystems, particularly those of the northern Bering Sea. To understand how climate change may alter predator demand for prey resources, we quantified the relationship between temperature and allometric rates of prey consumption for 3 major groundfish predators: walleye pollock Gadus chalco grammus, Pacific cod Gadus macrocephalus, and arrowtooth flounder Atheresthes stomias. We contrasted regional patterns in foraging rates of more than 120000 fish collected annually from 1981 to 2011 from the eastern Bering Sea (EBS), Gulf of Alaska (GOA), and Aleutian Islands (AI). From field observations, we estimate that juveniles and adults of each species eat 1.15 to 3.94 and 0.84 to 3.13 times their body weight (BW) yr(-1), respectively (i.e. 0.2 to 1.2% BW d(-1)), with arrowtooth in all 3 regions and adult EBS Pacific cod exhibiting the highest rates. If historical patterns signify future conditions, we estimate that a 2 degrees C projected increase in water temperature would cause 26 and 14% increases in daily rations of adult EBS pollock and Pacific cod, respectively, whereas we predict a 37% decline in the daily rations of EBS arrowtooth. Similarly, we predict that GOA pollock, Pacific cod and arrowtooth rations would increase markedly (70, 34, and 65%, respectively). Although daily ration of AI arrowtooth may increase by 31%, our models predict 41 and 3% declines in AI pollock and Pacific cod rations, respectively. These results portend (sometimes counterintuitively) region-and species-specific shifts in Alaska groundfish predator for aging rates and trophodynamic interactions concomitant with climate change.

Laman, E. A., Rooper, C. N., Turner, K., Rooney, S., Cooper, D. W., & Zimmermann, M. (2018). Using Species Distribution Models to Describe Essential Fish Habitat in Alaska. *Canadian Journal of Fisheries and Aquatic Sciences,* 75(8), 1230-1255. https://doi.org/10.1139/cjfas-2017-0181

Describing essential habitat is an important step toward understanding and conserving harvested species in ecosystem-based fishery management. Using data from fishery-independent ichthyoplankton, groundfish surveys, and commercial fisheries observer data, we utilized species distribution modeling techniques to predict habitat-based spatial distributions of federally managed species in Alaska. The distribution and abundance maps were used to refine existing essential fish habitat descriptions for the region. In particular, we used maximum entropy and generalized additive modeling to delineate distribution and abundance of early (egg, larval, and pelagic juvenile) and later (settled juvenile and adult) life history stages of groundfishes and crabs across multiple seasons in three large marine ecosystems (Gulf of Alaska, eastern Bering Sea, and Aleutian Islands) and the northern Bering Sea. We present a case study, featuring Kamchatka flounder (Atheresthes evermanni), from the eastern and northern Bering Sea to represent the >400 habitat-based distribution maps generated for more than 80 unique species-region-season-life-stage combinations. The results of these studies will be used to redescribe essential habitat of federally managed fishes and crabs in Alaska.

Stevenson, D. E., & Lewis, K. A. (2010). Observer-Reported Skate Bycatch in the Commercial Groundfish Fisheries of Alaska. *Fishery Bulletin,* 108(2), 208-217. Retrieved from https://spo.nmfs.noaa.gov/content/observer-reported-skate-bycatch-commercial-groundfish-fisheries-alaska

We analyzed skate catch data collected by observers in the North Pacific Groundfish Observer Program (NPGOP) from 1998 through 2008 to document recent changes in the identification of skates by observers and to examine the species composition of observed skate catch in Alaska's groundfish fisheries as well as recent trends in skate retention by commercial fishermen. Historically, almost all skate bycatch has been reported by NPGOP observers as "skate unidentified." However, since 2004 observers have been trained to identify skates to the genus and species level. In 2008 over 95% of all skates were identified at least to the genus level, and over 50% were identified to species. The most common species of skates identified by observers in groundfish fisheries are Bathyraja parmifera (Alaska skate), Raja binoculata (big skate), and Bathyraja aleutica (Aleutian skate). Species composition of reported skate catch generally reflects recent survey-derived biomass estimates, with B. parmifera dominating the catches in the Bering Sea and, to a lesser extent, in the Aleutian Islands region, and species of the genus Raja dominating catches in the Gulf of Alaska. A relatively high percentage of the skate catch on longline vessels is still reported at the family or genus level because of difficulties in the identification of skates not brought onboard the vessel. For the larger skate species, the proportion retained for processing has increased in recent years as the market price for skate product has increased. Although observed skate catch does not give a complete account of skate bycatch in the fisheries of the region, observer data provide critical information for the appropriate management of skate populations in Alaska.

Vulstek, S. C., Linderoth, T. P., Guyon, J. R., & Tallmon, D. A. (2013). Spatio-Temporal Population Genetic Structure and Mating System of Red King Crab (Paralithodes camtschaticus) in Alaska. *Journal of Crustacean Biology,* 33(5), 691-701. https://doi.org/10.1163/1937240x-00002173

Red king crab, Paralithodes camtschaticus Tilesius, 1815, an economically and culturally important species in the state of Alaska, experienced drastic reductions in abundance over large portions of their Alaskan range by 1980. Abundance of crabs in some of the most important historical fishing areas have failed to rebound, some even in the absence of fishing, highlighting the need for additional research to infer genetic structure and reproductive biology of the species that can then be used to inform management efforts. Red king crab samples were collected from eleven locations throughout Alaska (n = 845), of these, six locations were sampled at least one generation apart. Results of this study suggest moderate rates of gene flow within the Gulf of Alaska/Western Alaska region. Levels of genetic differentiation among populations within Southeast Alaska were higher than seen elsewhere, and there was strong evidence of multiple distinct populations. Red king crab in Bristol Bay and in two areas in Southeast Alaska show signs of recent population bottlenecks and shifts in allele frequencies not observed in previous studies that used less polymorphic genetic markers. In addition to population genetic structure analyses, 24 female red king crab and their broods were collected for purposes of inferring mating system. There was no evidence of multiple paternity in any brood. The results of this study support continued management of distinct geographic groups within the Gulf of Alaska/Western Alaska region and suggest that finer-scale management may be beneficial in Southeast Alaska.

Section IV: Aleutian Islands, Central Gulf of Alaska

Biology

Bizzarro, J. J., Broms, K. M., Logsdon, M. G., Ebert, D. A., Yoklavich, M. M., Kuhnz, L. A., & Summers, A. P. (2014). Spatial Segregation in Eastern North Pacific Skate Assemblages. *Plos One,* 9(10), 26. https://doi.org/10.1371/journal.pone.0109907

Skates (Rajiformes: Rajoidei) are common mesopredators in marine benthic communities. The spatial associations of individual species and the structure of assemblages are of considerable importance for effective monitoring and management of exploited skate populations. This study investigated the spatial associations of eastern North Pacific (ENP) skates in continental shelf and upper continental slope waters of two regions: central California and the western Gulf of Alaska. Long-term survey data were analyzed using GIS/spatial analysis techniques and regression models to determine distribution (by depth, temperature, and latitude/longitude) and relative abundance of the dominant species in each region. Submersible video data were incorporated for California to facilitate habitat association analysis. We addressed three main questions: 1) Are there regions of differential importance to skates?, 2) Are ENP skate assemblages spatially segregated?, and 3) When skates co-occur, do they differ in size? Skate populations were highly clustered in both regions, on scales of 10s of kilometers; however, high-density regions (i.e., hot spots) were segregated among species. Skate densities and frequencies of occurrence were substantially lower in Alaska as compared to California. Although skates are generally found on soft sediment habitats, Raja rhina exhibited the strongest association with mixed substrates, and R. stellulata catches were greatest on rocky reefs. Size segregation was evident in regions where species overlapped substantially in geographic and depth distribution (e. g., R. rhina and Bathyraja kincaidii off California; B. aleutica and B. interrupta in the Gulf of Alaska). Spatial niche differentiation in skates appears to be more pronounced than previously reported.

Wilson, M. T., Dougherty, A., Matta, M. E., Mier, K. L., & Miller, J. A. (2018). Otolith Chemistry of Juvenile Walleye Pollock *Gadus chalcogrammus* in Relation to Regional Hydrography: Evidence of Spatially Split Cohorts. *Marine Ecology Progress Series,* 588, 163-178. https://doi.org/10.3354/meps12425

For many marine ecosystems, uncertainty about nursery locations and the spatial dynamics of juvenile fish impedes our understanding of fish production. Walleye pollock Gadus chalcogrammus occur throughout the coastal North Pacific Ocean and support some of the world's largest fisheries. We used otolith microchemistry to answer questions about whether cohorts of young-of-the-year (age-0) walleye pollock are spatially split in the western Gulf of Alaska (GOA). Demographics indicate a possible cohort split between habitat influenced by the Alaska Coastal Current (ACC) (Semidi regions) and habitat more influenced by oceanic influxes (Kodiak region). We used a stratified-random sampling design to select 204 age-0 juveniles collected with a small-mesh trawl during late summer 2007 and 2011. Laser ablation-inductively coupled plasma mass spectrometry was then used to measure the composition of elements assimilated into their otoliths within 1 wk of capture (otolith edge) and over their life histories (otolith edge to core). Otolith edge chemistry varied by region of capture, primarily in strontium: calcium (Sr:Ca), barium: Ca (Ba:Ca), and manganese: Ca (Mn:Ca). Semidi-region otoliths were

discriminated from Kodiak otoliths by lower Sr: Ca and higher Ba: Ca and Mn: Ca with 78% (2007) and 79% (2011) success. We estimated that exchange between these 2 habitats was limited for >= 3 (2007) and >= 7 (2011) weeks, sufficient to explain ob served demographic differences. We hypothesize that a Semidi-Kodiak split buffers the western GOA population against losses due to density-dependent mechanisms and downstream transport.

Chemistry

Ding, X., & Henrichs, S. M. (2002). Adsorption and Desorption of Proteins and Polyamino Acids by Clay Minerals and Marine Sediments. *Marine Chemistry,* 77(4), 225-237. https://doi.org/10.1016/S0304-4203(01)00085-8

The adsorption and desorption of proteins and polyamino acids on illite, montmorillonite, goethite, and marine sediments was investigated. Three 14C-labeled hydrophilic proteins, Rubisco from C. reinhardtii, and GroEL and GroES from genetically modified Escherichia coli, were synthesized and purified for this study. The proteins were strongly and rapidly adsorbed by the clay minerals and marine sediments, and much of the adsorbed protein was not readily desorbed. Sodium dodecyl sulfate (SDS) extraction and separation by SDS-polyacrylamide gel electrophoresis (PAGE) and sucrose density gradients showed that Rubisco and GroEL were adsorbed on illite and sediments in their original forms. The apparent adsorption partition coefficients of the proteins were on the order of 102 l/kg on illite, 103–104 l/kg on goethite and montmorillonite, and 200 and 75 l/kg on Skan Bay and Resurrection Bay (Alaska) sediments, respectively. These partition coefficients are sufficiently large to permit sedimentary protein preservation via an adsorptive mechanism. Generally, basic polyamino acids had greater adsorption partition coefficients than acidic polyamino acids. Molecular size did not affect the electrostatic interaction between polyamino acids and mineral surfaces. Adsorption of bovine serum albumin (BSA) and negatively charged polyamino acids inhibited Rubisco adsorption, while positively charged cytochrome c and polyamino acids increased Rubisco adsorption. These results indicate that electrostatic interactions dominated in protein adsorption.

Geology

Zimmermann, M., Prescott, M. M., & Haeussler, P. J. (2019). Bathymetry and Geomorphology of Shelikof Strait and the Western Gulf of Alaska. *Geosciences,* 9(10). https://doi.org/10.3390/geosciences9100409

We defined the bathymetry of Shelikof Strait and the western Gulf of Alaska (WGOA) from the edges of the land masses down to about 7000 m deep in the Aleutian Trench. This map was produced by combining soundings from historical National Ocean Service (NOS) smooth sheets (2.7 million soundings); shallow multibeam and LIDAR (light detection and ranging) data sets from the NOS and others (subsampled to 2.6 million soundings); and deep multibeam (subsampled to 3.3 million soundings), single-beam, and underway files from fisheries research cruises (9.1 million soundings). These legacy smooth sheet data, some over a century old, were the best descriptor of much of the shallower and inshore areas, but they are superseded by the newer multibeam and LIDAR, where available. Much of the offshore area is only mapped by non-hydrographic single-beam and underway files. We combined these disparate data sets by proofing them against their source files, where possible,

in an attempt to preserve seafloor features for research purposes. We also attempted to minimize bathymetric data errors so that they would not create artificial seafloor features that might impact such analyses. The main result of the bathymetry compilation is that we observe abundant features related to glaciation of the shelf of Alaska during the Last Glacial Maximum including abundant end moraines, some medial moraines, glacial lineations, eskers, iceberg ploughmarks, and two types of pockmarks. We developed an integrated onshore–offshore geomorphic map of the region that includes glacial flow directions, moraines, and iceberg ploughmarks to better define the form and flow of former ice masses.

Section V: Aleutian Islands, Eastern Bering Sea

Biology

Rooper, C. N., Goddard, P., & Wilborn, R. (2019). Are Fish Associations with Corals and Sponges More Than an Affinity to Structure: Evidence across Two Widely Divergent Ecosystems? *Canadian Journal of Fisheries and Aquatic Sciences,* 76(12), 2184-2198. https://doi.org/10.1139/cjfas-2018-0264

The role of deep-sea coral and sponge ecosystems as habitat for marine fishes has been widely studied, with many finding significant associations, especially for rockfishes. However, rockfishes also thrive in areas largely devoid of corals and sponges. We compared the use of deep-sea corals and sponges by fish species in two ecosystems. Rockfishes (Sebastes spp.) and Pacific cod (Gadus macrocephalus) densities were significantly correlated to structured seafloors at the scale of transects across both regions. Regional effects were not significant for most rockfish species and Pacific cod. At smaller scales only Pacific cod and rockfishes had significant associations with structure. The size of the individual fish and the size of the structure both had significant impacts on the distance of fish from structure, with smaller fish closer to structure and closer to smaller structure. Over half of the individual fishes surveyed were associated with sponges. The implication of this research is that the presence of structure increases the density of rockfishes, and removal of deep-sea corals and sponges is likely to reduce the overall density of rockfishes.

Sohn, D., Ciannelli, L., & Duffy-Anderson, J. T. (2010). Distribution and Drift Pathways of Greenland Halibut (Reinhardtius hippoglossoides) During Early Life Stages in the Eastern Bering Sea and Aleutian Islands. *Fisheries Oceanography,* 19(5), 339-353. https://doi.org/10.1111/j.1365-2419.2010.00549.x

We describe the spatial distribution and dispersal pathways of Greenland halibut (Reinhardtius hippoglossoides) early life stages based on historical field data from the eastern Bering Sea and adjacent water along the eastern Aleutian Islands. Our results indicate that Greenland halibut from preflexion larvae to newly settled juveniles have a long pelagic duration and are subject to extended drift pathways. Hatching may occur in deep water, below 530 m, and larvae rise in the water column as they grow. Flexion/postflexion larvae are mostly found around the Pribilof Islands over the middle shelf (50-100-m isobaths) in July, and settling occurs during late summer on the middle shelf near St. Matthew Island. However, given that age-1 individuals were primarily found on the outer shelf, it appears that Greenland halibut actively move to deeper water with age (or size). The mechanisms of slope-shelf connectivity in preflexion larvae may be related to the Bering Slope Current in the vicinity of both Bering and Pribilof Canyons. This study shows that Greenland halibut early life stages have extensive horizontal ontogenetic migrations in the Bering Sea, and utilize a range of geographic areas over the basin and slope along the Aleutian Islands and in the eastern Bering Sea. Based on these results, it is hypothesized that settlement success and recruitment of Greenland halibut may be influenced by variability in currents and flows of the Bering Sea slope and shelf during their transport.

Sydeman, W. J., Thompson, S. A., Piatt, J. F., Garcia-Reyes, M., Zador, S., Williams, J. C., . . . Renner, H. M. (2017). Regionalizing Indicators for Marine Ecosystems: Bering Sea-Aleutian Island Seabirds, Climate, and Competitors. *Ecological Indicators,* 78, 458-469. https://doi.org/10.1016/j.ecolind.2017.03.013

Seabirds are thought to be reliable, real-time indicators of forage fish availability and the climatic and biotic factors affecting pelagic food webs in marine ecosystems. In this study, we tested the hypothesis that temporal trends and interannual variability in seabird indicators reflect simultaneously occurring bottom-up (climatic) and competitor (pink salmon) forcing of food webs. To test this hypothesis, we derived multivariate seabird indicators for the Bering Sea-Aleutian Island (BSAI) ecosystem and related them to physical and biological conditions known to affect pelagic food webs in the ecosystem. We examined covariance in the breeding biology of congeneric pelagic gulls (kittiwakes Rissa tridactyla and R. brevirostris) and auks (murres Uria aalge and U. lomvia), all of which are abundant and well-studied in the BSAI. At the large ecosystem scale, kittiwake and murre breeding success and phenology (hatch dates) covaried among congeners, so data could be combined using multivariate techniques, but patterns of response differed substantially between the genera. While data from all sites (n = 5) in the ecosystem could be combined, the south eastern Bering Sea shelf colonies (St. George, St. Paul, and Cape Peirce) provided the strongest loadings on indicators, and hence had the strongest influence on modes of variability. The kittiwake breeding success mode of variability, dominated by biennial variation, was significantly related to both climatic factors and potential competitor interactions. The murre indicator mode was interannual and only weakly related to the climatic factors measured. The kittiwake phenology indicator mode of variability showed multi-year periods ("stanzas") of late or early breeding, while the murre phenology indicator showed a trend towards earlier timing. Ocean climate relationships with the kittiwake breeding success indicator suggest that early-season (winter-spring) environmental conditions and the abundance of pink salmon affect the pelagic food webs that support these seabirds in the BSAI ecosystem.

Section VI: Aleutian Islands, Eastern Bering Sea, Gulf of Alaska

Biology

Litzow, M. A., & Mueter, F. J. (2014). Assessing the Ecological Importance of Climate Regime Shifts: An Approach from the North Pacific Ocean. *Progress in Oceanography,* 120, 110-119. https://doi.org/10.1016/j.pocean.2013.08.003

We used an indicator approach to address outstanding questions concerning the ecological importance of low-frequency climate variability in the northeast Pacific Ocean. Our data consist of a previously-published set of 33 climate and 64 biology time series, updated by us for the years 1965-2011 (for climate data) and 1965-2008 (for biology data). A model-selection approach showed that the first axis of variability in large-scale climate indices (PC1(ci)), the first and second axes for local climate parameters (PC1(cp) and PC2(cp)) and the second axis for biological variability (PC2(biol)) all showed temporal variability best described by abrupt shifts. In contrast, PC1(biol) showed gradual, rather than abrupt, temporal variability, suggesting that the leading axis of biological variability was not dominated by abrupt transitions following climate regime shifts. The leading mode of variability in detrended North Pacific sea surface temperature, the Pacific Decadal Oscillation, showed reduced amplitude from the late 1980s until the mid-2000s, and we found that this change in PDO behavior was associated with a decline in the strength of the leading pattern of basin-scale biological variability (PC1(biol)). A reversion to a PDO-negative state in the winter of 2007/08 was associated with the largest observed annual change in the PC1(bio)-PC2(bio) Phase space, suggesting renewed ecological importance of the PDO. However, a subset of biology time series (n = 23) for which more recent data were available did not show persistent change in PC1(bio) or PC2(bio) during 2008-2011, thus failing to support the hypothesis of widespread ecological response to the putative 2007/08 shift. To further assess the possible ecological importance of low-frequency climate variability in recent years, we compared changes in the PDO-North Pacific Gyre Oscillation (NPGO) phase space for 2007/08 with ecologically important (1976/77) and less important (1988/89) climate regime shifts of the past. We found that all three shifts involved PDO-NPGO variability of similar magnitude (i.e., similar pulse disturbances), but that the 1976/77 shift was followed by a period of stability in a new climate state (i.e., strong press disturbance), while the 1988/89 shift was not followed by a period of stability (weak press disturbance). Data through 2013 suggest that the press disturbance following 2007/08 is similar to that following 1976/77, implying that the putative 2007/08 shift may eventually prove to be ecologically important. Our "pulse-press" approach provides a formal framework for distinguishing transient and persistent climate perturbations at the ends of time series.

Morley, J. W., Selden, R. L., Latour, R. J., Frolicher, T. L., Seagraves, R. J., & Pinsky, M. L. (2018). Projecting Shifts in Thermal Habitat for 686 Species on the North American Continental Shelf. *Plos One,* 13(5), 28. https://doi.org/10.1371/journal.pone.0196127

Recent shifts in the geographic distribution of marine species have been linked to shifts in preferred thermal habitats. These shifts in distribution have already posed challenges for living marine resource management, and there is a strong need for projections of how species might be impacted by future changes in ocean temperatures during the 21st century. We modeled thermal habitat for 686 marine

species in the Atlantic and Pacific oceans using long-term ecological survey data from the North American continental shelves. These habitat models were coupled to output from sixteen general circulation models that were run under high (RCP 8.5) and low (RCP 2.6) future greenhouse gas emission scenarios over the 21 st century to produce 32 possible future outcomes for each species. The models generally agreed on the magnitude and direction of future shifts for some species (448 or 429 under RCP 8.5 and RCP 2.6, respectively), but strongly disagreed for other species (116 or 120 respectively). This allowed us to identify species with more or less robust predictions. Future shifts in species distributions were generally poleward and followed the coastline, but also varied among regions and species. Species from the U.S. and Canadian west coast including the Gulf of Alaska had the highest projected magnitude shifts in distribution, and many species shifted more than 1000 km under the high greenhouse gas emissions scenario. Following a strong mitigation scenario consistent with the Paris Agreement would likely produce substantially smaller shifts and less disruption to marine management efforts. Our projections offer an important tool for identifying species, fisheries, and management efforts that are particularly vulnerable to climate change impacts.

Orlov, A. M., Savinykh, V. F., Kulish, E. F., & Pelenev, D. V. (2012). New Data on the Distribution and Size Composition of the North Pacific Spiny Dogfish *Squalus suckleyi* (Girard, 1854). *Scientia Marina,* 76(1), 111-122. https://doi.org/10.3989/scimar.03439.22C

The results of long-term research on the spatial and vertical distribution of the North Pacific spiny dogfish Squalus suckleyi in the North Pacific Ocean and its size composition are presented. In total, data from 7059 catches of this species were analyzed (3178 with associated capture depth). The description of size composition is based on measurements of 413 specimens caught by driftnets, 328 by pelagic trawls and 722 by bottom trawls. This species was found to be most widely distributed in the North Pacific in the summer and autumn months during feeding migrations. Seasonal and long-term changes in the spatial distribution were observed. A wide distribution of S. suckleyi in the Bering Sea was recorded after the year 2000, which is likely associated with recent climate change. Occurrence of the species in the water column and near the bottom differed considerably. In the water column, the maximum number of captures was observed within the upper 25 m layer (about 90%). Near the bottom, this species was most abundant at depths less than 50 m (over 45%) and within a depth range of 101-200 m (about 50%). The catch of S. suckleyi during the daytime was considerably larger than in the night, possibly due to vertical diurnal migrations. This species was found at water temperatures ranging from 0 to 12.7 degrees C, and maximum catches were observed at temperatures over 8 C. Size compositions of bottom and pelagic trawl catches were similar (mean length 69.1 and 68.6 cm respectively) while driftnet catches were composed of larger specimens (mean length 75.3 cm).

Spencer, P. D., & Dorn, M. W. (2013). Incorporation of Weight-Specific Relative Fecundity and Maternal Effects in Larval Survival into Stock Assessments. *Fisheries Research,* 138, 159-167. https://doi.org/10.1016/j.fishres.2012.05.003

Marine fish populations may exhibit a number of complexities in their reproductive dynamics, such as weight-specific relative fecundity (i.e. eggs produced per spawner weight increases with spawner size) and maternal effects (i.e. reduced larval survival with reduced spawner age), that are typically not incorporated in stock assessment models. Improved information on reproductive biology could alter

estimates of stock productivity and potentially improve estimation of stock-recruitment parameters. In this study, we examined the influence of maternal effects and weight-specific relative fecundity on stock status (defined as reproductive potential and measured as eggs, larvae, or spawning stock biomass), F-msy, and the statistical fit of stock-recruitment curves estimated within the Bering Sea/Aleutian Islands Pacific ocean perch (Sebastes alutus) and Gulf of Alaska walleye pollock (Theragra chakogramma) statistical catch-at-age assessment models. In each example, estimates of recruitment strength and the variation around stock-recruitment curves were relatively insensitive to various indices of reproductive potential. However, weight-specific relative fecundity increased estimates of Fmsy, whereas maternal effects decreased estimates of Fmsy. The range of Fmsy estimates obtained for walleye pollock from eight indices of reproductive potential was 0.12-0.19, whereas the Fmsy range for Pacific ocean perch from three indices of reproductive potential was 0.079-0.084. For walleye pollock, weight-specific relative fecundity and recent increases in spawner weight-at-age resulted in an upward trend in reproductive potential relative to constant relative fecundity with spawner size. The two examples demonstrate the influence of reproductive biology upon stock productivity even in cases where residual recruitment variation is relatively unaffected, and motivate the ongoing monitoring of reproductive status and its incorporation in estimation of fishing rate reference points.

Section VII: Aleutian Islands, Gulf of Alaska

Biology

Bryan, T. L., & Metaxas, A. (2006). Distribution of Deep-Water Corals Along the North American Continental Margins: Relationships with Environmental Factors. *Deep-Sea Research Part I-Oceanographic Research Papers,* 53(12), 1865-1879. https://doi.org/10.1016/j.dsr.2006.09.006

Despite the increasing attention to assemblages of deep-water corals in the past decade, much of this research has been focused on documenting and enumerating associated fauna. However, an understanding of the distribution of most species of coral and the ecological processes associated with these assemblages is still lacking. In this study, we qualitatively and quantitatively described the habitats of two families of deep-water corals in relation to six oceanographic factors (depth, slope, temperature, current, chlorophyll a concentration and substrate) on the Pacific and Atlantic Continental Margins of North America (PCM and ACM study areas, respectively). This study focused primarily on the distributions of Primnoidae and Paragorgiidae because of the large number of documented occurrences. For each environmental factor, deep-water coral locations were compared to the surrounding environment using chi(2) tests. On both continental margins, coral locations were found to be not randomly distributed within the study areas, but were within specific ranges for most environmental factors. In the PCM study area, Paragorgiidae and Primnoidae locations were found in areas with slopes ranging from 0 degrees to 10.0 degrees, temperature from -2.0 to 11.0 degrees C and currents from 0 to 143 cm s(-1). In the ACM study area, Paragoragiidae and Primnoidae locations were found in areas with slopes ranging from 0 degrees to 1.4 degrees, temperature ranging from 0 to 11.0 degrees C and currents ranging from 0 to 207 cm s(-1). Although the patterns in habitat characteristics were similar, differences existed between families with respect to particular environmental factors. In both study areas, most environmental parameters in locations where corals occurred were significantly different from the average values of these parameters as determined with chi(2) tests ($p < 0.05$) except for substrate in Paragorgiidae locations and depth in Primnoidae locations on the PCM. This is the first study to show coral distributional patterns at the continental shelf/slope scale.

Bryan, T. L., & Metaxas, A. (2007). Predicting Suitable Habitat for Deep-Water Gorgonian Corals on the Atlantic and Pacific Continental Margins of North America. *Marine Ecology Progress Series,* 330, 113-126. https://doi.org/10.3354/meps330113

Mapping marine habitats and species distributions is essential in conservation and resource management. The generation of such maps, however, is particularly challenging for the poorly sampled deep-sea species. In this study, we explored the spatial suitability of deep-water coral (Families Paragorgiidae and Primnoidae) habitat on both the Pacific and Atlantic Continental Margins of North America (PCM and ACM) using Biomapper, a modeling program which can determine habitat suitability using presence-only data. The PCM study area was divided into 2 regions to limit the geographic size of the modelled area: PCM:AK, which encompasses Alaska and PCM:BC-CA, which encompasses British Columbia, Washington, Oregon, and California. Suitable habitat was determined based on quantitative relationships between physical seascape factors and biological data. For the PCM study area, the most accurate model for Paragorgiidae in PCM:AK combined temperature, slope, current and chlorophyll (chl)

a concentration (Spearman's rho = 0.79), whereas in the PCM:BC-CA it combined depth and chl a concentration (rho = 0.66). For Primnoidae, in the PCM:AK the most accurate combination included depth, slope, current and chl a concentration (rho = 0.90), and in the PCM:BC-CA, it included depth, temperature, slope and current (rho = 0.85). In the ACM study area, the most accurate model for Paragorgiidae combined temperature, slope and chl a concentration (rho = 0.71), whereas the one for Primnoidae combined temperature, slope, current and chl a concentration (rho = 0.74). In both study areas, corals were predicted to occur in areas of complex topography, mainly along the continental shelf break and on seamounts. Sensitivity analyses indicated that predicted mean values of seascape factors, in coral habitat as well as niche breadth, varied with number of coral locations, but to a much lesser extent with spatial resolution. To our knowledge, this is the first study to use Biomapper for the prediction of suitable habitat in marine species.

Gerlinsky, C. D., Haulena, M., Trites, A. W., & Rosen, D. A. S. (2018). Reference Ranges and Age-Related and Diving Exercise Effects on Hematology and Serum Chemistry of Female Steller Sea Lions (Eumetopias jubatus). *Journal of Zoo and Wildlife Medicine,* 49(1), 18-29. https://doi.org/10.1638/2017-0072R.1

Decreased health may have lowered the birth and survival rates of Steller sea lions (Eumetopias jubatus) in the Gulf of Alaska and Aleutian Islands over the past 30 yr. Reference ranges for clinical hematology and serum chemistry parameters needed to assess the health of wild sea lion populations are limited. Here, blood parameters were serially measured in 12 captive female Steller sea lions ranging in age from 3 wk to 16 yr to establish baseline values and investigate age-related changes. Whether diving activity affects hematology parameters in animals swimming in the ocean compared with animals in a traditional aquarium setting was also examined. Almost all blood parameters measured exhibited significant changes with age. Many of the age-related changes reflected developmental life history changes, including a change in diet during weaning, an improvement of diving capacity, and the maturity of the immune system. Mean corpuscular hemoglobin and mean corpuscular volume were also higher in the ocean diving group compared with the aquarium group, likely reflecting responses to increased exercise regimes. These data provide ranges of hematology and serum chemistry values needed to evaluate and compare the health and nutritional status of captive and wild Steller sea lions.

Goyert, H. F., Garton, E. O., & Poe, A. J. (2018). Effects of Climate Change and Environmental Variability on the Carrying Capacity of Alaskan Seabird Populations. *The Auk,* 135(4), 975-991. https://doi.org/10.1642/auk-18-37.1

Marine birds in Alaska, USA, have been monitored systematically for more than 4 decades, and yet it remains unclear why some populations have increased while others have declined. We analyzed the population dynamics of 5 seabird species—Black-legged (Rissa tridactyla) and Red-legged kittiwakes (R. brevirostris), Common (Uria aalge) and Thick-billed murres (U. lomvia), and Tufted Puffins (Fratercula cirrhata)—across 4 decades in Alaska. We tested hypotheses that each species' carrying capacity varied continuously through time with climate cycles and/or in response to habitat covariates. Using an information-theoretic approach, we evaluated competing candidate stochastic growth models of each species' annual rate of change, incorporating various environmental covariates. The North Pacific Index and Pacific Decadal Oscillation were the most important climatic covariates across the whole of Alaska,

where the former generally was negatively related to rates of population change, and the latter positively related. Across the 40-yr time series, we found slight decreases in zooplankton (i.e. krill) concentrations across the Gulf of Alaska, and significant increases in sea surface temperature across the Aleutian Islands. Kittiwakes showed the greatest level of sensitivity to these 2 environmental changes. Our results provide evidence that deteriorating secondary productivity (i.e. euphausiids) has contributed to declines of Black-legged Kittiwakes in the Gulf of Alaska. In contrast, the carrying capacity of murres has increased across the state, even in regions affected by warming waters and reduced productivity. These results suggest that kittiwakes act as indicators of detrimental impacts of climatic variability, whereas murres demonstrate resilience to such environmental change. Identifying the ecological factors that explain seabird population dynamics is necessary to understand the implications of climate and environmental change for long-term marine ecosystem dynamics.

Smith, K. R., Somerton, D. A., Yang, M. S., & Nichol, D. G. (2004). Distribution and Biology of Prowfish (Zaprora silenus) in the Northeast Pacific. *Fishery Bulletin,* 102(1), 168-178. Retrieved from https://spo.nmfs.noaa.gov/content/distribution-and-biology-prowfish-zaprora-silenus-northeast-pacific

The prowfish (Zaprora silenus) is an infrequent component of bottom trawl catches collected on stock assessment surveys. Based on presence or absence in over 40,000 trawl catches taken throughout Alaskan waters southward to southern California, prowfish are most frequently encountered in the Gulf of Alaska and the Aleutian Islands at the edge of the continental shelf Based on data from two trawl surveys, relative abundance indicated by catch per swept area reaches a maximum between 100 m and 200 m depth and is much higher in the Aleutian Islands than in the Gulf of Alaska. Females weigh 3.7% more than males of the same length. Weight-length functions are W (g) = 0.0164 L-2.92 (males) and W = 0.0170 L2.92 (females). Length at age does not differ between sexes and is described by L = 89.3(1 - e-(0-181(t+0.554))), where L is total length in cm and t is age in years. Females reached 50% maturity at a length of 57.0 cm and an age of 5.1 years. Prowfish diet is almost entirely composed of gelatinous zooplankton, primarily scyphozoa and salps.

Trites, A. W., Deecke, V. B., Gregr, E. J., Ford, J. K. B., & Olesiuk, P. F. (2007). Killer Whales, Whaling, and Sequential Megafaunal Collapse in the North Pacific: A Comparative Analysis of the Dynamics of Marine Mammals in Alaska and British Columbia Following Commercial Whaling. *Marine Mammal Science,* 23(4), 751-765. https://doi.org/10.1111/j.1748-7692.2006.00076.x

The hypothesis that commercial whaling caused a sequential megafaunal collapse in the North Pacific Ocean by forcing killer whales to eat progressively smaller species of marine mammals is not supported by what is known about the biology of large whales, the ecology of killer whales, and the patterns of ecosystem change that took place in Alaska, British Columbia, and elsewhere in the world following whaling. A comparative analysis shows that populations of seals, sea lions, and sea otters increased in British Columbia following commercial whaling, unlike the declines noted in the Gulf of Alaska and Aleutian Islands. The declines of seals and sea lions that began in western Alaska around 1977 were mirrored by increases in numbers of these species in British Columbia. A more likely explanation is that the seal and sea lion declines and other ecosystem changes in Alaska stem from a major oceanic regime

shift that occurred in 1977. Killer whales are unquestionably a significant predator of seals, sea lions, and sea otters-but not because of commercial whaling.

Trumble, S. J., & Castellini, M. A. (2002). Blood Chemistry, Hematology, and Morphology of Wild Harbor Seal Pups in Alaska. *The Journal of Wildlife Management,* 66(4), 1197-1207. https://doi.org/10.2307/3802953

Recent declines in harbor seal (Phoca vitulina) populations in Alaska have emphasized the need to obtain health index biomarkers for comparative purposes. This study was designed to compare blood chemistry and morphology reference range values between 2 harbor seal pup populations in Alaska, 1 population in continued decline within Prince William Sound, and another population in recent increase on Tugidak Island. Significant site-specific differences occurred in 5 of the 8 mean hematology values as well as in 11 plasma chemistry values. We also determined significant year-to-year variability in 8 (36%) mean plasma chemistries. These results form the largest available field-based blood reference database for harbor seal pups. They demonstrate that blood values can vary on the population scale and that health assessment or ecophysiological studies involving blood chemistry must utilize an appropriate set of reference values for valid comparisons.

Williams, B., Risk, M., Stone, R., Sinclair, D., & Ghaleb, B. (2007). Oceanographic Changes in the North Pacific Ocean over the Past Century Recorded in Deep-Water Gorgonian Corals. *Marine Ecology Progress Series,* 335, 85-94. https://doi.org/10.3354/meps335085

Deep-water gorgonian corals are long-lived and abundant in the North Pacific Ocean. Gorgonians have annually-resolved skeletal organic bands, making them proxies of environmental changes. Specimens of Primnoa sp. were collected from the Gulf of Alaska in 2001, 2003, and 2004. Organic band counts and Pb-210 dating were combined to produce a growth chronology for 2 specimens. Organic skeletal growth bands were dissected and analysed for C-13 and N-15 to investigate long-term changes in production and cycling of organic matter in surface waters. Three specimens were analyzed: PAL, P26 and P88. Specimen PAL, with a record spanning 125 yr, exhibits a statistically significant systematic depletion of C-13 and N-15 over time. The magnitude of the depletion trend in the carbon record over the past 50 yr is equivalent to the C-13 depletion of ocean surface dissolved inorganic carbon from the input of anthropogenic carbon into the atmosphere (the Suess effect). The depletion in N-15 may reflect changes in plankton composition at the bottom of the food web.

Geology

Matveenkov, V. V., Sedov, A. P., & Volokitina, L. P. (2005). The Possible Relation of Hydrocarbon Accumulations with Transform Plate Boundaries. *Oceanology,* 45(4), 572-579. Retrieved from https://www.elibrary.ru/item.asp?id=9133773

The formation of hydrogen and methane proceeds at the process of serpentinization of the rocks of the upper mantle during their interaction with oceanic water. Methane may not only accumulate in the sediments in the form of gas hydrate fields but also transform the organic matter of the sediments into hydrocarbons. The transform boundaries between lithospheric plates represent the most promising structures from the point of view of the formation of fields of this origin. In this paper, we consider the

region of the Queen Charlotte transform fault and the western part of the Aleutian island arc and deep-water trench. A similar situation may occur at the boundaries of microplates as well. The tectonic boundary between the Okhotsk and the Sakhalin-Hokkaido microplates is assessed as an example.

Maurya, S., Taira, T., & Romanowicz, B. (2019). Location of Seismic "Hum" Sources Following Storms in the North Pacific Ocean. *Geochemistry Geophysics Geosystems,* 20(3), 1454-1467. https://doi.org/10.1029/2018gc008112

We investigate the spatially and temporally varying distributions of sources of the Earth's low-frequency seismic hum at high space-time resolution during a seismically quiet 7-day period in December 2015, when two large storms with different reaches propagate across the North Pacific Ocean. We integrate information from a variety of data from ocean wave height, infragravity wave prediction model, and broadband seismic data. We analyze seismic data to understand the seismic hum better: power spectral density at stations for detection and location of sources using array beamforming and backprojection methods, with a similar to 3-hr temporal and similar to 5 degrees spatial resolution. For storms propagating west to east across the northern Pacific hitting the west coast of North America broadscale, we show that the distribution of hum sources is consistent with a model of seismic energy generated via infragravity waves, produced near the impact location of the storm, and propagating along the coast as well as toward the open ocean. The generation of seismic hum depends strongly on the reach of the storm and is very weak for a storm with more northerly propagation toward Alaska. At shorter periods (e.g., similar to 70s), the seismic hum is generated in a narrow band that follows the coast, reaching progressively further to the north, while at longer periods (e.g. 150s), it covers a broader area reaching far into the deep ocean. It may thus be possible to predict the distribution of the strongest hum sources, to first order, from the knowledge of the direction of propagation and strength of northern Pacific storms. Plain Language Summary The Earth's low-frequency "hum" originates primarily in the oceans and is generated through the interaction of infragravity waves (IG) with the seafloor. However high-resolution spatial and temporal distribution of hum remains unclear. We study a 6-day-long time window devoid of large earthquakes in December 2015, when two distinct large storms originate in the western Pacific, and propagate across the northern Pacific Ocean, generating IG waves and hum as they reach the coasts. Using array beamforming and backprojection approaches, our results show the striking difference in the hum generated by the two storms: the first one initially generates strong hum along the Cascadia coast, progressively extending toward Alaska and the Aleutians, while at the longest periods (e.g., 150s) it also reaches the open ocean basins. This provides a strong indication that both shallow and deep water IG waves propagating far from their source are responsible for the generation of the observed hum. In contrast, the second large storm generates hum only briefly, and the sources are mostly confined to the near coast in Alaska.

Section VIII: Beaufort Sea

Biology

Bowman, J. S., Larose, C., Vogel, T. M., & Deming, J. W. (2013). Selective Occurrence of Rhizobiales in Frost Flowers on the Surface of Young Sea Ice near Barrow, Alaska and Distribution in the Polar Marine Rare Biosphere. *Environmental Microbiology Reports,* 5(4), 575-582. https://doi.org/10.1111/1758-2229.12047

Frost flowers are highly saline ice structures that grow on the surface of young sea ice, a spatially extensive environment of increasing importance in the Arctic Ocean. In a previous study, we reported organic components of frost flowers in the form of elevated levels of bacteria and exopolymers relative to underlying ice. Here, DNA was extracted from frost flowers and young sea ice, collected in springtime from a frozen lead offshore of Barrow, Alaska, to identify bacteria in these understudied environments. Evaluation of the distribution of 16S rRNA genes via four methods (microarray analysis, T-RFLP, clone library and shotgun metagenomic sequencing) indicated distinctive bacterial assemblages between the two environments, with frost flowers appearing to select for Rhizobiales. A phylogenetic placement approach, used to evaluate the distribution of similar Rhizobiales sequences in other polar marine studies, indicated that some of the observed strains represent widely distributed members of the marine rare biosphere in both the Arctic and Antarctic.

Hunt, B. P. V., Nelson, R. J., Williams, B., McLaughlin, F. A., Young, K. V., Brown, K. A., . . . Carmack, E. C. (2014). Zooplankton Community Structure and Dynamics in the Arctic Canada Basin During a Period of Intense Environmental Change (2004–2009). *Journal of Geophysical Research: Oceans,* 119(4), 2518-2538. https://doi.org/10.1002/2013jc009156

Mesozooplankton were sampled in the Canada Basin in the summers of 2004, 2006, 2007, 2008, and fall 2009. Six taxa (Calanus hyperboreus, Calanus glacialis, Oithona similis, Limacina helicina, Microcalanus pygmaeus, and Pseudocalanus spp.) accounted for 77–91% of the abundance in all years, and 70–80% of biomass in 2004–2008. The biomass of C. hyperboreus and C. glacialis was reduced in 2009, likely due to seasonal migration below the sampling depth. Mean abundance was consistent across surveys while biomass increased from 18.92 to 32.56 mg dry weight m−3 between 2004 and 2008. Multivariate analysis identified a clear separation between shelf and deep basin (>1000 m) assemblages. Within the deep basin abundance and biomass were higher in the west, associated with a higher chlorophyll maximum. In 2007 and 2008 considerable heterogeneity developed in the assemblage structure, associated with variability in the contribution of the short-lived (<1 year) copepod species O. similis and M. pygmaeus. Conversely, the long lived (≥2 years) C. hyperboreus and C. glacialis showed an increasingly consistent spatial distribution of high biomass from 2004 to 2008. We propose that a greater dependence on autochthonous basin production by the short-lived species resulted in their decreased secondary production in the freshening Beaufort Gyre in 2007 and 2008. Conversely, long-lived species were supported by high allochthonous production on the Beaufort and Chukchi shelves and lipid stores accumulated from this source enabled them to persist in the low chlorophyll a biomass conditions of the Canada Basin.

Smoot, C. A., & Hopcroft, R. R. (2017). Cross-Shelf Gradients of Epipelagic Zooplankton Communities of the Beaufort Sea and the Influence of Localized Hydrographic Features. *Journal of Plankton Research,* 39(1), 65-78. https://doi.org/10.1093/plankt/fbw080

Biological, chemical and physical oceanographic data were collected in the Beaufort Sea between Point Barrow, Alaska and the Mackenzie River during August and September from 2010 to 2014 in order to provide baseline information for the Beaufort Sea's poorly characterized zooplankton communities. Mean holozooplankton abundance and biomass across the survey years ranged from 1110 to 3380 ind. m−3 and 23.8 to 76.9 mg DW m−3, respectively. The zooplankton community was predominantly Arctic in faunal character during all surveys, although Pacific and Atlantic expatriates were observed. The community was dominated by Calanus glacialis, Calanus hyperboreus, Metridia longa, Oithona similis, Triconia borealis, Microcalanus pygmaeus, and the Pseudocalanus species complex; this group composed 44–81% of abundance and 52–71% of biomass across survey years. Despite the dominance of these taxa, seven distinct faunal groups were identified. These faunal groups reflect a transition from neritic to oceanic communities and the influence of more localized hydrographic features, such as Pacific-origin Alaska Coastal Water and Mackenzie River-derived Water. Community structure was most strongly related to temperature and salinity averaged over the upper 200 m, suggesting that future changes in the physical environment will be manifested by concurrent shifts in the distribution of Beaufort Sea zooplankton communities.

Smoot, C. A., & Hopcroft, R. R. (2017). Depth-Stratified Community Structure of Beaufort Sea Slope Zooplankton and Its Relations to Water Masses. *Journal of Plankton Research,* 39(1), 79-91. https://doi.org/10.1093/plankt/fbw087

Depth-stratified samples were collected along the Beaufort Sea slope during August and September 2012–2014 to characterize the vertical structure of zooplankton communities from 0 to 1000 m. We documented 95 holoplanktonic categories (88 species, 5 genera, 1 order and 1 phylum); greatest diversity was observed in the copepods (51 species and 1 genus), followed by the cnidarians (11 species and 1 genus) and amphipods (7 species and 3 genera). Distinct communities were associated with the main water masses in the study region: the Polar Mixed Layer (PML; 0–50 m), Arctic Halocline Water (50–200 m) and Atlantic Water (AW; 200–1000 m). Average abundance and biomass were highest in the PML (1230 ind. m−3 and 24.3 mg DW m−3, respectively) and declined to a minimum in AW (22 ind. m−3 and 1.9 mg DW m−3, respectively). Copepods dominated in the PML, with Calanus species, Oithona similis, Metridia longa, Triconia borealis, Microcalanus pygmaeus and Pseudocalanus spp. contributing more than 80% of copepod abundance and biomass. Mesopelagic copepods were important contributors to the AW community, which exhibited the highest species richness. Community structure was highly correlated with salinity and depth. We report similar species composition but higher biomass when compared with the interior basins, likely due to elevated coastal production.

Wiese, F. K., Harvey, H. R., McMahon, R., Neubert, P., Gong, D., Wang, H., . . . Gryba, R. (2018). *Marine Arctic Ecosystem Study - Biophysical and Chemical Observations from Glider and Benthic Surveys in 2016.* Retrieved from [no URL available]

The Department of the Interior, Bureau of Ocean Energy Management (BOEM) and its partners, ONR, NOPP, Shell, USARC, US Coast Guard, seek to advance knowledge of the Arctic marine ecosystem. The Marine Arctic Ecosystem Study (MARES) arose from increased attention on climate change, energy development, and related sustainability issues in the Arctic. Results from this study are intended to inform government, industry, and communities on regulatory needs, operational challenges, and resource management and provide important context for economic development, environmental protection, sustainability of local communities, and health and safety.

The focus area of MARES is the eastern Beaufort Sea shelf from Kaktovik to the Mackenzie Delta coastline to a depth of 1,000 m. The overarching scientific goal of MARES, as initially envisioned, was to increase our understanding of the impact of physical drivers (ocean, ice, atmosphere) on the trophic structure and function of the marine ecosystem on the Beaufort shelf with special attention to the implications on marine mammals and local communities. The intent was to implement an integrated, multidisciplinary study combining retrospective analyses, field studies, modeling, and synthesis spanning atmosphere, ice, physical, chemical, and biological oceanography from benthos to fish, marine mammals, and people.

Chemistry

Dainard, P. G., Gueguen, C., Yamamoto-Kawai, M., Williams, W. J., & Hutchings, J. K. (2019). Interannual Variability in the Absorption and Fluorescence Characteristics of Dissolved Organic Matter in the Canada Basin Polar Mixed Waters. *Journal of Geophysical Research-Oceans,* 124(7), 5258-5269. https://doi.org/10.1029/2018jc014896

Dissolved organic matter (DOM) absorption and fluorescence properties were investigated for seawater samples collected from the polar mixed layer (0-30 m) of the Canada Basin in 2010-2012. Sea ice concentration as well as fractions of meteoric and sea ice meltwater (f(MW) and f(SIM)) calculated from oxygen isotope ratio (delta O-18) were applied to assess the importance of discrete freshwater inputs to the distribution of DOM. Parallel factor analysis identified four humic-like (C1-2 and C4-C5) and one protein-like (C3) fluorescent components in 380 excitation-emission matrix spectra. Surprisingly, despite different sea ice cover and biological regimes, DOM composition was largely homogeneous spanning these annual surveys. A strong and reoccurring coastal influence on DOM absorption and humic-like DOM was observed each year and was particularly pronounced during the summer 2011 survey. Enrichment of DOM humic signal (C1, C2, and C4) in brine-rich (f(SIM) < 0) waters relative to sea ice melt-dominated waters (f(SIM) > 0; $p < 0.05$) was found during 2011 and 2012 in the offshore region (>76 degrees N) where coastal influences were minimal (f(MW) < 0.1). Similar f(SIM) < 0 were found for 2011 and 2012, either when considering the Canada Basin as a whole or the offshore region (>76 degrees N) exclusively, which could imply that brine formation influenced humic signals in polar mixed layer seawater. Findings herein highlight that future projected changes in freshwater sources and brine production in the Canada Basin will likely implicate the distribution and composition of DOM. Plain Language Summary In this paper we showed that despite different sea ice cover in summer-early fall, the average levels and composition of colored dissolved organic matter remained relatively unchanged in surface waters in the Canada Basin in 2010-2012. Only the northwest region experiencing strong brine

rejection showed elevated humic signals. We also suggest to use the 140 degrees W line as reference for dissolved organic matter monitoring in the Canada Basin in future studies.

Moore, C. W., Obrist, D., Steffen, A., Staebler, R. M., Douglas, T. A., Richter, A., & Nghiem, S. V. (2014). Convective Forcing of Mercury and Ozone in the Arctic Boundary Layer Induced by Leads in Sea Ice. *Nature,* 506(7486), 81-+. https://doi.org/10.1038/nature12924

The ongoing regime shift of Arctic sea ice from perennial to seasonal ice is associated with more dynamic patterns of opening and closing sea-ice leads (large transient channels of open water in the ice)(1-3), which may affect atmospheric and biogeochemical cycles in the Arctic(4). Mercury and ozone are rapidly removed from the atmospheric boundary layer during depletion events in the Arctic(5-7), caused by destruction of ozone along with oxidation of gaseous elemental mercury (Hg(0)) to oxidized mercury (Hg(II)) in the atmosphere and its subsequent deposition to snow and ice(5). Ozone depletion events can change the oxidative capacity of the air by affecting atmospheric hydroxyl radical chemistry(8), whereas atmospheric mercury depletion events can increase the deposition of mercury to the Arctic(6,9-11), some of which can enter ecosystems during snowmelt(12). Here we present near-surface measurements of atmospheric mercury and ozone from two Arctic field campaigns near Barrow, Alaska. We find that coastal depletion events are directly linked to sea-ice dynamics. A consolidated ice cover facilitates the depletion of Hg(0) and ozone, but these immediately recover to near-background concentrations in the upwind presence of open sea-ice leads. We attribute the rapid recoveries of Hg(0) and ozone to lead-initiated shallow convection in the stable Arctic boundary layer, which mixes Hg(0) and ozone from undepleted air masses aloft. This convective forcing provides additional Hg(0) to the surface layer at a time of active depletion chemistry, where it is subject to renewed oxidation. Future work will need to establish the degree to which large-scale changes in sea-ice dynamics across the Arctic alter ozone chemistry and mercury deposition in fragile Arctic ecosystems.

Geology

Craig, J. D., Sherwood, K. W., & Johnson, P. P. (1985). *Geologic Report for the Beaufort Sea Planning Area, Alaska.* Retrieved from [No URL available.]

The Federal Outer Continental Shelf (OCS) Beaufort Sea Planning Area extends approximately 500 miles along the northern continental margin of Alaska from the Canadian border to 162 degrees west longitude, where it meets the Chukchi Sea OCS Planning Area. The planning area includes continental shelf, slope, and abyssal plain physiographic provinces. The Beautfort continental shelf is relatively narrow, and most of the planning area lies in the abyssal plain of the Arctic Ocean. For geological and logistical reasons, only the continental shelf is thought to have any realistic potential for economic accumulations of hydrocarbons. Lease blocks on the shelf are tentatively scheduled for public offering at least Sale 97. Northern Alaska is divisible into two major geologic provinces: (1) a landward province containing Paleozoic and Mesozoic rocks underlain by continental crust and (2) an offshore province containing a thick clastic wedge of Cretaceous and Tertiary sediments deposited on the subsiding continental margin underlain by trasitional to oceanic crust. The gently southward-dipping surface of the continental basement complex, termed the "Arctic Platform," is separated from the post-Jurassic continental margin along a highly faulted flexure termed the "Hinge Line." Acoustic and economic basement of the Arctic Platform consists of a metamorphic complex (the Franklinian sequence) formed

by a regional orogeny in Devonian time. The basement complex is overlain by Middle (?) Devonian to Lower Cretaceous strata (the Ellesmerian sequence) deposited in a stable shelf setting. The Ellesmerian sequence generally thins northward toward the orogenic terrane which existed before the rifting of the Beaufort continental margin in Early Cretaceous time. A structurally anomalous basin (informally termed the "Northeast Chukchi Basin") containing greater than 30,000 feet of Paleozoic sediments underlies the northeastern Chukchi shelf. These lower Ellesmerian sedimentary depostis are juxtaposed with the basement complex of the Arctic Platform across a poorly resolved fault zone termed the "Barrow fault." Ellesmerian sedimentation terminated in Early Cretaceous time with the uplift of an incipient rift zone in the vicinity of the present contiental margin. This uplift and associated erosion produced a regionally extensive unconformity that truncated the Ellesmerian sequence on some onshore and most offshore parts of the Arctic Platform. Extensional tectonics early in the rifting episode produced grabens which were filled with Lower Cretaceous sediments (the Rift sequence) derived from nearby uplifted blocks. A broad, SE-plunging structural high, the "Barrow Arch," was created by the subsidence of flanking basins (Colville and Nuwuk) following continental breakup. Subsidence of the offshore continental margin in Cretaceous and Tertiary time created deep structural basins (Nuwuk and Kaktovik Basins) beneath the present Beaufort shelf. An immense elastic wedge (the Brookian sequence) prograded northward from the Brooks Range orogenic belt into these depocenters. All North Slope producing oil fields occur within the Ellesmerian sequence, and any area of northern Alaska where these rocks occur is considered highly prospective. The northernmost parts of the Arctic Platform are considered to be less prospective because Ellesmerian rocks are absent as a result of northward pinch-out by onlap and erosion at overlying unconformities. Paleozoic strata in the Northeast Chukchi Basin are involved in numerous fault and fold structures, and the potential for significant hydrocarbon accumulations is accordingly high. Untested Rift sequence rocks deposited in infrarift grabens on the northern Arctic Platform have good reservoir and source rock potential. Numerous structural and stratigraphic traps may exist within the deep basins seaward of the High Line filled with Brookian clastic units. Potential reservoirs in this prograding clastic wedge are likely to be deltaic or basinal sandstones, which suggests that individual reservoirs may be thin and lenticular. Rotational folds associated with listric faulting near the basin margins are the most attractive exploration objectives in the western Beaufort (Nuwuk Basin); compressional folds and fault traps form the most prevalent plays in the eastern Beaufort (Katovik Basin). Geologic features and processes which may affect petroleum-related activities in the planning area include a mobile and pervasive ice cover, active seabed scouring by ice and currents, unstable seafloor sediments, massive slumps on the outer shelf, subsea permafrost, shallow gas accumulations, abnormal formation pressure, near-seafloor faults, and modern seismicity. Ice movement may exert great stresses on platforms as well as on the sea bed. Ice gouging on the shelf may necessitate burial of pipelines and wellheads. Strudel scouring of the seafloor near the mouths of rivers is active during spring flood periods. Subsea permafrost has been confirmed in several nearshore areas and presents unique engineering problems for foundations, gravel excavations, and pipeline routing. Shallow gas may be trapped in several ways and presents a serious drilling hazard, particularly in areas dissected by near-seafloor faults. Abnormally high formation pressures have been encountered in Cenozoic sedimentary basins in Eastern Alaska and the Beaufort Sea. Earthquake activity has been documented on the eastern Beaufort shelf and may be related to ongoing tectonism in the northeastern Brooks Rnage. Surface fault displacements and massive slumps on the outer Beaufort shelf may be triggered by these shallow-focus, moderate-magnitude earthquakes.

McDougall, K. (1994). *Late Cenozoic Benthic Formainifera of the Hla Borehole Series, Beaufort Sea Shelf, Alaska.* Retrieved from https://digital.library.unt.edu/ark:/67531/metadc1115009/

A report about benthic foraminiferal faunas in 18 borholes from the eastern Beaufort Sea shelf.

Northern Land Use Research, I., Corporation, U., & Alaska, G. (Cartographer). (2005). Appendix A. Beaufort Sea Lease Sale Map. Retrieved from [No URL available.]

No abstract available.

Northern Land Use Research, I., Corporation, U., & Alaska, G. (2005). *Review of the Geological-Geophysical Data and Core Analysis to Determine Archaeological Potential of Buried Landforms, Beaufort Sea Shelf, Alaska.* Retrieved from https://www.boem.gov/sites/default/files/boem-newsroom/Library/Publications/2007/2007_004-part-2.pdf

No abstract available.

Sathy Naidu, A., & Mowatt, T. C. (1992). Origin of Gravels from the Southern Coast and Continental Shelf of the Beaufort Sea, Arctic Alaska. *ICAM Proceedings*. Retrieved from [No URL available]

Gravel and larger sized materials from the seafloor of the continental shelf area of the Beaufort Sea, Arctic Ocean, as well as from adjacent onshore portions of northern Alaska, feature a variety of lithologic types: diabasic, volcanic, granitic, sedimentary clastic and carbonate, and high-grade metamorphic rocks. Presumably, fragments such as these were carried to their present collection sites by some mechanism involving ice-transport; via paleo/contemporary ice-rafting, or continental/subcontinental ice sheets. If this suite of samples represents an assemblage derived from a single general source area, the most likely source area would seem to be somewhere in the Canadian Arctic. However, if more than one source area furnished materials, the problem of ascertaining such sources becomes considerably more complex. Present interpretation leads to speculative sources in the Canadian Arctic, in particular the Coronation Gulf area or/and the Arctic Archipelago.

Stone, D. B., Goodliffe, A. M., & Crumley, S. G. (1991). *Oliktok Magnetic Survey (April 1990).* Retrieved from [No URL available]

No abstract available.

Thurston, D. K., & Choromanski, D. R. (1999). *The Alaska Geological Society Science & Technology Conference 1999.* Retrieved from [No URL available]

This presentation is the first public release of geological information from shallow hazards site clearance surveys in the Alaska Outer Continental Shelf. The Arco Alaska Warthog #1 well site is located in Camden Bay, Beaufort Sea, Alaska approximately 3.1 miles offshore. The site lies in a growth faulted area near the southern flank of the Camden Anticline, the northern flank of the Marsh Creek anticlinorium, and south of the Hinge Line fault zone. In 1997, the Warthog #1 well site was surveyed for geologic hazards clearance by Fairweather E&P Services. The 6 x 4.8 km survey area encompasses both State and Federal waters and has a variable grid line-spacing between 100 x 300 m and 1200 x 1200 m. Geophysical survey systems included fathometer, side scan sonar, subbottom profilers, and a high-resolution 24 channel airgun array. Water depths range from 2 to 13 m from southwest to northwest. Sediments are Holocene mud and Pleistocene Flaxman Island member deposits of the Gubik Formation composed predominantly of silt and sand with abundant boulder and cobble-sized material. Analysis of subbottom profiles show that "boulder patches" seen on side scan sonographs are sea floor outcrops of Pleistocene lag deposits. Side scan sonographs and fathometer records indicate that ice gouging is sparse and shallow (less than 1 m deep). Shoals, north of the survey area, are erosional remnants of Pleistocene deposits and form a barrier to encroaching ice floes from the Arctic Ocean. Near the site, there are small terrace-like features rising approximately 1 m in relief. These may be related to wave action during lower sea level stands or, alternatively, may be caused by a seafloor outcrop of more erosion resistant Pleistocene strata. Two kilometers south of the well site are several seafloor features that range from 2 to 4 m in relief, which are related to tectonic processes such as faulting or folding. The sea floor is underlain by a system of stream channels buried 3 to 12 m beneath Pleistocene and Holocene sediments which exhibit profiles typical of fluvial systems, including channel axis and channel-edge features such as terraces, levees, and stratified fill. The channels are incised into Pleistocene boulder and cobble laden strata. The elevated inter-channel areas of this boulder unit crop out at the sea floor forming the "boulder patch" seen on side scan sonographs. Channel widths are on the order of 50 to 150 meters. Subbottom profiler records indicate that shallow gas may be present as indicated by typical anomalies. Profiles also indicate the possible existence of buried peat layers. Buried permafrost is present but not discernable on seismic profiles. A CDP line through the site reveals a series of three shallow faults that are apparently antithetic and synthetic to a deeper growth fault. This system of faults intersects the seafloor and correlate with the southern shoals on the bathymetric records suggesting relatively recent seismic activity. An earthquake of magnitude 3.2 occurred in 1989 within 7 km of the site.

Management

Durell, G. S., & Neff, J. M. (2019). Effects of Offshore Oil Exploration and Development in the Alaskan Beaufort Sea: Long-Term Patterns of Hydrocarbons in Sediments. *Integrated Environmental Assessment and Management,* 15(2), 224-236. https://doi.org/10.1002/ieam.4129

The United States Bureau of Ocean Energy Management (BOEM) has sponsored 4 major monitoring projects in the oil and gas development area of the Alaskan Beaufort Sea since the 1980s, the last being the Arctic Nearshore Impact Monitoring in the Development Area III (ANIMIDA III) Project (2014-2017). These studies were conducted to better understand the physical, chemical, and biological environments and how oil and gas activities may impact them. This paper focuses on monitoring sediment hydrocarbon chemistry. The projects included measuring polycyclic aromatic hydrocarbons (PAHs), n-alkanes and isoprenoids (SHCs), and sterane/triterpene (S/T) geochemical biomarkers and determining

their distribution, possible sources, and environmental significance in the sediments of the Beaufort Sea and rivers emptying into it. Concentrations of hydrocarbons in sediments were variable on both spatial and temporal scales; surface sediment concentrations of total PAHs (TPAHs), the class of hydrocarbons of greatest environmental interest, averaged between 300 and 700 mu g/kg in different years of monitoring between 1985 and 2015. The concentrations were similar to those measured in other marine regions of Alaska where oil activities have not occurred. Sediment TPAH concentrations were below sediment quality guidelines values, indicating a low risk of harm to benthic marine communities. The hydrocarbons in the Beaufort Sea sediments are primarily from non-oil petrogenic and biogenic sources, with small amounts of pyrogenic hydrocarbons. Most of the hydrocarbons are carried to the Beaufort Sea in coastal erosion and river inputs of hydrocarbon-rich materials, such as peat and shale. The majority of the Beaufort Sea Development Area, including near production facilities, contains uncontaminated sediments with only a few small areas near (<100 m) some exploratory wells where petroleum hydrocarbon concentrations are above regional background.

Pearce, T., Ford, J. D., Duerden, F., Smit, B., Andrachuk, M., Berrang-Ford, L., & Smith, T. (2011). Advancing Adaptation Planning for Climate Change in the Inuvialuit Settlement Region (ISR): A Review and Critique. *Regional Environmental Change,* 11(1), 1-17. https://doi.org/10.1007/s10113-010-0126-4

This paper reviews scientific and gray literature addressing climate change vulnerability and adaptation in the Inuvialuit Settlement Region (ISR) in the western Canadian Arctic. The review is structured using a vulnerability framework, and 420 documents related directly or indirectly to climate change are analyzed to provide insights on the current state of knowledge on climate change vulnerability in the ISR as a basis for supporting future research and long-term adaptation planning in the region. The literature documents evidence of climate change in the ISR which is compromising food security and health status, limiting transportation access and travel routes to hunting grounds, and damaging municipal infrastructure. Adaptations are being employed to manage changing conditions; however, many of the adaptations being undertaken are short term, ad-hoc, and reactive in nature. Limited long-term strategic planning for climate change is being undertaken. Current climate change risks are expected to continue in the future with further implications for communities but less is known about the adaptive capacity of communities. This review identifies the importance of targeted vulnerability research that works closely with community members and decision makers to understand the interactions between current and projected climate change and the factors which condition vulnerability and influence adaptation. Research gaps are identified, and recommendations for advancing adaptation planning are outlined.

Marine Culture Heritage

Dixon, E. J. J., Sharma, G. D., & Stoker, S. W. (1978). *Beaufort Sea Cultural Resources Study, Final Report.* University of Alaska Museum Fairbanks, AK. Retrieved from [No URL available]

The two volumes which comprise this report represent the results of an analysis of the northern portion of Alaska's Outer Continental Shelf. This particular cultural resource study represents the third such research project undertaken by the University of Alaska Museum for the Bureau of Land Management's Alaska Outer Continental Shelf Office. Specifically, the area under discussion extends from Point Barrow in the west to Demarkation Point in the east and northward from the present Beaufort coast to the edge

of the continental shelf. All aspects of the research were executed with the ultimate objective of determining the probability of archeological site occurrence on the outer continental shelf.

During the Pleistocene, a global lowering of sea level occurred as a result of the entrapment of vast quantities of water in the form of glacial ice, exposing vast areas of the outer continental shelf as dry land. Such habitat most certainly supported human settlements. In Alaska, the outer continental shelf is of particular archeological importance because, when exposed during Pleistocene times, it created a continuous land connection between North America and Asia. Most anthropological scholars concur that man entered the Americas during late Pleistocene times by crossing the then exposed outer continental shelf, commonly referred to as the Bering Land Bridge. The outer continental shelf below the Beaufort Sea, which is the subject of this report, formed the northernmost extension of the Bering Land Bridge and has been frequently postulated as a probable migration route for the humans populating the New World.

An interdisciplinary research team consisting of Dr. G. D. Sharma (marine geologist), Dr. Samual Stoker (biological oceanographer, Mr. E. James Dixon, Jr. (archeologist) executed the research. Dr. Sharma's analysis focused on examination of bottom topography, sediment distributions, and geological processes from numerous published and unpublished sources. In addition to a written narrative discussing his analysis and observations, Dr. Sharma prepared bathymetric maps of the study area. These maps have applicability to many scholars and researchers analyzing both biological and physical processes in the Beaufort Sea. For the purposes of this report, they served as base maps from which paleogeographic maps were prepared which represented major sea level stillstands which Dr. Sharma has postulated for the study area based on his previous analysis (Sharma, 1977) of the western Gulf of Alaska. Dr. Sharma's narrative and maps comprise the first section of this report.

Dr. Stoker's analysis is essentially uniformitarian, in that following an analysis of present ecological conditions, he extrapolates them into the past based on an analysis of paleoenvironmental studies pertinent to the study area. Dr. Stoker discusses his analysis of former ecological conditions for each stillstand postulated by Dr. Sharma and provides maps upon which he has outlined areas of probable species habitat suitable for human exploitation. These maps accompany his written narrative in section II.

Mr. Dixon reviewed archeological research conducted in terrestrial regions adjacent to the study area and delineated a cultural chronology for the north slope region. Significant in his discussion is supporting data for the conclusion that man has occupied the area for the past 11,000 years, thus confirming human occupation of terrestrial habitat adjacent to the study area at a time of much lower sea level. Mr. Dixon's narrative constitutes section III of Volume 1.

Based on Dr. Sharma's and Dr. Stoker's analyses, Mr. Dixon ranked the study area for regions of high, medium, and low probability of archeological site occurrence and preservation based on paleoecological criteria and geological processes. All potential OCS lease sale areas were ranked as to archeological probability. Surveys to identify potential cultural resources are recommended for high probability areas only. Areas of high, medium, and low probability of archaeological site occurrence were plotted on BLM/OCS protraction diagrams, contained in Volume 2 of this report.

Rogers, J. S. (2014). *Submerged Cultural Resources Assessment, Liberty Development Project, Beaufort Shelf, Alaska.* Retrieved from https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/About_BOEM/BOEM_Regions/Alaska_Region/Leasing_and_Plans/Plans/BPLiberty_SubmergedCulturalResourcesAssessmentFeb2014.pdf

This report provides the results of an archaeological analysis of seafloor coring and seismic survey data conducted in support of the Liberty Project for BP Exploration (Alaska) Inc. (BPXA) This review addresses a condition in BPXA's ancillary activities notice issued by the Bureau of Ocean Energy Management (BOEM, 2013 Winter Geotechnical and Seabottom Investigation, Liberty Development, Beaufort Sea, Alaska). No cultural resources, of either historic or prehistoric origin, were identified in any of the coring materials or remote-sensing data.

Physics

Hearon, G., Dickins, D., K, A., & Morris, K. (2009). *Mapping Sea Ice Overflood Using Remote Sensing: Smith Bay to Camden Bay.* Retrieved from https://www.boem.gov/sites/default/files/boem-newsroom/Library/Publications/2009/2009_017.pdf

This study was commissioned by the U.S. Department of Interior, Minerals Management Service (MMS), Alaska Outer Continental Shelf Region to map the extent of peak river overflooding onto the landfast ice in the nearshore region of the Alaskan Beaufort Sea during the 13-year period between 1995 and 2007. River overflood on the sea ice occurs annually in the nearshore region of the study area during a brief period in the spring when river break-up precedes the break-up of the landfast sea ice. River overflood constitutes a potential hazard to offshore oil and gas development, as it relates to facilities access, oil spill spreading, and the associated phenomenon of strudel drainage and potential seabed scouring. While the overall goal of this study is to improve the knowledge of the spatial and temporal variability in overflooding and related pipeline and facility siting concerns, the specific study objectives are to 1) document maximum river overflood boundaries from Smith Bay to Camden Bay between 1995 and 2007 using remote sensing and historical helicopter-based surveys, 2) assess and compare different remote sensing platforms for mapping river overflood, 3) investigate environmental factors that contribute to river overflood, 4) assess hazards associated with river overflood, and 5) incorporate the overflood and strudel mapping information into a GIS database.

Kelly, S. J., Proshutinsky, A., Popova, E. K., Aksenov, Y. K., & Yool, A. (2019). On the Origin of Water Masses in the Beaufort Gyre. *Journal of Geophysical Research-Oceans,* 124(7), 4696-4709. https://doi.org/10.1029/2019jc015022

The Beaufort Gyre is a key feature of the Arctic Ocean, acting as a reservoir for freshwater in the region. Depending on whether the prevailing atmospheric circulation in the Arctic is anticyclonic or cyclonic, either a net accumulation or release of freshwater occurs. The sources of freshwater to the Arctic Ocean are well established and include contributions from the North American and Eurasian Rivers, the Bering Strait Pacific water inflow, sea ice meltwater, and precipitation, but their contribution to the Beaufort Gyre freshwater accumulation varies with changes in the atmospheric circulation. Here we use a Lagrangian backward tracking technique in conjunction with the 1/12-degree resolution Nucleus for

European Modelling of the Ocean model to investigate how sources of freshwater to the Beaufort Gyre have changed in recent decades, focusing on increase in the Pacific water content in the gyre between the late 1980s and early 2000s. Using empirical orthogonal functions we analyze the change in the Arctic oceanic circulation that occurred between the 1980s and 2000s. We highlight a waiting room advective pathway that was present in the 1980s and provide evidence that this pathway was caused by a shift in the center of Ekman transport convergence in the Arctic. We discuss the role of these changes as a contributing factor to changes in the stratification, and hence potentially the biology, of the Beaufort Gyre region. Plain Language Summary The Beaufort Gyre, a clockwise ice and water circulation in the Arctic Ocean, is an important feature of the Arctic because it stores a large volume of fresh-relative to the rest of the ocean-water. Depending on the atmospheric circulation driving it, the Beaufort Gyre can either accumulate or release this freshwater. The sources of relatively freshwater to the Beaufort Gyre are Arctic rivers, the Bering Strait, and melting sea ice. By tracking virtual particles in a high-resolution ocean model, we investigate how these sources have changed in recent decades, and identify a change in the pathways bringing them to the Beaufort Gyre. This change in ocean circulation was found to correlate with a change in the mixed layer depth in the model.

McClelland, J. W., Townsend-Small, A., Holmes, R. M., Pan, F. F., Stieglitz, M., Khosh, M., & Peterson, B. J. (2014). River Export of Nutrients and Organic Matter from the North Slope of Alaska to the Beaufort Sea. *Water Resources Research,* 50(2), 1823-1839. https://doi.org/10.1002/2013wr014722

While river-borne materials are recognized as important resources supporting coastal ecosystems around the world, estimates of river export from the North Slope of Alaska have been limited by a scarcity of water chemistry and river discharge data. This paper quantifies water, nutrient, and organic matter export from the three largest rivers (Sagavanirktok, Kuparuk, and Colville) that drain Alaska's North Slope and discusses the potential importance of river inputs for biological production in coastal waters of the Alaskan Beaufort Sea. Together these rivers export approximate to 297,000 metric tons of organic carbon and approximate to 18,000 metric tons of organic nitrogen each year. Annual fluxes of nitrate-N, ammonium-N, and soluble reactive phosphorus are approximately 1750, 200, and 140 metric tons per year, respectively. Constituent export from Alaska's North Slope is dominated by the Colville River. This is in part due to its larger size, but also because constituent yields are greater in the Colville watershed. River-supplied nitrogen may be more important to productivity along the Alaskan Beaufort Sea coast than previously thought. However, given the dominance of organic nitrogen export, the potential role of river-supplied nitrogen in support of primary production depends strongly on remineralization mechanisms. Although rivers draining the North Slope of Alaska make only a small contribution to overall river export from the pan-arctic watershed, comparisons with major arctic rivers reveal unique regional characteristics as well as remarkable similarities among different regions and scales. Such information is crucial for development of robust river export models that represent the arctic system as a whole.

Moore, G. W. K., Schweiger, A., Zhang, J., & Steele, M. (2018). Collapse of the 2017 Winter Beaufort High: A Response to Thinning Sea Ice? *Geophysical Research Letters,* 45(6), 2860-2869. https://doi.org/10.1002/2017gl076446

The winter Arctic atmosphere is under the influence of two very different circulation systems: extratropical cyclones travel along the primary North Atlantic storm track from Iceland toward the eastern Arctic, while the western Arctic is characterized by a quasi-stationary region of high pressure known as the Beaufort High. The winter (January through March) of 2017 featured an anomalous reversal of the normally anticyclonic surface winds and sea ice motion in the western Arctic. This reversal can be traced to a collapse of the Beaufort High as the result of the intrusion of low-pressure systems from the North Atlantic, along the East Siberian Coast, into the Arctic Basin. Thin sea ice as the result of an extremely warm autumn (October through December) of 2016 contributed to the formation of an anomalous thermal low over the Barents Sea that, along with a northward shift of the tropospheric polar vortex, permitted this intrusion. The collapse of the Beaufort High during the winter of 2017 was associated with simultaneous 2-sigma sea level pressure, surface wind, and sea ice circulation anomalies in the western Arctic. As the Arctic sea ice continues to thin, such reversals may become more common and impact ocean circulation, sea ice, and biology. Plain Language Summary The warming that the Arctic is currently experiencing has garnered attention in both the popular and scientific press. Indeed, the retreat and thinning of the region's sea ice is one of the most significant and irrefutable indicators of human influence on the climate. In addition to these long-term trends, the past several years have seen record warmth and extreme events in the region, such as above-freezing winter temperatures at the North Pole, which may be harbingers of even more dramatic changes in the future. In this paper, we document a recent and previously unknown consequence of this warming: the collapse of the winter Beaufort High that occurred as a result of the intrusion of North Atlantic cyclones into the western Arctic. This phenomenon occurred, for the first time, during the winter of 2017 and resulted in a reversal in surface winds and sea ice motion across the entire western Arctic. We argue that the extreme warmth during the autumn of 2016 resulted in reduced sea ice extent and thickness in the eastern Arctic that persisted into the winter of 2017 allowing extratropical cyclones from the North Atlantic to intrude into the western Arctic.

Weingartner, T., & Kasper, J. (2011). *Idealized Modeling of Circulation under Landfast Ice.* Retrieved from https://espis.boem.gov/final%20reports/5163.pdf

Idealized analytical and numerical models are used to elucidate the effects of a spatially variable landfast ice cover on under ice circulation. Three separate forcing mechanisms are investigated; lateral inflow onto an ice covered shelf (an elevated sea level at the western boundary), a spatially uniform upwelling wind blowing along the seaward landfast ice edge and a buoyant inflow under the ice cover that enters the domain through the southern coastal wall. The idealized models are configured to resemble the shallow Alaskan Beaufort Sea shelf. Models show that the inclusion of landfast ice means shelf response is significantly different from an ice free shelf. In the case of a lateral inflow, landfast ice spreads the inflow offshore (in a manner similar to bottom friction) but the change in surface stress across the ice edge (from ice covered to ice free) limits the offshore spreading. In the case of an upwelling wind along the ice edge, the low sea level at the ice edge (due to ice edge upwelling) leads to a cross-shore sea level slope between the coast (high sea level) and the ice edge (low sea level) which drives a geostrophically balanced flow upwind. In the absence of along-shore changes in wind or ice the circulation does not vary along the shelf and currents near the coast are near zero. Along- and cross-

shore variations in the ice ocean friction coefficient introduce differences in the response time of the under ice flow and can lead to along-shore sea level slopes which drive significant along-shore flows near the coast (< 0.06 m s-1). In the case of a time dependant buoyant inflow, the landfast ice spreads the buoyant inflow much further offshore (~9 times the local baroclinic Rossby radius, ~45 km) than in the ice free case (< 30 km). When the ice width is finite, the change in surface across the ice edge acts to restrict offshore flow (in the anti-cyclonic bulge) and inhibits onshore flow further downstream.

Weingartner, T. J., Danielson, S. L., Potter, R. A., Trefry, J. H., Mahoney, A., Savoie, M., . . . Sousa, L. (2017). Circulation and Water Properties in the Landfast Ice Zone of the Alaskan Beaufort Sea. *Continental Shelf Research,* 148, 185-198. https://doi.org/10.1016/j.csr.2017.09.001

Moorings, hydrography, satellite-tracked drifters, and high-frequency radar data describe the annual cycle in circulation and water properties in the landfast ice zone (LIZ) of the Alaskan Beaufort Sea. Three seasons, whose duration and characteristics are controlled by landfast ice formation and ablation, define the LIZ: “winter”, “break-up”, and “open-water”. Winter begins in October with ice formation and ends in June when rivers commence discharging. Winter LIZ ice velocities are zero, under-ice currents are weak (~5 cm s−1), and poorly correlated with winds and local sea level. The along-shore momentum balance is between along-shore pressure gradients and bottom and ice-ocean friction. Currents at the landfast ice-edge are swift (~35 cm s−1), wind-driven, with large horizontal shears, and potentially unstable. Weak cross-shore velocities (~1 cm s−1) imply limited exchanges between the LIZ and the outer shelf in winter. The month-long break-up season (June) begins with the spring freshet and concludes when landfast ice detaches from the bottom. Cross-shore currents increase, and the LIZ hosts shallow (~2 m), strongly-stratified, buoyant and sediment-laden, under-ice river plumes that overlie a sharp, ~1 m thick, pycnocline across which salinity increases by ~30. The plume salt balance is between entrainment and cross-shore advection. Break-up is followed by the 3-month long open-water season when currents are swift (≥20 cm s−1) and predominantly wind-driven. Winter water properties are initialized by fall advection and evolve slowly due to salt rejection from ice. Fall waters and ice within the LIZ derive from local rivers, the Mackenzie and/or Chukchi shelves, and the Arctic basin.

Zhong, W. L., Steele, M., Zhang, J. L., & Cole, S. T. (2019). Circulation of Pacific Winter Water in the Western Arctic Ocean. *Journal of Geophysical Research-Oceans,* 124(2), 863-881. https://doi.org/10.1029/2018jc014604

Pacific Winter Water (PWW) enters the western Arctic Ocean from the Chukchi Sea; however, the physical mechanisms that regulate its circulation within the deep basin are still not clear. Here, we investigate the interannual variability of PWW with a comprehensive data set over a decade. We quantify the thickening and expansion of the PWW layer during 2002-2016, as well as its changing pathway. The total volume of PWW in the Beaufort Gyre (BG) region is estimated to have increased from 3.480.04x10(14)m(3) during 2002-2006 to 4.110.02x10(14)m(3) during 2011-2016, an increase of 18%. We find that the deepening rate of the lower bound of PWW is almost double that of its upper bound in the northern Canada Basin, a result of lateral flux convergence of PWW (via lateral advection of PWW from the Chukchi Borderland) in addition to the Ekman pumping. In particular, of the 70-m deepening of PWW at its lower bound observed over 2003-2011 in the northwestern basin, 43% resulted from lateral flux convergence. We also find a redistribution of PWW in recent years toward the

Chukchi Borderland associated with the wind-driven spin-up and westward shift of the BG. Finally, we hypothesize that a recently observed increase of lower halocline eddies in the BG might be explained by this redistribution, through a compression mechanism over the Chukchi Borderland. Plain Language Summary Pacific Winter Water (PWW) is a deeper freshwater source via subduction in contrast to the wind-driven Ekman convergence of freshwater in the surface Ekman layer of the western Arctic Ocean. It supplies the western Arctic Ocean with acidifying water. Our study reveals a redistribution of PWW associated with the wind-driven spin-up of Beaufort Gyre. The lateral advection of PWW from the Chukchi Borderland to the northern Canada Basin plays an important role in the deepening of PWW lower bound at the edge of Beaufort Gyre. In addition, the total volume of PWW has increased about 18% over the years 2002-2016. Our findings provide an important implication not only for the physical oceanographer but also for the marine chemists and biologists.

Zhong, W. L., Zhang, J. L., Steele, M., Zhao, J. P., & Wang, T. (2019). Episodic Extrema of Surface Stress Energy Input to the Western Arctic Ocean Contributed to Step Changes of Freshwater Content in the Beaufort Gyre. *Geophysical Research Letters,* 46(21), 12173-12182. https://doi.org/10.1029/2019gl084652

The recent dramatic decline of sea ice in the western Arctic Ocean changes the transfer of momentum across the ice-ocean boundary layer. The surface stress energy input through the surface geostrophic current in the Beaufort Gyre (BG) based on a numerical model is 0.03 mW/m(2) in 1992-2004 versus 0.23 mW/m(2) in 2005-2017. This energy input is primarily concentrated over the southern Canada Basin and the Chukchi Sea. It is 1.38 x 10(16) J in observations versus 4.90 x 10(16) J in the model in the BG during 2003-2014. We find that some well-known freshwater changes in the BG over 1992-2017 resulted from episodic extrema of energy input in 2007, 2012, and 2016. In particular, most of the energy input in 2007 was transformed into potential energy (57%) which resulted in a new state of freshwater budget. Our study suggests that as of 2016, the BG had not yet reached a saturated freshwater state. Our results provide a way to predict the future changes of BG freshwater content.

Section IX: Beaufort Sea, Chukchi Sea

Biology

Angliss, R. P., Ferguson, M. C., Hall, P., Helker, V., Kennedy, A., & Sformo, T. (2015). *Comparing Manned Aerial Surveys to Unmanned Aerial Surveys for Cetacean Monitoring in the Arctic: Field Report.* Retrieved from https://www.onr.navy.mil/reports/FY15/mbanglis.pdf

No abstract available.

Ashjian, C. J., Braund, S. R., Campbell, R. G., George, J. C., Kruse, J., Maslowski, W., . . . Spitz, Y. H. (2010). Climate Variability, Oceanography, Bowhead Whale Distribution, and Inupiat Subsistence Whaling near Barrow, Alaska. *Arctic,* 63(2), 179-194. Retrieved from https://www.jstor.org/stable/27821962

The annual migration of bowhead whales (Balaena mysticetus) past Barrow, Alaska, has provided subsistence hunting to Inupiat for centuries. Bowheads recurrently feed on aggregations of zooplankton prey near Barrow in autumn. The mechanisms that form these aggregations, and the associations between whales and oceanography, were investigated using field sampling, retrospective analysis, and traditional knowledge interviews. Oceanographic and aerial surveys were conducted near Barrow during August and September in 2005 and 2006. Multiple water masses were observed, and close coupling between water mass type and biological characteristics was noted. Short-term variability in hydrography was associated with changes in wind speed and direction that profoundly affected plankton taxonomic composition. Aggregations of ca. 50-100 bowhead whales were observed in early September of both years at locations consistent with traditional knowledge. Retrospective analyses of records for 1984-2004 also showed that annual aggregations of whales near Barrow were associated with wind speed and direction. Euphausiids and copepods appear to be upwelled onto the Beaufort Sea shelf during E or SE winds. A favorable feeding environment is produced when these plankton are retained and concentrated on the shelf by the prevailing westward Beaufort Sea shelf currents that converge with the Alaska Coastal Current flowing to the northeast along the eastern edge of Barrow Canyon.

Cronin, T. M., Seidenstein, J., Keller, K., McDougall, K., Rueter, A., & Gemery, L. (2019). The Benthic Foraminifera Cassidulina from the Arctic Ocean: Application to Paleoceanography and Biostratigraphy. *Micropaleontology,* 65(2), 105-125. Retrieved from http://www.micropress.org/microaccess/check/2119

We investigated the morphology, biostratigraphy, shell stable isotope composition and paleogeography of the common Arctic benthic foraminifera, Cassidulina teretis (Tappan 1951) (sometimes assigned to Islandiella (Norvang 1958), for application to Quaternary paleoceanography. Cassidulina teretis, which has been studied by several generations of Arctic foraminiferal specialists, is used in Arctic Ocean palcoccanographic reconstructions based on foraminiferal assemblages and, increasingly, isotope shell chemistry. Here we review its modern and fossil distribution including discussions of its taxonomy, ecology, biostratigraphy and shell chemistry. Cassidulina teretis Tappan 1951, originally described from

the Gubik Formation, northern Alaska coastal plain, has variability in test size, apertural morphology and development of an umbilical boss representing intra- and inter-population differences across the Arctic and subarctic in modern, Quaternary and Pliocene assemblages. Nonetheless, our studies and those previously published lead us to conclude that populations fmm the Arctic Ocean represent a single species proposed by Tappan as Cassidulina teretis. Its modern distribution is mainly 200 to 1000 m water depth, often living within the core of the relatively warm Atlantic Layer. However, shallower occurrences suggest other factors, such as food supply, are also critical to its ecology. The Holocene distribution of Cassidulina teretis in the Beaufort Sea boundary indicate millennial-scale changes in relative abundance related to changing Atlantic Layer influence, sea-ice cover, surface productivity and food availability. There are extremely large changes in its abundance during the last deglacial interval on the Yermak Plateau, Barents Sea slope and the Laptev Sea reflecting rapid ocean changes during the Bolling-Allerod, Younger Dryas, and Preboreal. Similarly, C. teretis abundance changes during the last 300,000 years allow us to use it, at least regionally, as a useful biostratigraphic marker. The stable isotopic composition of Cassidulina teretis tests holds promise for establishing an isotope stratigraphy across the Arctic Ocean and perhaps also in the Nordic Seas, off Iceland and in the northern North Atlantic Ocean, once disequilibrium values and offsets from other Arctic benthic species are more firmly established.

David, C., Lange, B., Krumpen, T., Schaafsma, F., van Franeker, J. A., & Flores, H. (2016). Under-Ice Distribution of Polar Cod *Boreogadus saida* in the Central Arctic Ocean and Their Association with Sea-Ice Habitat Properties. *Polar Biology,* 39(6), 981-994. https://doi.org/10.1007/s00300-015-1774-0

In the Arctic Ocean, sea-ice habitats are undergoing rapid environmental change. Polar cod (Boreogadus saida) is the most abundant fish known to reside under the pack-ice. The under-ice distribution, association with sea-ice habitat properties and origins of polar cod in the central Arctic Ocean, however, are largely unknown. During the RV Polarstern expedition ARK XXVII/3 in the Eurasian Basin in 2012, we used for the first time in Arctic waters a Surface and Under Ice Trawl with an integrated bio-environmental sensor array. Polar cod was ubiquitous throughout the Eurasian Basin with a median abundance of 5000 ind. km−2. The under-ice population consisted of young specimens with a total length between 52 and 140 mm, dominated by 1-year-old fish. Higher fish abundance was associated with thicker ice, higher ice coverage and lower surface salinity, or with higher densities of the ice-amphipod Apherusa glacialis. The fish were in good condition and well fed according to various indices. Back-tracking of the sea-ice indicated that sea-ice sampled in the Amundsen Basin originated from the Laptev Sea coast, while sea-ice sampled in the Nansen Basin originated from the Kara Sea. Assuming that fish were following the ice drift, this suggests that under-ice polar cod distribution in the Eurasian Basin is dependent on the coastal populations where the sea-ice originates. The omnipresence of polar cod in the Eurasian Basin, in a good body condition, suggests that the central Arctic under-ice habitats may constitute a favourable environment for this species survival, a potential vector of genetic exchange and a recruitment source for coastal populations around the Arctic Ocean.

de la Vega, C., Jeffreys, R. M., Tuerena, R., Ganeshram, R., & Mahaffey, C. (2019). Temporal and Spatial Trends in Marine Carbon Isotopes in the Arctic Ocean and Implications for Food Web Studies. *Global Change Biology,* 25(12), 4116-4130. https://doi.org/10.1111/gcb.14832

The Arctic is undergoing unprecedented environmental change. Rapid warming, decline in sea ice extent, increase in riverine input, ocean acidification and changes in primary productivity are creating a crucible for multiple concurrent environmental stressors, with unknown consequences for the entire arctic ecosystem. Here, we synthesized 30 years of data on the stable carbon isotope (delta C-13) signatures in dissolved inorganic carbon (delta C-13-DIC; 1977-2014), marine and riverine particulate organic carbon (delta C-13-POC; 1986-2013) and tissues of marine mammals in the Arctic. delta C-13 values in consumers can change as a result of environmentally driven variation in the delta C-13 values at the base of the food web or alteration in the trophic structure, thus providing a method to assess the sensitivity of food webs to environmental change. Our synthesis reveals a spatially heterogeneous and temporally evolving delta C-13 baseline, with spatial gradients in the delta C-13-POC values between arctic shelves and arctic basins likely driven by differences in productivity and riverine and coastal influence. We report a decline in delta C-13-DIC values (-0.011 parts per thousand per year) in the Arctic, reflecting increasing anthropogenic carbon dioxide (CO2) in the Arctic Ocean (i.e. Suess effect), which is larger than predicted. The larger decline in delta C-13-POC values and delta C-13 in arctic marine mammals reflects the anthropogenic CO2 signal as well as the influence of a changing arctic environment. Combining the influence of changing sea ice conditions and isotopic fractionation by phytoplankton, we explain the decadal decline in delta C-13-POC values in the Arctic Ocean and partially explain the delta C-13 values in marine mammals with consideration of time-varying integration of delta C-13 values. The response of the arctic ecosystem to ongoing environmental change is stronger than we would predict theoretically, which has tremendous implications for the study of food webs in the rapidly changing Arctic Ocean.

Divine, L. M., Bluhm, B. A., Mueter, F. J., & Iken, K. (2017). Diet Analysis of Alaska Arctic Snow Crabs (Chionoecetes opilio) Using Stomach Contents and Δ13c and Δ15n Stable Isotopes. *Deep Sea Research Part II: Topical Studies in Oceanography,* 135, 124-136. https://doi.org/10.1016/j.dsr2.2015.11.009

We used stomach content and stable δ13C and δ15N isotope analyses to investigate male and female snow crab diets over a range of body sizes (30–130 mm carapace width) in five regions of the Pacific Arctic (southern and northern Chukchi Sea, western, central, and Canadian Beaufort Sea). Snow crab stomach contents from the southern Chukchi Sea were also compared to available prey biomass and abundance. Snow crabs consumed four main prey taxa: polychaetes, decapod crustaceans (crabs, amphipods), echinoderms (mainly ophiuroids), and mollusks (bivalves, gastropods). Both approaches revealed regional differences. Crab diets in the two Chukchi regions were similar to those in the western Beaufort (highest bivalve, amphipod, and crustacean consumption). The Canadian Beaufort region was most unique in prey composition and in stable isotope values. We also observed a trend of decreasing carbon stable isotopes in crabs from the Chukchi to those in the Canadian Beaufort, likely reflecting the increasing use of terrestrial carbon sources towards the eastern regions of the Beaufort Sea from Mackenzie River influx. Cannibalism on snow crabs was higher in the Chukchi regions relative to the Beaufort regions. We suggest that cannibalism may have an impact on recruitment in the Chukchi Sea via reduction of cohort strength after settlement to the benthos, as known from the Canadian Atlantic. Prey composition varied with crab size only in some size classes in the southern Chukchi and central

Beaufort, while stable isotope results showed no size-dependent differences. Slightly although significantly higher mean carbon isotope values for males in the southern Chukchi may not be reflective of a gender-specific pattern but rather be driven by low sample size. Finally, the lack of prey selection relative to availability in crabs in the southern Chukchi suggests that crabs consume individual prey taxa in relative proportions to prey field abundances. The present study is the first to provide a baseline of the omnivorous role of snow crabs across the entire Pacific Arctic, as well as evidence for cannibalism in the Chukchi Sea. In light of climate change predictions for the Alaska Arctic, and the potential for future fisheries harvest of snow crabs in this region, continued monitoring of snow crabs, including population and trophic dynamics, is increasingly important to assess snow crab impacts on benthic communities and vice versa.

Dupont, F. (2012). Impact of Sea-Ice Biology on Overall Primary Production in a Biophysical Model of the Pan-Arctic Ocean. *Journal of Geophysical Research-Oceans,* 117. https://doi.org/10.1029/2011jc006983

The contribution of sea-ice biology and impact of Arctic warming on overall primary production in a Pan-Arctic ocean model are investigated in a 57 year (1950-2006) simulation at coarse resolution using a simple ecosystem model. The ice biology model formally represents the growth and aggregation of micro algae into an ice-water interface, nearly undisturbed by surface mixed layer dynamics. The importance of this so-called 'ice-algae' stems from their significant contribution to the total primary production (up to 50% depending on the locations, according to observations described in Gosselin et al. (1997). Simple 1D tests reveal that, depending on their initial biomass and light availability, ice algae can affect the temporal variation of surface nutrients, while they marginally impact the total primary production, or the long term position of the nutricline. The sea-ice primary production is found in the model to be as high as 40% of the total primary production depending on the location and 7.5% for the whole Arctic. The modeled primary production of the ocean is negatively correlated to the September ice cover whereas the production in the ice is more weakly positively correlated. Because of the negative correlation between sea ice cover and pelagic primary production, the short term response to the continuing ice decline will be an increased total production as seen in the model, while the ice algae production would decline.

Ferguson, M. C., Angliss, R. P., Kennedy, A., Lynch, B., Willoughby, A., Helker, V., . . . Clarke, J. T. (2018). Performance of Manned and Unmanned Aerial Surveys to Collect Visual Data and Imagery for Estimating Arctic Cetacean Density and Associated Uncertainty. *Journal of Unmanned Vehicle Systems,* 6(3), 109-127. https://doi.org/10.1139/juvs-2018-0001

Manned aerial surveys are routinely used to assess cetacean distribution and density, often over large geographic areas. Unmanned aircraft systems (UAS) have been identified as a technology that could augment or replace manned aerial surveys for cetaceans. To understand what research questions involving cetacean distribution and density can be addressed using manned and UAS technology in the Arctic, we conducted paired aerial surveys for cetaceans near Utqiaġvik (Barrow), Alaska. We present the methods and operational results from the project, and challenges encountered during the field work. Fall arctic weather varied dramatically over small spatiotemporal scales and harsh environmental conditions increased the maintenance required for repeated UAS operations. Various technologies, such

as temperature and humidity sensors, a software system that provided near-term forecasts of highly variable weather, and a surface-based air traffic radar feed, directly contributed to the ability to conduct routine, successful, beyond line-of-sight UAS flights under these situations. We provide recommendations for future projects to help streamline project planning and enhance researchers' ability to use UAS to collect data needed for ecological research.

Finley, K. J. (2001). Natural History and Conservation of the Greenland Whale, or Bowhead, in the Northwest Atlantic. *Arctic,* 54(1), 55-76. https://doi.org/10.14430/arctic764

One of the longest-living mammals, the Greenland whale or bowhead (Balaena mysticetus) is specialized to filter small crustaceans, especially Calanus copepods, from barren Arctic seas. Brought to near extinction by commercial whaling, the North Atlantic 'meta-population' remains at less than 5% of its former abundance, and none of its three constituent stocks has shown demonstrable recovery during the last century. Two of these stocks, the Baffin Bay and Hudson Bay populations, occur in coastal waters of the Eastern Canadian Arctic during summer. Each of these two stocks numbers in the low hundreds and exists in isolated groups segregated by age and sex, showing strong fidelity to essential habitats. A skewed age distribution, predation by killer whales (Orcinus orca), hunting, net entanglement, tourism, climate change, habitat loss, and inbreeding suppression are some of the factors that may affect the bowhead's recovery. We need local and historical knowledge to understand the bowhead's natural history. Together with scientific data, such knowledge is also useful in evaluating the status of the species and prescribing a management plan. A recovery plan must employ the precautionary principle, both within the international 'meta-population' context and at the sub-population level; it must take a historical view and seek to protect abandoned habitats. Canada has conducted whaling activities that violate international agreements and diminish the effectiveness of the international Whaling Commission.

Givens, G. H., Huebinger, R. M., Patton, J. C., Postma, L. D., Lindsay, M., Suydam, R. S., . . . Bickham, J. W. (2010). Population Genetics of Bowhead Whales (Balaena mysticetus) in the Western Arctic. *Arctic,* 63(1), 1-12. Retrieved from https://www.jstor.org/stable/40513365

Bowhead whales (Balaena mysticetus) in the Bering, Chukchi, and Beaufort seas experienced a severe reduction as a result of commercial whaling in the 19th century. Since the cessation of commercial whaling, the population has recovered to a size that is approaching pre-whaling estimates. Inupiat and Yupik communities in northern and western Alaska hunt these Western Arctic (WA) bowheads along their migratory path during spring and fall. This hunting is regulated by the International Whaling Commission. Recent but preliminary analysis of available genetic data (207 whales and 10 microsatellite markers) raised the question of the presence of multiple, genetically distinct populations within the WA bowheads. Here we re-examined this question on the basis of a study of 414 whales and 22 newly developed microsatellite loci. We identified widespread departures from Hardy-Weinberg equilibrium; however, we were unable to detect significant evidence of multiple genetic populations within the WA bowheads that could explain this Hardy-Weinberg disequilibrium, particularly when compared to the strength of evidence for differentiation between WA bowheads and other populations from distant regions such as the Okhotsk Sea and eastern Canada: There was conclusive evidence of genetic differentiation among the three regions. The statistical rejection of panmixia within the WA improves

our understanding of bowhead whale biology, and the lack of evidence for multiple populations within the WA enables risk-averse management of aboriginal hunting of Western Arctic bowhead whales.

Mishin, A. V., Evseenko, S. A., Bol'shakov, D. V., & Bol'shakova, Y. Y. (2018). Ichthyoplankton of Russian Arctic Seas: 1. Polar Cod *Boreogadus saida*. *Journal of Ichthyology,* 58(5), 710-716. https://doi.org/10.1134/s0032945218050156

The information on the size composition and distribution of the larvae and juveniles of polar cod Boreogadus saida on the shelf of Russian Arctic seas (the Kara Sea, the Laptev Sea, and the East Siberian Sea) is presented for the period of July-September 2015-2017. The larvae and juveniles are widely distributed here, forming the largest accumulations on the continental slopes in the areas least affected by the river runoff. Both seasonal and regional differences are observed in the size composition of the early developmental stages of the polar cod: the juvenile average length increases from summer through autumn and southwards.

Quakenbush, L. T., Small, R. J., & Citta, J. J. (2010). *Satellite Tracking of Western Arctic Bowhead Whales.* Retrieved from https://www.adfg.alaska.gov/static/research/programs/marinemammals/pdfs/bowhead_tracking_2010_final_report_w_append.pdf

The western Arctic (or Bering-Chukchi-Beaufort) stock of bowhead whales (Balaena mysticetus) is of high importance due to the nutritional and cultural role of bowhead whales to coastal Alaska Natives of the Bering, Chukchi, and Beaufort seas, their role in the marine ecosystem, and because their summer range overlaps with areas identified for potential oil and gas development. Movement and feeding patterns of this stock of bowhead whales, however, are not well understood. Increasing our understanding of bowhead whale movements, habitat use, and behavior will aid in resource planning and conservation. We worked with Native whalers from Alaska and marine mammal hunters from Canada to attach 46 satellite transmitters to bowhead whales during a five year period. This final report covers the time period from August 2005 to July 2010 and includes movements and behavior of 37 bowhead whales tagged near Barrow, Alaska and nine tagged in Canada. We have documented the annual distribution of western Arctic bowhead whales, including summering and wintering areas, and the migratory routes that connect these areas. At the request of the Alaska Eskimo Whaling Commission, we conducted traditional knowledge interviews in as many whaling villages as possible and report our findings. We have described how bowhead whales move through Oil and Gas Lease Sale Area 193 in the spring and fall. We have described locations and times when shipping may affect bowhead migration or feeding and have documented an interaction between a bowhead whale and a seismic vessel.

Rand, K., Logerwell, E., Bluhm, B., Chenelot, H., Danielson, S., Iken, K., & Sousa, L. (2018). Using Biological Traits and Environmental Variables to Characterize Two Arctic Epibenthic Invertebrate Communities in and Adjacent to Barrow Canyon. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 152, 154-169. https://doi.org/10.1016/j.dsr2.2017.07.015

The Arctic's Barrow Canyon, located in the northeastern Chukchi and western Beaufort seas, supports a rich and diverse benthic ecosystem and is often termed an ecological "hotspot" of productivity. Within and adjacent to Barrow Canyon, the epibenthic invertebrate communities vary, with biomass and taxonomic distributions related to habitat variation. Here we asked if the patterns observed are due to Barrow Canyon's variation in near-seafloor physical hydrography, and whether differences in taxonomic distribution also reflect differences in functional properties of the epibenthic invertebrate community. Data were collected using a standardized 83-112 bottom trawl during two surveys in and adjacent to Barrow Canyon: the northeast Chukchi Sea survey in 2013 and the western Beaufort Sea survey in 2008. A portion of the Beaufort Sea survey also used a liner to retain smaller organisms. A suite of nine environmental variables were examined, that included depth, bottom water temperature, bottom hardness as measured by acoustics, and circulation model hindcast current speed. They explained 18-47% of observed variance for each of the three data sets (Chukchi Sea, Beaufort Sea lined net (LN), Beaufort Sea unlined net (UN)). In the Chukchi Sea, bottom hardness and depth were significant variables. In the Beaufort Sea LN hauls, depth, bottom temperature, and the mean current speed on the day of sampling were significant variables and in the Beaufort Sea UN hauls, depth was the only significant variable. Of the 150 + collected taxa from each survey, similar to 20 made up 90% of the total biomass in the Beaufort and Chukchi Seas, and six of the 20 taxa were common to both study areas. We used biological traits analysis (BTA) of body morphology, trophic, and reproductive traits to further characterize the epibenthos at the head of Barrow Canyon in the Chukchi Sea and into Barrow Canyon in the Beaufort Sea. Although the Chukchi and Beaufort seas differed taxonomically in abundance and distribution, they were functionally similar based on the biological traits we examined. A traits analysis can advance knowledge of a community of organisms; however, it is most informative if used as a complement to a taxonomic composition analysis of abundance and distribution.

Steiner, N., Azetsu-Scott, K., Hamilton, J., Hedges, K., Hu, X. M., Janjua, M. Y., . . . Tallmann, R. (2015). Observed Trends and Climate Projections Affecting Marine Ecosystems in the Canadian Arctic. *Environmental Reviews,* 23(2), 191-239. https://doi.org/10.1139/er-2014-0066

Past trends and future projections of key atmospheric, oceanic, sea ice, and biogeochemical variables were assessed to increase our understanding of climate change impacts on Canadian Arctic marine ecosystems. Four subbasins are evaluated: Beaufort Sea, Canadian Arctic Archipelago, Baffin Bay/Davis Strait, and Hudson Bay Complex. Limited observations, especially for ecosystem variables, compromise the trend analyses. Future projections are predominately from global models with few contributions from available marine basin scale models. The assessment indicates a significant increase in air temperature, slight increases in precipitation and snow depth, and appreciable changes in atmospheric circulation patterns. Projections suggest an increase in storm strength and size, leading to enhanced storm surges and coastal erosion, a slight increase in wave heights, increases in gustiness, and small changes in mean wind speed. An Arctic-wide decrease in the extent of multiyear ice and a spatial and temporal increase in ice-free waters in summer have been observed and are projected to continue into the future. Limited observations of ocean properties show local freshening (Beaufort Sea) and summer warming (Baffin Bay). These trends are projected to continue along with localized strengthening in

stratification. Increased ocean acidification has been observed and is projected to continue throughout the Canadian Arctic, leading to severely decreased saturation states of calcium carbonate (aragonite and calcite). Qualitative analysis of biological observations indicate large regional differences. Increased primary production and double bloom development is seen in areas of sea ice retreat where nutrient supply is sufficient, and unchanged or reduced production is seen where nutrients are low or suppressed in response to enhanced stratification. Future primary production projections show inconsistent results, with light-dependent increase or nutrient-limited decrease dominating, dependent on the model. For the next decade, natural intradecadal variability is expected to be of similar importance as longer-term trends. To improve our capacity to assess and project climate change adaptation in marine ecosystems, more consistent observations are needed, especially over marine areas and for biogeochemical variables. Higher resolution basin-scale models are also required to provide locally applicable projections relevant for Arctic communities and management units.

Wassmann, P., Duarte, C. M., Agusti, S., & Sejr, M. K. (2011). Footprints of Climate Change in the Arctic Marine Ecosystem. *Global Change Biology,* 17(2), 1235-1249. https://doi.org/10.1111/j.1365-2486.2010.02311.x

In this article, we review evidence of how climate change has already resulted in clearly discernable changes in marine Arctic ecosystems. After defining the term 'footprint' and evaluating the availability of reliable baseline information we review the published literature to synthesize the footprints of climate change impacts in marine Arctic ecosystems reported as of mid-2009. We found a total of 51 reports of documented changes in Arctic marine biota in response to climate change. Among the responses evaluated were range shifts and changes in abundance, growth/condition, behaviour/phenology and community/regime shifts. Most reports concerned marine mammals, particularly polar bears, and fish. The number of well-documented changes in planktonic and benthic systems was surprisingly low. Evident losses of endemic species in the Arctic Ocean, and in ice algae production and associated community remained difficult to evaluate due to the lack of quantitative reports of its abundance and distribution. Very few footprints of climate change were reported in the literature from regions such as the wide Siberian shelf and the central Arctic Ocean due to the limited research effort made in these ecosystems. Despite the alarming nature of warming and its strong potential effects in the Arctic Ocean the research effort evaluating the impacts of climate change in this region is rather limited.

Wiese, F. K., Gryba, R., & Kelly, B. P. (2017). *Marine Arctic Ecosystem Study - Pilot Program: Marine Mammals Tagging and Tracking.* Retrieved from https://www.boem.gov/sites/default/files/boem-newsroom/Library/Publications/2017/BOEM-2017-017.pdf

One of the first components of the overall study was a marine mammal tagging and tracking pilot program funded through the National Ocean Partnership Program by BOEM, Shell, and the Office of Naval Research. Started in 2015, the pilot program was funded with a one-year field season focused on refining capture, tagging, and data collection methods and developed as a precursor to a larger-scale two-year marine mammal field program that would focus on habitat use patterns and impacts of changes to the marine ecosystem. Subsequent cancelation of the main marine mammal field program, however, prompted a detailed data analysis of pilot program results as a stand-alone product. That

analysis forms the basis of this report. Thus, this report constitutes the final technical report (replacing deliverable 5.0 K—Synthesis Report) for the work performed under task order M15PD00015 or "Task Order 2" which falls within the broader scope of ID/IQ contract M14PC00008.

Wooller, M. J., Iken, K., & O'Brien, D. M. (2019). *Identifying Sources of Organic Mater to Benthic Organisms in the Beaufort and Chukchi Outer Continental Shelves.* Retrieved from https://www.boem.gov/sites/default/files/boem-newsroom/Library/Publications/2019/BOEM_2019-030.pdf

Benthic invertebrate communities are an essential ecosystem component in Arctic food webs in terms of energy transfer to higher trophic levels and mineralization. Currently, the proportional contributions of different sources of organic matter (marine, terrestrial, or microbial production) that sustain benthic organisms in the Arctic are unclear. This project provided a better understanding of the organic matter sources consumed by benthic organisms using a state-of-theart essential amino acid (EAA) "fingerprinting" approach. Unlike non-essential amino acids, the term "essential" means that they only originate from the organisms that synthesized them (e.g., photosynthetic or microbial organisms) and cannot be synthesized by consumers. The EAAs have specific stable carbon isotope fingerprints, depending on the producer type, and they differ between marine, terrestrial, and microbial producers. The EAA fingerprints are incorporated into and conserved within consumers, creating a pattern or "stable isotope fingerprint," which can be statistically compared with the EAA fingerprints of the primary producers. "Fingerprints" allow the separation of microbial and terrestrial carbon sources from marine production, filling a gap identified in previous benthic food web work involving systems in the Arctic. This is a particularly powerful tool to quantify the proportional contribution by microbial, terrestrial plant, and marine primary producers to consumers. We found that EAA fingerprints in the soft tissues of clams from the Arctic marine environment were reflected in the signatures preserved in the shells of these organisms. This important methodological finding will allow future application of the approach to analyses of archeological and geological clam samples. We compared results from our analyses of primary producers (endmembers in terrestrial plants and phytoplankton) with literature values and found that most endmembers of the same category had very similar EAA fingerprints. This suggests that EAA isotope fingerprints of primary producers are taxon-specific and driven by broad and deep phylogenetic differences in EAA synthesis rather than environmental and geographic differences. Archived benthic invertebrates were analyzed from three regions, Hanna Shoal, Chukchi Sea, and the Beaufort Sea. In the Hanna Shoal and Chukchi samples, which came from a relatively uniform water depth, we found that phytoplankton and terrestrial derived EAAs made the greatest proportional contributions to benthic invertebrates. This finding supports observations of highly productive phytoplankton blooms in the region. The Hanna Shoal bivalve model estimated that bacteria made up the next highest proportion of bivalve EAAs, which may reflect the reworking and ecological availability of more refractory organic matter. There appeared to be some differences between the two bivalve species analyzed from the Hanna Shoal. Phytoplankton was estimated to contribute a higher proportion of EAAs, and terrestrial organic matter and bacteria less, to Astarte spp. than found with Macoma spp. These differences are likely due to their different feeding modes. In contrast to the Chukchi region and Hanna Shoal, the results from the Beaufort region indicated a greater contribution of EAAs from sources other than phytoplankton and terrestrial organic matter. Most notably, there appeared to be a greater contribution of bacterial and macroalgal sources of EAAs in the invertebrates. Additionally, water depth influenced the source of the proportional contributions, with more bacterial-derived EAAs at greater depth. A future direction would be to apply compound-specific amino acid and fatty acid analyses on the

same sample. This would allow the determination of the proportional contribution of marine photosynthetic sources as a whole (vs. terrestrial and bacterial sources), and the determination of proportional contributions of ice algae and phytoplankton based on the fatty acids data.

Zhang, J. L., Spitz, Y. H., Steele, M., Ashjian, C., Campbell, R., Berline, L., & Matrai, P. (2010). Modeling the Impact of Declining Sea Ice on the Arctic Marine Planktonic Ecosystem. *Journal of Geophysical Research-Oceans,* 115. https://doi.org/10.1029/2009jc005387

We have developed a coupled 3-D pan-Arctic biology/sea ice/ocean model to investigate the impact of declining Arctic sea ice on the marine planktonic ecosystem over 1988-2007. The biophysical model results agree with satellite observations of a generally downward trend in summer sea ice extent during 1988-2007, resulting in an increase in the simulated photosynthetically active radiation (PAR) at the ocean surface and marine primary productivity (PP) in the upper 100 m over open water areas of the Arctic Ocean. The simulated Arctic sea ice thickness has decreased steadily during 1988-2007, leading to an increase in PAR and PP in sea ice-covered areas. The simulated total PAR in all areas of the Arctic Ocean has increased by 43%, from 146 TW in 1988 to 209 TW in 2007; the corresponding total PP has increased by 50%, from 456 Tg C yr(-1) in 1988 to 682 Tg C yr(-1) in 2007. The simulated PAR and PP increases mainly occur in the seasonally and permanently ice-covered Arctic Ocean. In addition to increasing PAR, the decline in sea ice tends to increase the nutrient availability in the euphotic zone by enhancing air-sea momentum transfer, leading to strengthened upwelling and mixing in the water column and therefore increased nutrient input into the upper ocean layers from below. The increasing nutrient availability also contributes to the increase in the simulated PP, even though significant surface nutrient drawdown in summer is simulated. In conjunction with increasing surface absorption of solar radiation and rising surface air temperature, the increasing surface water temperature in the Arctic Ocean peripheral seas further contributes to the increase in PP. As PP has increased, so has the simulated biomass of phytoplankton and zooplankton.

Chemistry

Bates, N. R., & Mathis, J. T. (2009). The Arctic Ocean Marine Carbon Cycle: Evaluation of Air-Sea CO2 Exchanges, Ocean Acidification Impacts and Potential Feedbacks. *Biogeosciences,* 6(11), 2433-2459. https://doi.org/10.5194/bg-6-2433-2009

At present, although seasonal sea-ice cover mitigates atmosphere-ocean gas exchange, the Arctic Ocean takes up carbon dioxide (CO2) on the order of −66 to −199 Tg C year−1 (1012 g C), contributing 5–14% to the global balance of CO2 sinks and sources. Because of this, the Arctic Ocean has an important influence on the global carbon cycle, with the marine carbon cycle and atmosphere-ocean CO2 exchanges sensitive to Arctic Ocean and global climate change feedbacks. In the near-term, further sea-ice loss and increases in phytoplankton growth rates are expected to increase the uptake of CO2 by Arctic Ocean surface waters, although mitigated somewhat by surface warming in the Arctic. Thus, the capacity of the Arctic Ocean to uptake CO2 is expected to alter in response to environmental changes driven largely by climate. These changes are likely to continue to modify the physics, biogeochemistry, and ecology of the Arctic Ocean in ways that are not yet fully understood. In surface waters, sea-ice melt, river runoff, cooling and uptake of CO2 through air-sea gas exchange combine to decrease the calcium carbonate (CaCO3) mineral saturation states (Ω) of seawater while seasonal phytoplankton

primary production (PP) mitigates this effect. Biological amplification of ocean acidification effects in subsurface waters, due to the remineralization of organic matter, is likely to reduce the ability of many species to produce CaCO3 shells or tests with profound implications for Arctic marine ecosystems.

Bates, N. R., Orchowska, M. I., Garley, R., & Mathis, J. T. (2013). Summertime Calcium Carbonate Undersaturation in Shelf Waters of the Western Arctic Ocean - How Biological Processes Exacerbate the Impact of Ocean Acidification. *Biogeosciences,* 10(8), 5281-5309. https://doi.org/10.5194/bg-10-5281-2013

The Arctic Ocean accounts for only 4% of the global ocean area, but it contributes significantly to the global carbon cycle. Recent observations of seawater CO2-carbonate chemistry in shelf waters of the western Arctic Ocean, primarily in the Chukchi Sea, from 2009 to 2011 indicate that bottom waters are seasonally undersaturated with respect to calcium carbonate (CaCO3) minerals, particularly aragonite. Nearly 40% of sampled bottom waters on the shelf have saturation states less than one for aragonite (i.e., Omega(aragonite) < 1.0), thereby exposing the benthos to potentially corrosive water for CaCO3-secreting organisms, while 80% of bottom waters present had Omega(aragonite) values less than 1.5. Our observations indicate seasonal reduction of saturation states (Omega) for calcite (Omega(calcite)) and aragonite (Omega(aragonite)) in the subsurface in the western Arctic by as much as 0.8 and 0.5, respectively. Such data indicate that bottom waters of the western Arctic shelves were already potentially corrosive for biogenic and sedimentary CaCO3 for several months each year. Seasonal changes in Omega are imparted by a variety of factors such as phytoplankton photosynthesis, respiration/remineralization of organic matter and air-sea gas exchange of CO2. Combined, these processes either increase or enhance in surface and subsurface waters, respectively. These seasonal physical and biological processes also act to mitigate or enhance the impact of Anthropocene ocean acidification (OA) on Omega in surface and subsurface waters, respectively. Future monitoring of the western Arctic shelves is warranted to assess the present and future impact of ocean acidification and seasonal physico-biogeochemical processes on Omega values and Arctic marine ecosystems.

Berchet, A., Pison, I., Crill, P. M., Thornton, B., Bousquet, P., Thonat, T., . . . Saunois, M. (2020). Using Ship-Borne Observations of Methane Isotopic Ratio in the Arctic Ocean to Understand Methane Sources in the Arctic. *Atmospheric Chemistry and Physics,* 20(6), 3987-3998. https://doi.org/10.5194/acp-20-3987-2020

Characterizing methane sources in the Arctic remains challenging due to the remoteness, heterogeneity and variety of such emissions. In situ campaigns provide valuable datasets to reduce these uncertainties. Here we analyse data from the summer 2014 SWERUS-C3 campaign in the eastern Arctic Ocean, off the shore of Siberia and Alaska. Total concentrations of methane, as well as relative concentrations of (CH4)-C-12 and (CH4)-C-13, were measured continuously during this campaign for 35 d in July and August. Using a chemistry-transport model, we link observed concentrations and isotopic ratios to regional emissions and hemispheric transport structures. A simple inversion system helped constrain source signatures from wetlands in Siberia and Alaska, and oceanic sources, as well as the isotopic composition of lower-stratosphere air masses. The variation in the signature of lower-stratosphere air masses, due to strongly fractionating chemical reactions in the stratosphere, was suggested to explain a large share of the observed variability in isotopic ratios. These results point towards necessary efforts to

better simulate large-scale transport and chemistry patterns to make relevant use of isotopic data in remote areas. It is also found that constant and homogeneous source signatures for each type of emission in a given region (mostly wetlands and oil and gas industry in our case at high latitudes) are not compatible with the strong synoptic isotopic signal observed in the Arctic. A regional gradient in source signatures is highlighted between Siberian and Alaskan wetlands, the latter having lighter signatures (more depleted in C-13). Finally, our results suggest that marine emissions of methane from Arctic continental-shelf sources are dominated by thermogenicorigin methane, with a secondary biogenic source as well.

Biastoch, A., Treude, T., Rupke, L. H., Riebesell, U., Roth, C., Burwicz, E. B., . . . Wallmann, K. (2011). Rising Arctic Ocean Temperatures Cause Gas Hydrate Destabilization and Ocean Acidification. *Geophysical Research Letters,* 38(8). https://doi.org/10.1029/2011gl047222

Vast amounts of methane hydrates are potentially stored in sediments along the continental margins, owing their stability to low temperature - high pressure conditions. Global warming could destabilize these hydrates and cause a release of methane (CH4) into the water column and possibly the atmosphere. Since the Arctic has and will be warmed considerably, Arctic bottom water temperatures and their future evolution projected by a climate model were analyzed. The resulting warming is spatially inhomogeneous, with the strongest impact on shallow regions affected by Atlantic inflow. Within the next 100 years, the warming affects 25% of shallow and mid-depth regions containing methane hydrates. Release of methane from melting hydrates in these areas could enhance ocean acidification and oxygen depletion in the water column. The impact of methane release on global warming, however, would not be significant within the considered time span.

Collett, T. S., Lee, M. W., Agena, W. F., Miller, J. J., Lewis, K. A., Zyrianova, M. V., . . . Inks, T. L. (2011). Permafrost-Associated Natural Gas Hydrate Occurrences on the Alaska North Slope. *Marine and Petroleum Geology,* 28(2), 279-294. https://doi.org/10.1016/j.marpetgeo.2009.12.001

In the 1960s Russian scientists made what was then a bold assertion that gas hydrates should occur in abundance in nature. Since this early start, the scientific foundation has been built for the realization that gas hydrates are a global phenomenon, occurring in permafrost regions of the arctic and in deep water portions of most continental margins worldwide. In 1995, the U.S. Geological Survey made the first systematic assessment of the in-place natural gas hydrate resources of the United States. That study suggested that the amount of gas in the gas hydrate accumulations of northern Alaska probably exceeds the volume of known conventional gas resources on the North Slope. Researchers have long speculated that gas hydrates could eventually become a producible energy resource, yet technical and economic hurdles have historically made gas hydrate development a distant goal. This view began to change in recent years with the realization that this unconventional resource could be developed with existing conventional oil and gas production technology. One of the most significant developments was the completion of the BPXA-DOE-USGS Mount Elbert Gas Hydrate Stratigraphic Test Well on the Alaska North Slope, which along with the Mallik project in Canada, have for the first time allowed the rational assessment of gas hydrate production technology and concepts. Almost 40 years of gas hydrate research in northern Alaska has confirmed the occurrence of at least two large gas hydrate accumulations on the North Slope. We have also seen in Alaska the first ever assessment of how much gas could be technically

recovered from gas hydrates. However, significant technical concerns need to be further resolved in order to assess the ultimate impact of gas hydrate energy resource development in northern Alaska.

Douglas, T. A., Domine, F., Barret, M., Anastasio, C., Beine, H. J., Bottenheim, J., . . . Steffen, A. (2012). Frost Flowers Growing in the Arctic Ocean-Atmosphere-Sea Ice-Snow Interface: 1. Chemical Composition. *Journal of Geophysical Research-Atmospheres,* 117. https://doi.org/10.1029/2011jd016460

Frost flowers, intricate featherlike crystals that grow on refreezing sea ice leads, have been implicated in lower atmospheric chemical reactions. Few studies have presented chemical composition information for frost flowers over time and many of the chemical species commonly associated with Polar tropospheric reactions have never been reported for frost flowers. We undertook this study on the sea ice north of Barrow, Alaska to quantify the major ion, stable oxygen and hydrogen isotope, alkalinity, light absorbance by soluble species, organochlorine, and aldehyde composition of seawater, brine, and frost flowers. For many of these chemical species we present the first measurements from brine or frost flowers. Results show that major ion and alkalinity concentrations, stable isotope values, and major chromophore (NO3- and H2O2) concentrations are controlled by fractionation from seawater and brine. The presence of these chemical species in present and future sea ice scenarios is somewhat predictable. However, aldehydes, organochlorine compounds, light absorbing species, and mercury (part 2 of this research and Sherman et al. (2012)) are deposited to frost flowers through less predictable processes that probably involve the atmosphere as a source. The present and future concentrations of these constituents in frost flowers may not be easily incorporated into future sea ice or lower atmospheric chemistry scenarios. Thinning of Arctic sea ice will likely present more open sea ice leads where young ice, brine, and frost flowers form. How these changing ice conditions will affect the interactions between ice, brine, frost flowers and the lower atmosphere is unknown.

Fabry, V. J., McClintock, J. B., Mathis, J. T., & Grebmeier, J. M. (2009). Ocean Acidification at High Latitudes, the Bellwether. *Oceanography,* 22(4), 160-171. Retrieved from https://www.jstor.org/stable/24861032

Owing to anthropogenic-induced acidification, surface waters of the high latitudes are projected to become persistently undersaturated with respect to aragonite as early as mid-century. Seasonal aragonite undersaturation in surface and shallow subsurface waters of some northern polar seas has already been observed. Calcified marine organisms, including thecosomatous pteropods, foraminifers, cold-water corals, sea urchins, molluscs, and coralline algae, make up significant components of the rich communities in high latitudes, and they are thought to be at risk with increasing ocean acidification. Over the next decades, trends of rising temperatures and species invasions coupled with progressive ocean acidification are expected to increasingly influence both planktonic and benthic marine communities of Antarctica and the Arctic. The rate and magnitude of these changes underscore the urgent need for increased efforts in ocean acidity research and monitoring in polar and subpolar seas.

Helmig, D., Boylan, P., Johnson, B., Oltmans, S., Fairall, C., Staebler, R., . . . Shepson, P. B. (2012). Ozone Dynamics and Snow-Atmosphere Exchanges During Ozone Depletion Events at Barrow, Alaska. *Journal of Geophysical Research-Atmospheres,* 117. https://doi.org/10.1029/2012jd017531

The behavior of lower atmospheric ozone and ozone exchanges at the snow surface were studied using a suite of platforms during the Ocean-Atmosphere-Sea Ice-Snow (OASIS) Spring 2009 experiment at an inland, coastal site east of Barrow, Alaska. A major objective was to investigate if and how much chemistry at the snow surface at the site contributes to springtime ozone depletion events (ODEs). Between March 8 and April 16, seven ODEs, with atmospheric ozone dropping below 1.0 ppbv, were observed. The depth of the ozone-depleted layer was variable, extending from the surface to similar to 200-800 m. ODEs most commonly occurred during low wind speed conditions with flow coming from the Arctic Ocean. Two high-sensitivity ozone chemiluminescence instruments were used to accurately define the remaining sub-ppbv ozone levels during ODEs. These measurements showed variable residual ODE ozone levels ranging between 0.010 and 0.100 ppbv. During the most extended ODE, when ozone remained below 1.0 ppbv for over 78 h, these measurements showed a modest ozone recovery or production in the early afternoon hours, resulting in increases in the ozone mixing ratio of 0.100 to 0.800 ppbv. The comparison between high-sensitivity ozone measurements and BrO measured by longpath differential absorption spectroscopy (DOAS) during ODEs indicated that at low ozone levels formation of BrO is controlled by the amount of available ozone. Measurements of ozone in air drawn from below the snow surface showed depleted ozone in the snowpack, with levels consistently remaining <6 ppbv independent of above-surface ambient air concentrations. The snowpack was always a sink of ozone. Ozone deposition velocities determined from ozone surface flux measurements by eddy covariance were on the order of 0.01 cm s(-1), which is of similar magnitude as ozone uptake rates found over snow at other polar sites that are not subjected to ODEs. The results from these multiple platform measurements unequivocally show that snow-atmosphere chemical exchanges of ozone at the measurement site do not exhibit a major contribution to ozone removal from the boundary layer and the formation of ODE.

Hoekstra, P. F., O'Hara, T. M., Teixeira, C., Backus, S., Fisk, A. T., & Muir, D. C. G. (2002). Spatial Trends and Bioaccumulation of Organochlorine Pollutants in Marine Zooplankton from the Alaskan and Canadian Arctic. *Environmental Toxicology and Chemistry,* 21(3), 575-583. https://doi.org/10.1002/etc.5620210316

Planktonic copepods (Calanus glacialis and C. hyperboreus; n = 37) and water (n = 19) were collected to examine the spatial distribution and bioaccumulation of organochlorine contaminants (OCs) in the Alaskan and Canadian Arctic. The rank order of total OC (σ OC) group concentrations in Calanus samples was toxaphene ≥ σ polychlorinated biphenyls (PCBs) > σ hexachlorcyclohexane (HCH). σ DDT > σ chlordane-related compounds (CHLOR) > σ chlorobenzenes (ClBz). The dominant analyte was α-HCH in all water and zooplankton samples. The most abundant toxaphene congener in water and zooplankton samples was the hexachlorobornane B6-923. Organochlorine contaminant group concentrations in Alaskan zooplankton and water samples were lower than those in samples collected from sites in the eastern Canadian Arctic. Comparison of PCB and toxaphene congener profiles in zooplankton and water samples suggests that biotransformation by cytochrome P-4502B isozymes is low in Calanus, and limited phase I metabolism may occur. The log relationship of bioaccumulation factor (log BAF) versus octanol-water partition coefficient (log Kow) relationship was near 1: 1 for OCs within the log Kow range of 3 to 6. A curvilinear model provided a better relationship between these two variables when OC compounds

with log Kow > 6 were included. These results suggest that hydrophobic OCs (log Kow 3-6) in Calanus species are at equilibrium with the water concentrations and that physical partitioning, rather than biotransformation, is the major factor governing OC profiles in marine zooplankton.

Holmes, R. M., McClelland, J. W., Raymond, P. A., Frazer, B. B., Peterson, B. J., & Stieglitz, M. (2008). Lability of Doc Transported by Alaskan Rivers to the Arctic Ocean. *Geophysical Research Letters,* 35(3). https://doi.org/10.1029/2007GL032837

Arctic rivers transport huge quantities of dissolved organic carbon (DOC) to the Arctic Ocean. The prevailing paradigm is that DOC in arctic rivers is refractory and therefore of little significance for the biogeochemistry of the Arctic Ocean. We show that there is substantial seasonal variability in the lability of DOC transported by Alaskan rivers to the Arctic Ocean: little DOC is lost during incubations of samples collected during summer, but substantial losses (20?40%) occur during incubations of samples collected during the spring freshet when the majority of the annual DOC flux occurs. We speculate that restricting sampling to summer may have biased past studies. If so, then fluvial inputs of DOC to the Arctic Ocean may have a much larger influence on coastal ocean biogeochemistry than previously realized, and reconsideration of the role of terrigenous DOC on carbon, microbial, and food-web dynamics on the arctic shelf will be warranted.

Moreau, S., Vancoppenolle, M., Delille, B., Tison, J. L., Zhou, J. Y., Kotovitch, M., . . . Goosse, H. (2015). Drivers of Inorganic Carbon Dynamics in First-Year Sea Ice: A Model Study. *Journal of Geophysical Research-Oceans,* 120(1), 471-495. https://doi.org/10.1002/2014jc010388

Sea ice is an active source or a sink for carbon dioxide (CO2), although to what extent is not clear. Here, we analyze CO2 dynamics within sea ice using a one-dimensional halothermodynamic sea ice model including gas physics and carbon biogeochemistry. The ice-ocean fluxes, and vertical transport, of total dissolved inorganic carbon (DIC) and total alkalinity (TA) are represented using fluid transport equations. Carbonate chemistry, the consumption, and release of CO2 by primary production and respiration, the precipitation and dissolution of ikaite (CaCO(3)6H(2)O) and ice-air CO2 fluxes, are also included. The model is evaluated using observations from a 6 month field study at Point Barrow, Alaska, and an ice-tank experiment. At Barrow, results show that the DIC budget is mainly driven by physical processes, wheras brine-air CO2 fluxes, ikaite formation, and net primary production, are secondary factors. In terms of ice-atmosphere CO2 exchanges, sea ice is a net CO2 source and sink in winter and summer, respectively. The formulation of the ice-atmosphere CO2 flux impacts the simulated near-surface CO2 partial pressure (pCO(2)), but not the DIC budget. Because the simulated ice-atmosphere CO2 fluxes are limited by DIC stocks, and therefore <2 mmol m(-2) d(-1), we argue that the observed much larger CO2 fluxes from eddy covariance retrievals cannot be explained by a sea ice direct source and must involve other processes or other sources of CO2. Finally, the simulations suggest that near-surface TA/DIC ratios of approximate to 2, sometimes used as an indicator of calcification, would rather suggest outgassing.

Pan, H. J., Li, H. B., Chen, J. Y., Riedel, M., Holland, M., Zhang, Y., & Cai, S. J. (2020). Quantification of Gas Hydrate Saturation and Morphology Based on a Generalized Effective Medium Model. *Marine and Petroleum Geology,* 113, 16. https://doi.org/10.1016/j.marpetgeo.2019.104166

Numerous models have been developed for prediction of gas hydrate saturation based on the microstructural relationship between gas hydrates and sediment grains. However, quantification of hydrate saturation and morphology from elastic properties has been hindered by failing to account for complex hydrate distributions. Here, we develop a generalized effective medium model by applying the modified Hashin-Shtrikman bounds to a newly developed cementation theory. This model is validated by experimental data for synthetic methane and tetrahydrofuran hydrates. Good comparison of model predictions with experimental measurements not only reveals its ability to merge the results of contact cementation theory and effective medium theory, but also indicates its feasibility for characterizing complex morphologies. Moreover, the results of inverting acoustic measurements quantitatively confirm that for synthetic samples in "excess-gas" condition gas hydrates mainly occur as a hybrid-cementing morphology with a low percentage of pore-filling morphology, whereas for pressure-core hydrate-bearing sediments in natural environments they exist as matrix-supporting and pore-filling morphologies with a very low percentage of hybrid-cementing morphology. The hydrate saturations estimated from sonic and density logs in several regions including northern Cascadia margin (Integrated Ocean Drilling Program Expedition 311, Hole U1326D and Hole U1327E), Alaska North Slope (Mount Elbert test well) and Mackenzie Delta (Mallik 5L-38), are comparable to the referenced hydrate saturations derived from core data and resistivity, and/or nuclear magnetic resonance log data, confirming validity and applicability of our model. Furthermore, our results indicate that similar to 8% hybrid-cementing, similar to 33% matrix-supporting and similar to 59% pore-filling hydrates may coexist in the fine-grained and clay-rich marine sediments on the northern Cascadia margin, whereas similar to 10% hybrid-cementing, similar to 54% matrix-supporting and similar to 36% pore-filling hydrates may coexist in the coarse-grained and sand-dominated terrestrial sediments of the Alaska North Slope and Mackenzie Delta.

Sundseth, K., Pacyna, J. M., Banel, A., Pacyna, E. G., & Rautio, A. (2015). Climate Change Impacts on Environmental and Human Exposure to Mercury in the Arctic. *International Journal of Environmental Research and Public Health,* 12(4), 3579-3599. https://doi.org/10.3390/ijerph120403579

This paper reviews information from the literature and the EU ArcRisk project to assess whether climate change results in an increase or decrease in exposure to mercury (Hg) in the Arctic, and if this in turn will impact the risks related to its harmful effects. It presents the state-of-the art of knowledge on atmospheric mercury emissions from anthropogenic sources worldwide, the long-range transport to the Arctic, and it discusses the likely environmental fate and exposure effects on population groups in the Arctic under climate change conditions. The paper also includes information about the likely synergy effects (co-benefits) current and new climate change polices and mitigation options might have on mercury emissions reductions in the future. The review concludes that reductions of mercury emission from anthropogenic sources worldwide would need to be introduced as soon as possible in order to assure lowering the adverse impact of climate change on human health. Scientific information currently available, however, is not in the position to clearly answer whether climate change will increase or decrease the risk of exposure to mercury in the Arctic. New research should therefore be undertaken to model the relationships between climate change and mercury exposure.

Geology

Barnes, P. W., Miley, J. M., & Phillips, R. L. (1986). *1985 Field Studies, Beaufort and Chukchi Seas.* https://doi.org/10.3133/ofr86202

No abstract available.

Hoiland, C. W., Miller, E. L., & Pease, V. (2018). Greenschist Facies Metamorphic Zircon Overgrowths as a Constraint on Exhumation of the Brooks Range Metamorphic Core, Alaska. *Tectonics,* 37(10), 3429-3455. https://doi.org/10.1029/2018tc005006

Like many other mountain belts, the metamorphic core or hinterland of the Brooks Range fold and thrust belt in Arctic Alaska is characterized by multiply deformed and polymetamorphosed rocks whose histories have been challenging to decipher and thus difficult to relate to the supracrustal history of the orogen. The multiple greenschist and blueschist facies metamorphic events have been particularly difficult to resolve. This study provides petrologic context for recently identified low-temperature metamorphic zircon overgrowths at two localities across some 200km of orogenic strike that offer a unique and precise constraint on the timing of events recorded in the Brooks Range hinterland. In consideration of microstructural context, graphite thermometry, metamorphic mineral inclusions, and zircon trace element and Lu-Hf-isotope data, metamorphic zircon growth at 1145Ma in the southern Brooks Range is interpreted to coincide with greenschist facies metamorphism, most probably linked to decompression and/or increased temperatures within the orogenic core. Their age coincides with a proposed pulse of extension within a >600-km shear zone along the southern flank of the Brooks Range and a regional flare-up in magmatism and pronounced subsidence within hinterland depocenters (Yukon-Koyukuk Basin). These regional events are consistent with subduction retreat/rollback in mid-Cretaceous time. This study adds to a growing body of literature demonstrating the importance of searching for and characterizing metamorphic zircon growth in low- to medium-grade metamorphic terranes to provide better constraints on otherwise cryptic tectonic events. Plain Language Summary Rocks within mountain belts typically contain metamorphic minerals and textures that grew and developed in response to heating, burial, and deformation. In order to understand the evolution of mountains and the plate tectonic interactions that formed them, it is important to be able to determine when those metamorphic minerals and textures grew. The minerals best suited to directly dating tectonic events typically only grow at high temperatures (like >550 degrees C), whereas minerals that grow at lower temperatures are often easily disturbed during subsequent heating or tectonic events, rendering their ages suspect. In our study of the Brooks Range mountain belt in northern Alaska, we characterize low-temperature overgrowths on older zircon crystals that can provide excellent ages using the U-Pb radioactive decay scheme because of their closed system behavior with no loss of daughter products. In the case of the Brooks Range, these zircon overgrowths appear to have formed as enclosing rocks were uplifted toward the surface of the Earth. Their uplift coincided with formation of deep water marine basins and enhanced volcanic activity, which we interpret as due to southward rollback of the subduction zone beneath Alaska beginning similar to 115 million years ago.

Kossovaya, O. L., Tolmacheva, T. Y., Petrov, O. V., Isakova, T. N., Ivanova, R. M., Mirolyubova, E. S., . . . Gusev, E. A. (2018). Palaeozoic Carbonates and Fossils of the Mendeleev Rise (Eastern Arctic): A Study of Dredged Seafloor Material. *Journal of Geodynamics,* 120, 23-44. https://doi.org/10.1016/j.jog.2018.05.001

Fossiliferous carbonate rocks dredged during the "Arctic-2012" cruise on the Mendeleev Rise (eastern Arctic) provide proof of the presence of Upper Silurian(?)-Middle Devonian, Famennian-Tournaisian, Bashkirian-Kasimovian, Gshelian-lower Asselian(?) and Kungurian-Kazanian carbonate deposits. The wide spectrum of facies includes deposits of both photic zone (with fusulinids, algae, relicts of microbial and coral reefs) and deeper dysphotic areas (with trilobites, deep-water tentaculitids and ostracods). The results obtained suggest that there were at least three periods of carbonate platform sedimentation during the latest Silurian(?) to Permian. The Late Silurian?-Devonian biota do not show biogeographical differentiation, but rather are distributed globally. Shallow-water foraminifera and some algae of early Pennsylvanian-basal Cisuralian age belong to the warm-water province. These forms are unknown in the Moscovian-Permian of the Boreal Realm (Taimyr, New Siberian Islands, Verkhoyanie, Omolon Massif) but are typical for Alaska and Arctic Canada, Wrangel Island, Chukotka, Polar Urals and Svalbard. The disappearance of warm-water biota during late Artinskian-Kungurian times led to a subsequent predominance of smaller foraminifera: this assemblage with Protonodosaria is widely distributed in Permian deposits of Novaya Zemlya, Urals, Barents Sea and the eastern Arctic. The warm-water Bashkirian-Asselian biota suggests that the Mendeleev-Chukotka-Wrangel block was a low latitude shallow basin with predominant carbonate sedimentation, being part of the Arctida supercontinent, connected temporarily with the eastern margin of Laurasia (Chukcha-Alaska block).

Pe'eri, S., Madore, B., Nyberg, J., Snyder, L., Parrish, C., & Smith, S. (2016). Identifying Bathymetric Differences over Alaska's North Slope Using a Satellite-Derived Bathymetry Multi-Temporal Approach. *Journal of Coastal Research,* 76(sp1), 56-63, 58. https://doi.org/10.2112/SI76-006

Many nautical charts of Alaska's North Slope are based on chart data that have not been updated since the early 1950s. Additionally, these charts may have been compiled using inadequate data and contain unsurveyed areas. However, with more days per year of diminished Arctic sea-ice coverage, including along the North Slope, marine transportation in this region has increased during the past decade, thus increasing the need for updated nautical charts. Due to limited resources available for U.S. Arctic surveying, the National Oceanic and Atmospheric Administration (NOAA) is evaluating the capabilities of satellite-derived bathymetry (SDB). This technology has proven useful as a reconnaissance tool in tropical and subtropical waters and clear-water conditions, especially over sandy seafloor. But in the Arctic, glacial flour from land reduces water clarity and limits the light penetration depth, which may affect SDB calculations. A new multi-temporal SDB approach is described in this paper using multiple images to extract “clear water” areas acquired on different dates. As a proof-of-concept, the extinction depth and bathymetry were calculated over areas that overlap with NOAA Charts 16081 and 16082 using Landsat 7 and Landsat 8 imagery. The derived and charted bathymetry are similar in most areas up to 4.5 m deep. The results of the study also identified a potential uncharted shoal. The multi-temporal SDB approach was further investigated by NOAA and was used to process imagery for other areas along Alaska's North Slope. As a result, the new editions of NOAA Chart 16081 include the location of a potential uncharted shoal, which is the first time an SDB product was utilized for a NOAA chart.

Spencer, A. M., Embry, A. F., Gautier, D. L., Stoupakova, A. V., & Sorensen, K. (2011). An Overview of the Petroleum Geology of the Arctic. In *Arctic Petroleum Geology.* A. M. Spencer, A. F. Embry, D. L. Gautier, A. V. Stoupakova, & K. Sorensen (Eds.), (Vol. 35) https://doi.org/10.1144/m35.1

Nine main petroleum provinces containing recoverable resources totalling 61 Bbbl liquids + 269 Bbbloe of gas are known in the Arctic. The three best known major provinces are: West Siberia-South Kara, Arctic Alaska and Timan-Pechora. They have been sourced principally from, respectively, Upper Jurassic, Triassic and Devonian marine source rocks and their hydrocarbons are reservoired principally in Cretaceous sandstones, Triassic sandstones and Palaeozoic carbonates. The remaining six provinces except for the Upper Cretaceous-Palaeogene petroleum system in the Mackenzie Delta have predominantly Mesozoic sources and Jurassic reservoirs. There are discoveries in 15% of the total area of sedimentary basins (c. 8 x 10(6) km(2)), dry wells in 10% of the area, seismic but no wells in 50% and no seismic in 25%. The United States Geological Survey estimate yet-to-find resources to total 90 Bbbl liquids + 279 Bbbloe gas, with four regions - South Kara Sea, Alaska, East Barents Sea, East Greenland - dominating. Russian estimates of South Kara Sea and East Barents Sea are equally positive. The large potential reflects primarily the large undrilled areas, thick basins and widespread source rocks.

Management

Associates, S. R. B. (2010). *Subsistence Mapping of Nuiqsut, Kaktovik, and Barrow.* Retrieved from http://www.north-slope.org/assets/images/uploads/Braund%202010%20Beaufort%20maps%20MMS_MP_Final_Report_Apr2010.pdf

No abstract available.

Ford, J. D., & Pearce, T. (2010). What We Know, Do Not Know, and Need to Know About Climate Change Vulnerability in the Western Canadian Arctic: A Systematic Literature Review. *Environmental Research Letters,* 5(1), 9. https://doi.org/10.1088/1748-9326/5/1/014008

This letter systematically reviews and synthesizes scientific and gray literature publications (n = 420) to identify and characterize the nature of climate change vulnerability in the Inuvialuit Settlement Region of the western Canadian Arctic and identify gaps in understanding. The literature documents widespread evidence of climate change, with implications for human and biophysical systems. Adaptations are being employed to manage changing conditions and are indicative of a high adaptive capacity. However, barriers to adaptation are evident and are expected to constrain adaptive capacity to future climate change. Continued climate change is predicted for the region, with differential exposure sensitivity for communities, groups and sectors: a function of social-economic-biophysical characteristics and projected future climatic conditions. Existing climate risks are expected to increase in magnitude and frequency, although the interaction between projected changes and socio-economic-demographic trends has not been assessed. The capacity for adapting to future climate change has also not been studied. The review identifies the importance of targeted vulnerability research that works closely with community members and other stakeholders to address research needs. Importantly, the fully categorized list of reviewed references accompanying this letter will be a valuable resource for those

working or planning to work in the region, capturing climate change research published since 1990. At a broader level, the systematic review methodology offers a promising tool for climate/environmental change studies in general where there is a large and emerging body of research but limited understanding of research gaps and needs.

Jeffers, J. (2010). Climate Change and the Arctic: Adapting to Changes in Fisheries Stocks and Governance Regimes. *Ecology Law Quarterly,* 37(3), 917-977. Retrieved from https://www.jstor.org/stable/43920934

This Note analyzes climate change impacts on Arctic fisheries and governance structures, and examines the role of science, policy, and law in minimizing future repercussions of such impacts. The Arctic is currently undergoing unprecedented shifts in marine species, and climatic conditions in the region are changing at a rate nearly twice as fast as those at lower latitudes. In addition, long-term climatic changes present entirely new challenges. These ecological and socioeconomic alterations will have a significant effect on fisheries governance structures and interactions between Arctic countries and could potentially destabilize existing management regimes. Positive changes to fishery stock compositions and distributions may also lead to conflicts between Arctic nations due to overlapping jurisdictional claims, unregulated fishing, and a lack of multi-regional agreements. The current Arctic regulatory and governance framework is not sufficient in scope and flexibility to adequately address future fishery changes brought on by climate change. This Note suggests that the region needs a new, dynamic management regime in order to successfully negotiate the uncertainties inherent in climate change predictions and anticipate the effects such climatic changes will have on fisheries stocks. I propose four primary components of such a regime: (1) increased overlap of nation-state actors and scientists, (2) institutional nesting, (3) division and management of resources (both in terms of jurisdictional concerns, as well as conservation and utilization principles), and (4) non-political measures. I integrate these components into specific governance options for the future, including the creation of an Arctic regional treaty, an overhaul of the Arctic Council, and the formation of an Arctic-wide Regional Fisheries Management Organization. This Note concludes that although a regional treaty or agreement is currently unrealistic, overhauling the Arctic Council and establishing a new Arctic Ocean Regional Fisheries Management Organization may be feasible options to create an effective governance regime.

Marine Culture Heritage

Faulk, K. L. (2011). *Marine Archaeology in Alaska - an Overview*. Paper presented at the Offshore Technology Conference, Houston, Texas, USA. https://doi.org/10.4043/21505-MS

Ongoing exploration and development activities in the Arctic and on the Alaskan Outer Continental Shelf (OCS) require marine archaeological assessments. Current United States requirements are based on known archaeological sites, and predictive models for potential submerged archaeological sites. At present the Bureau of Ocean Energy Management Regulation and Enforcement (BOEMRE) Alaska office requires archaeological assessments for any area deemed to be potentially archaeologically significant. BOEMRE guidelines have established that archaeological sites in Alaska may include prehistoric sites or historic sites fifty years of age or older. These historic sites may include downed aircraft, shipwrecks, submerged structures, or other manmade objects. The guidelines also provide for prehistoric site potential based on sea level low stands approximately 13,000 years BPE. Low stands along the Alaska

coast typically align with the 60 meter bathymetric contour making much of the shallow Alaska OCS a high potential area for submerged archaeological resources. Standard geophysical data is used to seek, and identify submerged archaeological sites in Alaskan and Arctic waters, just as it is used in the Gulf of Mexico Region. These data provide a glimpse into the history and prehistory of Alaska in a way unavailable on land. Previous studies focused on the unlikelihood of discovering unidentified submerged cultural resources in Alaska and the Arctic. Recent discoveries throughout the northern latitudes, however, have proven that the potential for intact, undocumented sites is highly likely on the Alaskan and Canadian OCS. This paper explores the potential for submerged cultural sites in Alaskan waters, recent discoveries in the Arctic region, and the potential for future unanticipated archaeological discoveries in northern waters. Mythology of Arctic Underwater Archaeology Several misconceptions seem to surround Arctic underwater archaeology. The first of misconception involves the Bering Land Bridge and the image of a narrow strip of land above the Bering Sea on one side and the Arctic Ocean on the other with people and animals moving in opposite directions. Certainly the existence of the Bering Land Bridge has been well documented by geologists and archaeologists alike. The bigger issue is the ability of the Land Bridge to provide a transit route into new hunting territory. For several decades archaeologists have deliberated over whether or not there was more than a single migration into the western hemisphere via the Bering Land Bridge, but current research demonstrates there were several waves of migration into the western hemisphere. These migrations likely occurred through a variety of means including the Bering Land Bridge, small boats arriving on the Pacific coast, and potentially even small boats arriving from the European continent on the Atlantic coast in the prehistoric past. The second misconception is that ice has destroyed any remnants of past cultures, but recent discoveries in the Canadian Arctic have proven this belief wrong. Research by Parks Canada supports the idea that there is less damage from the ice on submerged cultural resources than there is from the rapid freezing and thawing cycles which are eroding the headlands and beaches in the Arctic at a rapid rate. Indeed, shore-fast ice may very well provide some of the best protection for submerged cultural resources in Alaska. Seasonal ice movement may as well provide some small protection to submerged sites by either pulling sites into deeper water, or by depositing fine sands and gravels over the sites as the ice rafts move away from shore.

George, J. C. (1996). *Kurilchik Coorespondance and Article.* Retrieved from [No URL available]

No abstract available.

Kurilchyk, W. (1999). *Chasing Ghosts: A Cooperative American-Soviet Search to Recover Aviation History*. Retrieved from [No URL available]

A cooperative American-Soviet Search to recover lost aviation history. Illustrated with over 85 photographs and maps. On April 18, 1942, sixteen U.S. B-25 medium range bombers took of from the aircraft carrier Hornet on a bombing mission with the code name "Shanghai-la." After bombing Tokyo, fifteen crews were forced to bail out over China, or crashed. Only one crew, the sixteenth, landed safely--although contrary to orders -- in the Soviet Union. Fearing Japanese reprisal, the Soviets interned the crew (who escaped a year later) and impounded the plane--which is still missing. Where did it go?

Ota, J. M., Kitts, C., Bates, J., & Weast, A. (1999). *From Mars to Marine Archaeology: A Report on the Jeremy Project*. Paper presented at the Riding the Crest into the 21st Century, Seattle, WA. Retrieved from [No URL available]

In August 1998, Santa Clara University (SCU) conducted a marine archeological expedition off the coast of Alaska with the use of a modified Deep Ocean Engineering Phantom XTL underwater remotely operated vehicle (ROV). Conducted jointly with NASA, NOAA, U.S. Coast Guard, U.S. Department of Interior, and the U.S. Navy Arctic Submarine Research Lab, the mission goals were to locate a lost whaling fleet that sank near Barrow, Alaska in 1871 and to test NASA's underwater 3D mapping technology. Using the stereo image capture and processing system adopted from the Mars Pathfinder mission, the expedition team found positive evidence of a sunken ship near the last known location of the whaling fleet. This accomplishment set a precedence in being the first successful state permitted shipwreck search in the history of Alaska. "The Jeremy Project" after the name of the principal student investigator, this project showcases many of the positive aspects of hands-on underwater science and engineering education. Benefits include science driven engineering, simple designs allowing complete understanding of the system, rapid schedule permitting full exposure to the mission lifecycle from conception to field operation, integration of science and engineering students and departments, involvement with multiple external organizations, and the excitement of executing a novel and compelling student mission. This paper reports on the mission and accomplishments of The Jeremy Project as well as the technical systems used in its execution. Finally, the future plans of applying the technology to marine archaeology will be discussed as part of an ongoing program in studentdriven underwater research.

Reanier, R. E. (2008). *Cultural Resources in the Liberty Seismic Program Area, North Slope, Alaska.* Retrieved from [No URL available]

This brief report contains an analysis of the potential for subsea cultural resources in the Liberty Seismic Project area and provides locations of onshore cultural resources located at the perimeter of the project area. The site location information is based upon field observations since 1999 and on field recordation using CPS receivers since 2002. Comparison of the correct locations of many of these sites with those presently contained in the Alaska Heritage Resources Survey (AHRS) database reveals that many of the AHRS locations are in error. For example, Site 49-XBP-00022 near Point Brower is mislocated by about 1,700 feet, and site 49-XBP-00060, west of Tigvariak Island, is mislocated by about 600 feet. The reasons for these errors are varied, but most of them likely result from old coordinates that were estimated from topographic maps before GPS was in common use in archaeological fieldwork. This report provides geographic coordinates and makes recommendations for protection of these sites based upon their internal characteristics. All geographic coordinates provided in this report are in the North American Datum of 1983 (NAD83) and are derived from GPS data collected by the author unless otherwise indicated. This report contains locational information for cultural resource sites, and it should only be released to those person and companies who have permission from the State Historic Preservation Officer for access to such information.

Minerals Management Service. (2008). *Beaufort Sea and Chukchi Sea Planning Areas, Oil and Gas Lease Sales 209, 212, 217, and 221 - Draft Environmental Impact Statement.* Retrieved from https://www.boem.gov/About-BOEM/BOEM-Regions/Alaska-Region/Environment/Environmental-Analysis/Draft-Environmental-Impact-Statement-OCS-EIS/EA-MMS-2008-0055.aspx

This environmental impact statement (EIS) examines proposals for oil and gas leasing in the Beaufort Sea and Chukchi Sea Outer Continental Shelf (OCS) Planning Areas. A no-action alterative and four deferral alternatives also are analyzed for each planning area. This EIS addresses the potential impacts under the various alternatives and lease stipulations proposed as mitigation measures. The EIS also addresses, as appropriate, the existing impacts of ongoing activities in the two areas. The Proposed Actions examined in the EIS are to offer for lease about 73.4 million acres (about 29.5 million hectares; approximately 13,500 whole and partial blocks) identified as the program areas in the 2007-2012 5-Year Program.

Physics

Cornish, S. B., Kostov, Y., Johnson, H. L., & Lique, C. (2020). Response of Arctic Freshwater to the Arctic Oscillation in Coupled Climate Models. *Journal of Climate,* 33(7), 2533-2555. https://doi.org/10.1175/jcli-d-19-0685.1

The freshwater content (FWC) of the Arctic Ocean is intimately linked to the stratification-a physical characteristic of the Arctic Ocean with wide relevance for climate and biology. Here, we explore the relationship between atmospheric circulation and Arctic FWC across 12 different control-run simulations from phase 5 of the Coupled Model Intercomparison Project. Using multiple lagged regression, we seek to isolate the linear response of Arctic FWC to a step change in the strength of the Arctic Oscillation (AO) as well as the second and third orthogonal modes of SLP variability over the Arctic domain. There is broad agreement among models that a step change to a more anticyclonic AO leads to an increase in Arctic FWC, with an e-folding time scale of 5-10 yr. However, models differ widely in the degree to which a linear response to SLP variability can explain FWC changes. Although the mean states, time scales, and magnitudes of FWC variability may be broadly similar, the physical origins of variability are highly inconsistent among models. We perform a robustness test that incorporates a Monte Carlo approach to determine which response functions are most likely to represent causal, physical relationships within the models and which are artifacts of regression. Convolution with SLP reanalysis data shows that the four most robust response functions have some skill at reproducing observed accumulation of FWC during the late 1990s and 2000s, consistent with the idea that this change was largely wind driven.

Curchitser, E., Hedstrom, K., Danielson, S., & Weingartner, T. (2013). *Adaptation of an Arctic Circulation Model.* Retrieved from https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/BOEM_Newsroom/Library/Publications/BOEM_2013-202.pdf

This document is the final report for the U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM) Contract M10PC00116, Adaptation of an Arctic Circulation Model. The primary aim of the work done under this award was to use a state-of-the-art coupled circulation sea ice

numerical ocean model to simulate several decades of the currents in the Chukchi and Beaufort Seas, which can be used as inputs to oil-spill models. This document reviews the basic oceanography of the region of interest, describes the relevant details of the models and their implementation for this particular problem, and describes the model-data comparisons that have been performed as part of this current award.

Druckenmiller, M. L., Eicken, H., Johnson, M. A., Pringle, D. J., & Williams, C. C. (2009). Toward an Integrated Coastal Sea-Ice Observatory: System Components and a Case Study at Barrow, Alaska. *Cold Regions Science and Technology,* 56(2-3), 61-72. https://doi.org/10.1016/j.coldregions.2008.12.003

The morphology, stability and duration of seasonal landfast sea ice in Alaska's coastal zone is changing alongside large-scale ice thinning and retreat. The extent and complexity of change at the local level requires an integrated observing approach to assess implications of such change for coastal ecosystems and communities that rely on or make use of the sea-ice cover. Barrow, Alaska is an example of a community that experiences and utilizes a broad range of sea-ice types and conditions. The local population is increasingly forced to adapt to less stable sea ice, loss of multiyear ice and a shorter ice season. We are working toward an integrated coastal ice observatory to monitor landfast and adjacent pack ice and to maximize the usefulness of information to the community. The observatory includes: (1) satellite remote-sensing datasets distributed in near real-time; (2) a coastal sea-ice radar and webcam that monitor ice movement and evolution; (3) a mass-balance site that provides temperature profiles and thickness information for ice and snow; (4) sea-level measurements; (5) periodic ice thickness surveys using direct drilling and electromagnetic induction sounding; and (6) a program of regular, undirected observations by Inupiat sea-ice experts. We examine two significant landfast ice breakout events off Barrow in spring of 2007. During these events, Barrow's subsistence whaling community partook in a successful hunting season observing and responding to these breakout events and their impacts on ice stability. Using local expert knowledge to parse geophysical datasets obtained from the observatory has provided deeper insight into different approaches for assessing ice stability, and integrating information on ice growth, origin, morphology, and dynamics, as well as winds, weather, and currents.

Evans, W., Mathis, J. T., Cross, J. N., Bates, N. R., Frey, K. E., Else, B. G. T., . . . Takahashi, T. (2015). Sea-Air Co2 Exchange in the Western Arctic Coastal Ocean. *Global Biogeochemical Cycles,* 29(8), 1190-1209. https://doi.org/10.1002/2015GB005153

The biogeochemical seascape of the western Arctic coastal ocean is in rapid transition. Changes in sea ice cover will be accompanied by alterations in sea-air carbon dioxide (CO2) exchange, of which the latter has been difficult to constrain owing to sparse temporal and spatial data sets. Previous assessments of sea-air CO2 flux have targeted specific subregional areas of the western Arctic coastal ocean. Here a holistic approach is taken to determine the net sea-air CO2 flux over this broad region. We compiled and analyzed an extensive data set of nearly 600,000 surface seawater CO2 partial pressure (p CO2) measurements spanning 2003 through 2014. Using space-time colocated, reconstructed atmospheric p CO2 values coupled with the seawater p CO2 data set, monthly climatologies of sea-air p CO2 differences (Δp CO2) were created on a 0.2° latitude × 0.5° longitude grid.

Sea-air CO2 fluxes were computed using the Δp CO2 grid and gas transfer rates calculated from climatology of wind speed second moments. Fluxes were calculated with and without the presence of sea ice, treating sea ice as an imperfect barrier to gas exchange. This allowed for carbon uptake by the western Arctic coastal ocean to be assessed under existing and reduced sea ice cover conditions, in which carbon uptake increased 30% over the current 10.9 ± 5.7 Tg C (1 Tg = 1012 g) yr−1 of sea ice-adjusted exchange in the region. This assessment extends beyond previous subregional estimates in the region in an all-inclusive manner and points to key unresolved aspects that must be targeted by future research.

Higgins, M. E., & Cassano, J. J. (2010). Response of Arctic 1000 Hpa Circulation to Changes in Horizontal Resolution and Sea Ice Forcing in the Community Atmospheric Model. *Journal of Geophysical Research-Atmospheres,* 115, 17. https://doi.org/10.1029/2009jd013440

Arctic winter surface atmospheric circulation biases inherent to the Community Atmospheric Model version 3 (CAM3) are examined with emphasis on the influence of horizontal resolution (T42, similar to 2.8 degrees versus T85, similar to 1.4 degrees). Using geopotential height at 1000 hPa (Z1000) to represent surface circulation, the self-organizing map technique is used to better understand these biases from a synoptic climatology perspective. The previously documented low sea level pressure (SLP) bias over the Beaufort Sea, Canadian Archipelago, Greenland Sea, Norwegian Sea, and northern Europe and high SLP bias over the northern Pacific and Atlantic oceans are shown to result from an underprediction of weak Aleutian and Icelandic low patterns and an overprediction of strong Arctic low patterns, strong Icelandic low patterns, and patterns with pronounced ridges spanning the Arctic Ocean. Resolution-caused differences are shown to be the result of CAM3 at T85 resolution predicting fewer strong Icelandic lows, North Atlantic lows, and strong high-pressure ridges across the Arctic relative to CAM3 at T42 resolution. In addition, CAM3 at T85 resolution predicts more strong Arctic low patterns relative to CAM3 at T42 resolution. The ability of CAM3 at both resolutions to resolve mesoscale features such as polar lows near the sea ice edge is also explored. Despite these biases, CAM3 can still be used experimentally to examine atmospheric response to changing climatic conditions, particularly if results are viewed in the framework of a sensitivity study. With this in mind, the impact of future projections of sea ice on winter Arctic circulation is examined at both model resolutions. It is found that weak Arctic low patterns and strong Icelandic low patterns increase in frequency in the winter, while Aleutian/Icelandic low patterns and North Atlantic low/Pacific high patterns decrease in frequency in the winter with future projections of sea ice.

Keen, K. A., Thayre, B. J., Hildebrand, J. A., & Wiggins, S. M. (2018). Seismic Airgun Sound Propagation in Arctic Ocean Waveguides. *Deep-Sea Research Part I-Oceanographic Research Papers,* 141, 24-32. https://doi.org/10.1016/j.dsr.2018.09.003

Underwater recordings of seismic airgun surveys in the deep-water Beaufort Sea and on the shallow-water Chukchi Sea shelf were made from sites on the continental slope and shelf break north-northwest of Point Barrow, Alaska. Airgun pulses from the deep-water survey were recorded more than 500 km away, and from the shallow-water survey up to similar to 100 km. In the deep-water, received sound pressure levels show spherical spreading propagation; whereas, sound exposure levels exhibit cylindrical spreading propagation. Over the shallow-water shelf, transmission losses were much greater than

spherical spreading, due to energy loss in the seafloor. Understanding how sound propagates across large spatial scales in the Arctic Ocean is important for better management and mitigation of anthropogenic noise pollution in marine soundscapes, especially as diminished ice in the Arctic Ocean allows for longer range sound propagation.

Mahoney, A. R., Eicken, H., Shapiro, L. H., Gens, R., Heinrichs, T., Meyer, F. J., & Gaylord, A. (2012). *Mapping and Characterization of Recurring Spring Leads and Landfast Ice in the Beaufort and Chukchi Seas.* Retrieved from https://marinecadastre.gov/espis/studies/study-7020.html

This project is the continuation and extension of an earlier project with the same title (MMS OCS Study 2005-068 active from 2004-2006) supported by the Minerals Management Service (MMS). MMS OCS STUDY 2005-068 was confined to the southern Beaufort Sea and eastern Chukchi Sea for the time period 1993-2004. The current project extends the study area to cover the entire Chukchi Sea and includes new data since 2004. The aim of this continuing study is to map and document the spatial and temporal distribution of recurring lead systems, coastal polynyas and landfast ice in the Beaufort and Chukchi Seas. The expanded study region encompasses a large portion of the northern coast of Alaska and parts of the Russian and Canadian coasts and extends the analysis into 2010.

Meier, W. N., Hovelsrud, G. K., van Oort, B. E. H., Key, J. R., Kovacs, K. M., Michel, C., . . . Reist, J. D. (2014). Arctic Sea Ice in Transformation: A Review of Recent Observed Changes and Impacts on Biology and Human Activity. *Reviews of Geophysics,* 52(3), 185-217. https://doi.org/10.1002/2013rg000431

Sea ice in the Arctic is one of the most rapidly changing components of the global climate system. Over the past few decades, summer areal extent has declined over 30%, and all months show statistically significant declining trends. New satellite missions and techniques have greatly expanded information on sea ice thickness, but many uncertainties remain in the satellite data and long-term records are sparse. However, thickness observations and other satellite-derived data indicate a 40% decline in thickness, due in large part to the loss of thicker, older ice cover. The changes in sea ice are happening faster than models have projected. With continued increasing temperatures, summer ice-free conditions are likely sometime in the coming decades, though there are substantial uncertainties in the exact timing and high interannual variability will remain as sea ice decreases. The changes in Arctic sea ice are already having an impact on flora and fauna in the Arctic. Some species will face increasing challenges in the future, while new habitat will open up for other species. The changes are also affecting people living and working in the Arctic. Native communities are facing challenges to their traditional ways of life, while new opportunities open for shipping, fishing, and natural resource extraction. Significant progress has been made in recent years in understanding of Arctic sea ice and its role in climate, the ecosystem, and human activities. However, significant challenges remain in furthering the knowledge of the processes, impacts, and future evolution of the system.

Nomura, D., Eicken, H., Gradinger, R., & Shirasawa, K. (2010). Rapid Physically Driven Inversion of the Air-Sea Ice Co2 Flux in the Seasonal Landfast Ice Off Barrow, Alaska after Onset of Surface Melt. *Continental Shelf Research,* 30(19), 1998-2004. https://doi.org/10.1016/j.csr.2010.09.014

The air-sea ice CO2 flux was measured over landfast sea ice in the Chukchi Sea, off Barrow, Alaska in late May 2008 with a chamber technique. The ice cover transitioned from a cold early spring to a warm late spring state, with an increase in air temperature and incipient surface melt. During melt, brine salinity and brine dissolved inorganic carbon concentration (DIC) decreased from 67.3 to 18.7 and 3977.6 to 1163.5 mu mol kg(-1), respectively. In contrast, the salinity and DIC of under-ice water at depths of 3 and 5 m below the ice surface remained almost constant with average values of 32.4 +/- 0.3 (standard deviation) and 2163.1 +/- 16.8 mu mol kg(-1), respectively. The air-sea ice CO2 flux decreased from +0.7 to -1.0 mmol m(-2) day(-1) (where a positive value indicates CO2 being released to the atmosphere from the ice surface). During this early to late spring transition, brought on by surface melt, sea ice shifted from a source to a sink for atmospheric CO2, with a rapid decrease of brine DIC likely associated with a decrease in the partial pressure of CO2 of brine from a supersaturated to an undersaturated state compared to the atmosphere. Formation of superimposed ice coincident with melt was not sufficient to shut down ice-air gas exchange.

Shroyer, E. L., & Pickart, R. S. (2019). Pathways, Timing, and Evolution of Pacific Winter Water through Barrow Canyon. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 162, 50-62. https://doi.org/10.1016/j.dsr2.2018.05.004

Observations from a ship-based campaign in July-August 2009, combined with idealized numerical simulations, are used to investigate the seasonal delivery of Pacific Winter Water to Barrow Canyon and the subsequent adjustment of the flow down the canyon. As the current advects dense water, it transitions from a nearly barotropic structure near the canyon head to a strongly baroclinic flow with a subsurface maximum near the canyon mouth. Both the data and model indicate that the transit times along the three Chukchi Shelf pathways feeding Barrow Canyon - a coastal pathway, a southern Hanna Shoal pathway, and a northern Hanna Shoal pathway modulate the mode of winter water that occupies the canyon at a given time. In particular, remnant Pacific Winter Water carried along the rapid coastal pathway can precede the arrival of newly ventilated Pacific Winter Water carried along the two interior pathways. The observations and model indicate that the transition between water types draining from the canyon can occur rapidly over time scales of days to weeks. We also demonstrate that mixing along the path of the current is unlikely to result in the observed down-canyon transition from newly ventilated Pacific Winter Water to remnant winter water, further supporting the dominant role of advection. While the focus here is on the transition of winter water modes, the implication that seasonality within Barrow Canyon is tied to seasonality of the Bering Strait inflow, together with the relative transit times along advective pathways, should hold for other water types as well.

Spall, M. A., Pickart, R. S., Li, M., Itoh, M., Lin, P. G., Kikuchi, T., & Qi, Y. Q. (2018). Transport of Pacific Water into the Canada Basin and the Formation of the Chukchi Slope Current. *Journal of Geophysical Research-Oceans,* 123(10), 7453-7471. https://doi.org/10.1029/2018jc013825

Plain Language Summary A high-resolution regional ocean model together with moored hydrographic and velocity measurements is used to identify the pathways and mechanisms by which Pacific water,

modified over the Chukchi shelf, crosses the shelf break into the Canada Basin. Most of the Pacific water flowing into the Arctic Ocean through Bering Strait enters the Canada Basin through Barrow Canyon. Strong advection allows the water to cross the shelf break and exit the shelf. Wind forcing plays little role in this process. Some of the outflowing water from Barrow Canyon flows to the east into the Beaufort Sea; however, approximately 0.4 to 0.5Sv turns to the west forming the newly identified Chukchi Slope Current. This transport occurs at all times of year, channeling both summer and winter waters from the shelf to the Canada Basin. The model indicates that approximately 75% of this water was exposed to the mixed layer within the Chukchi Sea, while the remaining 25% was able to cross the shelf during the stratified summer before convection commences in late fall. We view the O(0.5)Sv of the Chukchi Slope Current as replacing Beaufort Gyre water that would have come from the east in the absence of the cross-topography flow in Barrow Canyon. The weak eastward flow on the Beaufort slope is also consistent with the local disruption of the Beaufort Gyre by the Barrow Canyon outflow. Using a combination of numerical models and field observations, we elucidate where and when waters of Pacific Ocean origin cross the shelf break and enter the interior of the Canada Basin. Most of these waters flow toward the west, forming the recently observed Chukchi Slope Current.

Weingartner, T., Pickart, R. S., Winsor, P., Corlett, W. B., Dobbins, E. L., Fang, Y. C., . . . Stoudt, C. (2017). *Characterization of the Circulation on the Continental Shelf Areas of the Northeastern Chukchi and Western Beaufort Seas.* Retrieved from https://permanent.fdlp.gov/gpo89500/5653.pdf

This proposed study is a continuation and expansion of the existing surface circulation study within the northeast Chukchi Sea. Prior to 2009, surface current observations on the Chukchi shelf were extremely limited. Through a joint Industry/BOEM supported study, the University of Alaska Fairbanks (UAF), Coastal Marine Institute began measuring surface currents during the open water period on the Chukchi shelf beginning in September 2009 with the deployment of long range (180 km), High Frequency (HF) radar systems located at the villages of Barrow and Wainwright.

In 2010, coverage was expanded to the southwest to include additional offshore lease areas. The surface current data was supplemented by water column profile data collected by Slocum Gliders. Acoustic Doppler current profilers (ADCPs) were also deployed across the Alaska Coastal Current at the head of Barrow Canyon to assess the annual flow regime, the connectivity between surface and subsurface currents during the open water season, and the changes in subsurface currents beneath the mobile pack ice and lead system during the winter months. This new study will expand our present efforts to improve understanding of the flow regime and shelf dynamics between the inner and outer Chukchi shelf, the exchange of waters between the Chukchi Sea and western Beaufort shelf through Barrow Canyon, and the upwelling of Atlantic Waters.

Zhang, J. L., Ashjian, C., Campbell, R., Hill, V., Spitz, Y. H., & Steele, M. (2014). The Great 2012 Arctic Ocean Summer Cyclone Enhanced Biological Productivity on the Shelves. *Journal of Geophysical Research-Oceans,* 119(1), 297-312. https://doi.org/10.1002/2013jc009301

A coupled biophysical model is used to examine the impact of the great Arctic cyclone of early August 2012 on the marine planktonic ecosystem in the Pacific sector of the Arctic Ocean (PSA). Model results indicate that the cyclone influences the marine planktonic ecosystem by enhancing productivity on the shelves of the Chukchi, East Siberian, and Laptev seas during the storm. Although the cyclone's passage

in the PSA lasted only a few days, the simulated biological effects on the shelves last 1 month or longer. At some locations on the shelves, primary productivity (PP) increases by up to 90% and phytoplankton biomass by up to 40% in the wake of the cyclone. The increase in zooplankton biomass is up to 18% on 31 August and remains 10% on 15 September, more than 1 month after the storm. In the central PSA, however, model simulations indicate a decrease in PP and plankton biomass. The biological gain on the shelves and loss in the central PSA are linked to two factors. (1) The cyclone enhances mixing in the upper ocean, which increases nutrient availability in the surface waters of the shelves; enhanced mixing in the central PSA does not increase productivity because nutrients there are mostly depleted through summer draw down by the time of the cyclone's passage. (2) The cyclone also induces divergence, resulting from the cyclone's low-pressure system that drives cyclonic sea ice and upper ocean circulation, which transports more plankton biomass onto the shelves from the central PSA. The simulated biological gain on the shelves is greater than the loss in the central PSA, and therefore, the production on average over the entire PSA is increased by the cyclone. Because the gain on the shelves is offset by the loss in the central PSA, the average increase over the entire PSA is moderate and lasts only about 10 days. The generally positive impact of cyclones on the marine ecosystem in the Arctic, particularly on the shelves, is likely to grow with increasing summer cyclone activity if the Arctic continues to warm and the ice cover continues to shrink.

Section X: Beaufort Sea, Northern Bering Sea, Chukchi Sea

Biology

Huntington, H. P., Quakenbush, L. T., & Nelson, M. (2016). Effects of Changing Sea Ice on Marine Mammals and Subsistence Hunters in Northern Alaska from Traditional Knowledge Interviews. *Biology Letters,* 12(8). https://doi.org/10.1098/rsbl.2016.0198

Marine mammals are important sources of food for indigenous residents of northern Alaska. Changing sea ice patterns affect the animals themselves as well as access to them by hunters. Documenting the traditional knowledge of Inupiaq and Yupik hunters concerning marine mammals and sea ice makes accessible a wide range of information relevant to understanding the ecosystem to which humans belong. We interviewed hunters in 11 coastal villages from the northern Bering Sea to the Beaufort Sea. Hunters reported extensive changes in sea ice and weather that have affected the timing of marine mammal migrations, their distribution and behaviour and the efficacy of certain hunting methods. Amidst these changes, however, hunters cited offsetting technological benefits, such as more powerful and fuel-efficient outboard engines. Other concerns included potential impacts to subsistence hunting from industrial activity such as shipping and oil and gas development. While hunters have been able to adjust to some changes, continued environmental changes and increased disturbance from human activity may further challenge their ability to acquire food in the future. There are indications, however, that innovation and flexibility provide sources of resilience.

Moore, S. E., & Grebmeier, J. M. (2018). The Distributed Biological Observatory: Linking Physics to Biology in the Pacific Arctic Region. *Arctic,* 71(5). https://doi.org/10.14430/arctic4606

In response to dramatic seasonal sea ice loss and other physical changes influencing biological communities, a Distributed Biological Observatory (DBO) was proposed in 2009 as a "change detection array" to measure biological responses to physical variability along a latitudinal gradient extending from the northern Bering Sea to the Beaufort Sea in the Pacific Arctic sector. In 2010, the Pacific Arctic Group (PAG) initiated a pilot program, focused on developing standardized sampling protocols in five regions of high productivity, biodiversity, and rates of change. In 2012, an academic team received funding to sample all five DBOe regions, with collateral support from the Interagency Arctic Research Policy Committee (IARPC) DBO Collaboration Team. The IARPC team met monthly from 2012 to 2016 and advanced the DBO from a pilot phase to an implementation phase, including 1) the addition of three new sampling regions in the Beaufort Sea, 2) the goal of linking the observatory to existing community-based observation programs, and 3) the development of a plan for a periodic Pacific Arctic Regional Marine Assessment (PARMA) beginning in 2018. The long-term future of the DBO will depend on active involvement of international and national partners focused on the common goal of improved pan-Arctic assessments of regional marine ecosystems in an era of rapid change.

Quakenbush, L. T., Citta, J. J., George, J. C., Heide-Jrgensen, M. P., Brower, H., Harwood, L., . . . Lea, E. (2018). *Bering-Chukchi-Beaufort Stock of Bowhead Whales: 2006-2017 Satellie Telemetry Results with Some Observations on Stock Sub-Structure.* International Whaling Commission. Retrieved from http://www.adfg.alaska.gov/static/home/library/pdfs/wildlife/research_pdfs/quakenbush_et_al_2018_bowhead_whales.pdf

Sixty-four satellite transmitters provided data on bowhead whales from the Bering-ChukchiBeaufort (BCB) stock between 2006 and 2017 to study their movements and behavior. Sixtyone of which were tagged in the Beaufort Sea and three were tagged in the Bering Sea. In winter, bowhead whales used the western Bering Sea in areas of heavy ice with little use of open water areas. All but one tagged whale migrated past Point Barrow in spring and went to Amundsen Gulf. That whale migrated up the Chukotka coast and summered in the Chukchi Sea. While most whales summered within the Canadian Beaufort Sea, extensive summer movements included travel far to the north and northeast to overlap with bowhead whales from the Baffin Bay-Davis Strait stock. Other summer movements included trips between the Canadian Beaufort and Barrow and back again. One whale, tagged near Point Barrow, traveled to the northern coast of Chukotka, Russia, in the following summer, and did not return to Canada that summer. Fall movements coincided in space and time with oil and gas activities and potentially with shipping activities. Core-use areas that are likely important feeding areas included Amundsen Gulf in spring and summer; Tuktoyaktuk Shelf in summer; Point Barrow in summer and fall; the northern Chukotka coast in fall; and the western Bering Sea in winter. Recent changes in late summer movements (i.e., greater use of mid and western Beaufort Sea) and less use of previous core-use areas in the Bering Sea in winter that were largely ice-free in winter 2016/17 and 2017/18 have occurred and may become more common. None of the movements from tagged whales suggest a multi-stock condition exists within the BCB bowhead whale population.

Quakenbush, L. T., Small, R. J., & Citta, J. J. (2013). *Satellite Tracking of Bowhead Whales: Movement and Analysis from 2006 to 2012 Final Report.* Retrieved from https://www.adfg.alaska.gov/static/research/programs/marinemammals/pdfs/bowhead_2013_boem_final_report.pdf

Bowhead whales (Balaena mysticetus) are the most important species for many subsistence communities along the coasts of the Beaufort and Chukchi seas and for Bering Sea island communities for their nutritional and cultural importance. Bowhead whale summer and fall habitats coincide with areas of oil and gas activity and interest, therefore information is needed to better understand bowhead feeding areas and migration routes in order to plan lease sales, permit development activities, and design effective mitigation measures. Within a five-year (2006-2010) satellite telemetry study, we have combined satellite tag technology and the tag deployment skills of Native subsistence whalers to greatly increase our knowledge of bowhead whale movements and behavior in a relatively short period of time. During this study we provided information on the movements and timing of spring migration, rate of travel, ice conditions and use of leads along the spring migration route and at spring destinations. We also documented interactions with seismic operations and summer movements beyond the known range of the western Arctic stock of bowhead whales. We documented fall use of the Barrow area, fall migration behavior through Chukchi Lease Sale Area 193, and intensive use of the northern Chukotka coast as well as the timing and route into the Bering Sea for winter. Most tagged bowhead whales spent the winter in the western Bering Sea in heavy ice and did not commonly frequent polynyas, the marginal

ice zone, or near shore areas. Diving data indicated that bowheads dove frequently to the bottom in winter and may be feeding. This final report is for the subsequent 3-yr study (2010-2013) in which we have continued the cooperative efforts with Native subsistence whalers, the Alaska Eskimo Whaling Commission, the North Slope Borough, the Greenland Institute of Natural Resources, the Department of Fisheries and Oceans Canada, and the local Canadian Hunters and Trappers Associations to further describe the yearround movements and behavior of the western Arctic stock of bowhead whales. Specifically, we have expanded our sample sizes to better address summer movements, fall migration especially in the Beaufort Sea, and to further evaluate the inter-annual variability of feeding areas and migration routes. We also deployed an oceanographic tag to associate water temperature and salinity with bowhead diving behavior and we began tagging from St. Lawrence Island to lessen potential biases in our data due to tagging location. In addition to bowhead whales, we also tagged, biopsied, and photographed gray whales in the Bering and Chukchi seas to learn more about gray whale movements and use of the study area. During the eight years of these studies we have developed a solid working relationship with subsistence whalers and our other partners and we are prepared to continue this relationship for the next five years to learn more about bowhead whales by using oceanographic tags and by developing an acoustic tag that will add to our understanding of bowhead behavior relative to noise. We will also focus on the variability of movements from year to year and how bowhead whales interact with industrial activities.

Section XI: Bering Sea

Biology

Amoroso, R. O., Parma, A. M., Pitcher, C. R., McConnaughey, R. A., & Jennings, S. (2018). Comment on "Tracking the Global Footprint of Fisheries". *Science,* 361, eaat6713. https://doi.org/10.1126/science.aat6713

Kroodsma et al. (Reports, 23 February 2018, p. 904) mapped the global footprint of fisheries. Their estimates of footprint and resulting contrasts between the scale of fishing and agriculture are an artifact of the spatial scale of analysis. Reanalyses of their global (all vessels) and regional (trawling) data at higher resolution reduced footprint estimates by factors of >10 and >5, respectively.

Humphries, G. R. W., Huettmann, F., Nevitt, G. A., Deal, C., & Atkinson, D. (2012). Species Distribution Modeling of Storm-Petrels (Oceanodroma furcata and O. leucorhoa) in the North Pacific and the Role of Dimethyl Sulfide. *Polar Biology,* 35(11), 1669-1680. https://doi.org/10.1007/s00300-012-1207-2

Storm-petrels have been shown to use dimethyl sulfide (DMS) as a foraging cue, suggesting that this compound may be used to predict their distribution. We describe a new distribution model that employs machine learning software and geographic information systems to model storm-petrel distribution. We used environmental predictor variables that included newly available climatologies of sea surface DMS concentrations to construct distribution maps of fork-tailed storm-petrel (Oceanodroma furcata) and Leach's storm-petrel (O. leucorhoa) in the North Pacific and Bering Sea. Model accuracy was assessed by (1) using the area under the receiver operating characteristic curve (AUC) values and (2) comparing predicted distributions to presence and non-detection data from two opportunistic pelagic surveys performed in summer 2008. Models using all predictor variables gave AUC values of 0.89 and 0.75, sensitivity values of 0.73 and 0.61, and specificity values of 0.83 and 0.73 for fork-tailed and Leach's storm-petrel, respectively. Models using all predictor variables except DMS gave AUC values of 0.87 and 0.74, sensitivity values of 0.81 and 0.60, and specificity values of 0.77 for fork-tailed and Leach's storm-petrel, respectively. The large-scale link between DMS and how storm-petrels use it to locate foraging areas was reinforced by the partial dependence of DMS on the relative index of occurrence (RIO) of storm-petrels, and by a decrease in AUC values when removing DMS as a predictor. This work is a preliminary step toward linking seabird distribution to globally important infochemicals and should be a basis for further study.

Kalishevich, T. G. (2015). Early Paleogene Thermophilic Invertebrates from the Eastern Coast of Kamchatka and Sakhalin. *Paleontological Journal,* 49(4), 337-341. https://doi.org/10.1134/s0031030115040085

Thermophilic marine invertebrates appeared on the eastern coast of Kamchatka in the Early Paleogene and on the island of Sakhalin in the Paleocene. Some mollusks and solitary corals probably migrated from the coast of North America to the far eastern coast of Russia by a warm marine current as the

faunal assemblages of these areas contain some genera and even species in common. The warm marine current was protected from cold northern waters by the Bering Land, which was located between the Chukot Peninsula and Alaska. A new bivalve species, Gastrochaena beringiana sp. nov., is described.

Orlov, A. M., & Tokranov, A. M. (2010). Reanalysis of Long-Term Surveys on the Ecology and Biology of Mud Skate (Rhinoraja taranetzi Dolganov, 1985) in the Northwestern Pacific (1993-2002). *Journal of Applied Ichthyology,* 26(6), 861-871. https://doi.org/10.1111/j.1439-0426.2010.01512.x

Based on data sampled in 1992-2002, the occurrence, spatial distribution, bathymetry, bottom temperatures preferences, size composition, feeding, and some features of reproductive biology of mud skate Rhinoraja taranetzi in the Pacific waters off the northern Kuril Islands and southeastern Kamchatka are considered. Throughout the year, the mud skate was most abundant in the central part of the study area, from the coast of Onekotan Island to the southern tip of Kamchatka peninsula. The proportion of this species in bottom trawl catches in different seasons has changed slightly. However, maximum catch occurred in September-December. In April-May mud skates occupied shallower depths (mean 230-270 m), moving deeper in the summer period (mean 340-390 m). In December-March the skate occurred at lower bottom temperatures (mean 0.8-1.6 degrees C) whereas the rest of the year it inhabited warmer waters with mean bottom temperatures of 2.5-3.1 degrees C. Throughout the year decreasing body weight with depth was observed, indicating that adult and juvenile mud skates inhabit different depths. Total length of mud skates in catches ranged from 17 to 70 cm with a mean of 51.71 cm. Relation between total length (TL, cm) and body weight (W, g) was: W = 0.0029TL(3.1614) (r(2) - 0.978). Males were more abundant among small skates (< 30 cm) only, whereas females predominated among larger skates (> 30 cm) comprising about 70% in 60-70 cm length class. Female mud skates were longer and heavier than males (mean length 56.9 vs 51.2 cm and mean weight 1206 vs 807 g, respectively). This species is considered to be benthophagous, consuming mostly amphipods (34.9% by weight), polychaete worms (27.6%), decapod crustaceans (12.7%), and fishery discards (13.9%). Small skates (20-40 cm) fed mostly on amphipods (85.4%); medium-sized (40-60 cm) ate amphipods (40.2%), polychaetes (29.1%) and decapods (19.3%); the largest individuals (> 60 cm) consumed fishery offal (27.9%) and less amphipods (26.6%) and polychaetes (27.7%). Preliminary data on the maturation of the species in the western Bering Sea showed that males and females become mature at lengths above 61 cm TL.

Phillips, C. D., Gelatt, T. S., Patton, J. C., & Bickham, J. W. (2011). Phylogeography of Steller Sea Lions: Relationships among Climate Change, Effective Population Size, and Genetic Diversity. *Journal of Mammalogy,* 92(5), 1091-1104. https://doi.org/10.1644/10-mamm-a-305.1

The biology of the Steller sea lion (Eumetopias jubatus) has been the subject of intense scientific investigation. This is primarily due to the rapid decline of population size in the western part of the species' range since the 1970s and the subsequent Threatened and Endangered species listings that had direct impact on the management of one of the world's largest fisheries. The Steller sea lion has emerged as an indicator species representing the environmental health of the North Pacific Ocean and Bering Sea. In this study, to better understand the historical processes that have culminated in the extant populations of E. jubatus, a large genetic data set consisting of 3 mitochondrial regions for >1,000 individuals was analyzed from multiple phylogeographic and demographic perspectives. The results

describe the role of climate change in shaping the population structure of E. jubatus. Climatically associated historical processes apparently involved differential demographic responses to ice ages (and putative glacial vicariance) dependent on population size. Ice ages during times of small effective population size promoted restricted gene flow and fragmentation, and ice ages occurring during times of large population size promoted gene flow and dispersal. These results illustrate that effective population size has a profound effect on how species respond to climate change, an observation with obvious implications for large mammals and endangered species under the present conditions of imminent anthropogenically caused climate change. In addition, the results confirm previous observations of strongly biased historic and contemporary gene flow involving dispersal from west to east. Furthermore, phylogenetic patterns in combination with available fossil data suggest the potential of an Asian origin of E. jubatus. The results of this study provide a detailed scenario for the history that has shaped contemporary populations of E. jubatus.

Santora, J. A., Eisner, L. B., Kuletz, K. J., Ladd, C., Renner, M., & Hunt, G. L. (2018). Biogeography of Seabirds within a High-Latitude Ecosystem: Use of a Data-Assimilative Ocean Model to Assess Impacts of Mesoscale Oceanography. *Journal of Marine Systems,* 178, 38-51. https://doi.org/10.1016/j.jmarsys.2017.10.006

We assessed the biogeography of seabirds within the Bering Sea Large Marine Ecosystem (LME), a highly productive and extensive continental shelf system that supports important fishing grounds. Our objective was to investigate how physical ocean conditions impact distribution of seabirds along latitudinal gradients. We tested the hypothesis that seabird biogeographic patterns reflect differences in ocean conditions relating to the boundary between northern and southern shelf ecosystems. We used a grid-based approach to develop spatial means (1975-2014) of summertime seabird species' abundance, species' richness, and a multivariate seabird assemblage index to examine species composition. Seabird indices were linked to ocean conditions derived from a data-assimilative oceanographic model to quantify relationships between physics (e.g., temperature, salinity, and current velocity), bathymetry and seabirds along latitudinal gradients. Species assemblages reflected two main sources of variation, a mode for elevated richness and abundance, and a mode related to partitioning of inner/middle shelf species from outer shelf-slope species. Overall, species richness and abundance increased markedly at higher latitudes. We found that latitudinal changes in species assemblages, richness and abundance indicates a major shift around 59-60 degrees N within inner and middle shelf regions, but not in the outer shelf. Within the middle shelf, latitudinal shifts in seabird assemblages strongly related to hydrographic structure, as opposed to the inner and outer shelf waters. As expected, elevated species richness and abundance was associated with major breeding colonies and within important coastal foraging areas. Our study also indicates that seabird observations supported the conclusion that the oceanographic model captured mesoscale variability of ocean conditions important for understanding seabird distributions and represents an important step for evaluating modeling and empirical studies. Biogeographic assessments of LMEs that integrate top predator distributions resolve critical habitat requirements and will benefit assessment of climate change impacts (e.g., sea-ice loss) predicted to affect high-latitude marine ecosystems.

Sigler, M. F. (2008). Forecast Fish, Shellfish, and Coral Population Responses to Ocean Acidification in the North Pacific Ocean and Bering Sea : An Ocean Acidification Research Plan for the Alaska Fisheries Science Center. Retrieved from https://repository.library.noaa.gov/view/noaa/485

The North Pacific Ocean is a sentinel region for signs of ocean acidification. Approximately 30-50% of global anthropogenic carbon dioxide (CO2) emissions are absorbed by the world's oceans. Dissolving CO2 increases the hydrogen ion (H+) concentration in the ocean, and thus reduces ocean pH. Corrosive waters reach shallower depths more so there than in other ocean basins, especially in Alaska, and so biological impacts will likely occur earlier than in many other places. Ocean acidification reduces the calcium carbonate (CaCO3) saturation point, which stresses calcifying organisms by making calcification more difficult. The Alaska Fisheries Science Center research plan will focus on commercially important fish and shellfish species, their prey (calcareous plankton) and shelter (corals). Ocean acidification will likely impact the ability of marine calcifiers, such as corals and shellfish, to make shells and skeletons from CaCO3. Ocean acidification may also affect fish, marine mammal and seabird species through reduced abundance of calcareous plankton at the base of the food web. Species-specific studies of shellfish, calcareous plankton, corals and fish will be conducted to understand physiological effects (growth and survival). The CaCO3 content of calcareous organisms is not well known and a survey of shellfish, calcareous plankton and corals will be conducted to assess species vulnerabilities to ocean acidification. The results of the species-specific studies will be incorporated into population and ecosystem models to forecast population and ecosystem impacts. Bioeconomic models of Alaskan crab fisheries will be used to forecast fishery performance for a range of climate and ocean acidification scenarios.

Siwicke, K. A., & Seitz, A. C. (2015). Interpreting Lamprey Attacks on Pacific Cod in the Eastern Bering Sea. *Transactions of the American Fisheries Society,* 144(6), 1249-1262. https://doi.org/10.1080/00028487.2015.1067254

Adult anadromous lampreys attack several species targeted by large-scale commercial fisheries in the North Pacific Ocean, and the potential negative impact to these host fishes is not well understood. The Arctic Lamprey Lethenteron camtschaticum and Pacific Lamprey Entosphenus tridentatus are anadromous species that feed in the eastern Bering Sea, and lamprey parasitism is evident on Pacific Cod Gadus macrocephalus near the Bering Slope. To examine this parasitic interaction, we first built models using morphological measurements from lamprey oral discs to predict which lamprey species caused the observed wounds on Pacific Cod. We then examined lamprey wounding rates and explored healing patterns related to the severity and location of lamprey wounds. We scanned 8,746 Pacific Cod for lamprey wounds and found that 4.9% of the cod had at least one wound. Lamprey wound morphology was better predicted by an oral disk model built for Pacific Lamprey than by a similar model built for Arctic Lamprey. The occurrence of lamprey wounds that had penetrated muscle tissue but had not completely healed was more prevalent as Pacific Cod length increased. Generalized additive model results indicated that latitude and mean Pacific Cod length were important in predicting lamprey wounding rates at a sampling station. Recently inflicted lamprey wounds that penetrated Pacific Cod muscle tissue were observed four times as often as superficial wounds that did not penetrate muscle tissue, but superficial wounds were twice as likely to reach a completely healed state. No difference was detected in the likelihood of a lamprey wound to reach a completely healed state among different host body regions. While there is a potential for lamprey attacks to negatively affect individual host fish, we emphasize the importance of understanding population dynamics between native lampreys and their

hosts, as this could aid in explaining variations in the natural mortality of commercially important fish species in the eastern Bering Sea.

Ueda, H. (2011). Physiological Mechanism of Homing Migration in Pacific Salmon from Behavioral to Molecular Biological Approaches. *General and Comparative Endocrinology,* 170(2), 222-232. https://doi.org/10.1016/j.ygcen.2010.02.003

The amazing abilities of Pacific salmon to migrate long distances from the ocean to their natal streams for spawning have been investigated intensively since 1950's, but there are still many mysteries because of difficulties to follow their whole life cycle and to wait their sole reproductive timing for several years. In my laboratory, we have tried to clarify physiological mechanisms of homing migration in Pacific salmon, using four anadromous Pacific salmon (pink, Oncorhynchus gorbuscha; chum. Oncorhynchus keta; sockeye, Oncorhynchus nerka; masu, Oncorhynchus masou) in the north Pacific Ocean as well as two lacustrine salmon (sockeye and masu) in Lake Toya and Lake Shikotsu, Hokkaido, Japan, where the lakes serve as a model "ocean". Three different approaches from behavioral to molecular biological researches have been conducted using these model fish. First, the homing behaviors of adult chum salmon from the Bering Sea to Hokkaido as well as lacustrine sockeye and masu salmon in Lake Toya were examined by means of physiological biotelemetry techniques, and revealed that salmon can navigate in open water using different sensory systems. Second, the hormone profiles in the brain-pituitary-gonadal (BPG) axis were investigated in chum salmon and lacustrine sockeye salmon during their homing migration by means of hormone specific time-resolved fluoroimmunoassay (TR-FIA) systems, and clarified that salmon gonadotropin-releasing hormone (sGnRH) plays leading roles on homing migration. Third, the olfactory functions of salmon were studied by means of electrophysiological, behavioral, and molecular biological techniques, and made clear that olfactory discriminating ability of natal stream odors. These results have discussed with the evolutional aspects of four Pacific salmon, sexual differences in homing profiles, and the possibility of dissolved free amino acids (DFAA) as natal stream odors for salmon.

Vincenzi, S., & Mangel, M. (2013). Linking Food Availability, Body Growth and Survival in the Black-Legged Kittiwake *Rissa tridactyla*. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 94, 192-200. https://doi.org/10.1016/j.dsr2.2013.03.029

Population dynamics of black-legged kittiwakes Rissa tridactyla in Bering Sea colonies are likely to increasingly experience climate-induced changes in the physical environment. Since adult kittiwakes are central place foragers with high energy requirements, increased variability of forage patch dynamics, as predicted for polar regions, may influence both quantity and quality of food available and consequently alter the population dynamics of kittiwake colonies. Here, we describe, conceptualize, and model the effects of environment and energy resources on kittiwake growth, fledging age (from 35 to 50 days) and survival from hatching up to first breeding (post-hatching productivity). For our life-history model, we use a von Bertalanffy growth function for body growth in mass. We model nestling mortality as a function of somatic growth, in order to account for oxidative damage and trade-offs in the allocation of resources, and energy available, since low food availability increases the risk of chicks' starvation and predation risk. In the case of a good environment (i.e., high food availability), the best strategy (i.e., highest post-hatching productivity) is to grow fast (about 18.6 g d(-1)) and to spend a moderately long

time in the nest (up to 45 days), while in the case of a poor environment the best strategy is to grow fast (about 18 g d(-1)) and leave the nest soon (35-40 days). Different ages at first breeding do not change the optimal strategies. We discuss the implications of optimal growth strategy in terms of evolution of life histories in kittiwakes and how our work, coupled with models of post-breeding survival and reproductive dynamics, could lead to the development of a full life-history model and the exploration of future evolutionary trajectories for traits like body growth and age at first breeding.

Volvenko, I. V. (2012). The Multidimensional Space of the Integral Characteristics of Biocenotic Assemblages: The Self-Similarity or Scale Invariance of Its Structure. *Russian Journal of Marine Biology,* 38(7), 509-519. https://doi.org/10.1134/s1063074012070061

In a virtual multidimensional space whose coordinate axes are integral characteristics, such as logarithms of the abundance and size of individuals, as well as the components of species diversity, the points that correspond to samples from various biocenotic assemblages form multilayered geometric figures of a similar shape. As was shown based on examples of pelagic macrofauna in the Bering Sea, Sea of Okhotsk, Sea of Japan, and adjacent waters of the Pacific Ocean, as well as phytoplankton, zooplankton, and zoobenthos in Lake Ladoga, Neva Bay, and the Gulf of Finland in the Baltic Sea, these figures possess some properties of fractals. This phenomenon results from the multidimensional domain of the integral characteristics, in which a multitude of points is aggregated along a segment, whose length and orientation relative to the coordinate axes reflects universal power laws at the biocenotic level of the organization of matter; power laws, such as y = a center dot x (b) , are known to be an unlimited source of self-similarity and scale invariance.

Chemistry

Mathis, J. T., Cross, J. N., & Bates, N. R. (2011). Coupling Primary Production and Terrestrial Runoff to Ocean Acidification and Carbonate Mineral Suppression in the Eastern Bering Sea. *Journal of Geophysical Research: Oceans,* 116(C2). https://doi.org/10.1029/2010JC006453

Water column pH and carbonate mineral saturation states were calculated from dissolved inorganic carbon (DIC) and total alkalinity data collected over the eastern Bering Sea shelf in the spring and summer of 2008. The saturation states (Ω) of the two most important carbonate minerals, calcite (Ωcalcite) and aragonite (Ωaragonite) were strongly coupled to terrestrial runoff from the Yukon and Kuskokwim rivers, primary production in the surface waters, and remineralization of organic matter at depth over the shelf. In spring, before ice melt occurred, pH over the shelf was largely confined to a range of 7.9?8.1 and Ωcalcite and Ωaragonite ranged from 1.5 to 3.0 and 0.8 to 2.0, respectively. At the stations closest to river outflows, aragonite was undersaturated in the water column from the surface to the bottom. During the summer sea ice retreat, high rates of primary production consumed DIC in the mixed layer, which increased pH and Ωcalcite and Ωaragonite. However, Ωcalcite and Ωaragonite decreased by ?0.3 in the bottom waters over the middle and outer shelf. Over the northern shelf, where export production is highest, Ωaragonite decreased by ?0.35 and became highly undersaturated. The observed suppression and undersaturation of Ωcalcite and Ωaragonite in the eastern Bering Sea are correlated with anthropogenic carbon dioxide uptake into the ocean and will likely be exacerbated

under business-as-usual emission scenarios. Therefore, ocean acidification could threaten some benthic and pelagic calcifying organisms across the Bering Sea shelf in the coming decades.

Song, X. L., Bai, Y., Cai, W. J., Chen, C. T. A., Pan, D. L., He, X. Q., & Zhu, Q. K. (2016). Remote Sensing of Sea Surface Pco(2) in the Bering Sea in Summer Based on a Mechanistic Semi-Analytical Algorithm (MeSAA). *Remote Sensing,* 8(7). https://doi.org/10.3390/rs8070558

The Bering Sea, one of the largest and most productive marginal seas, is a crucial carbon sink for the marine carbonate system. However, restricted by the tough observation conditions, few underway datasets of sea surface partial pressure of carbon dioxide (pCO(2)) have been obtained, with most of them in the eastern areas. Satellite remote sensing data can provide valuable information covered by a large area synchronously with high temporal resolution for assessments of pCO(2) that subsequently allow quantification of air-sea carbon dioxide 2 flux. However, pCO(2) in the Bering Sea is controlled by multiple factors and thus it is hard to develop a remote sensing algorithm with empirical regression methods. In this paper pCO(2) in the Bering Sea from July to September was derived based on a mechanistic semi-analytical algorithm (MeSAA). It was assumed that the observed pCO(2) can be analytically expressed as the sum of individual components controlled by major factors. First, a reference water mass that was minimally influenced by biology and mixing was identified in the central basin, and then thermodynamic and biological effects were parameterized for the entire area. Finally, we estimated pCO(2) with satellite temperature and chlorophyll data. Satellite results agreed well with the underway observations. Our study suggested that throughout the Bering Sea the biological effect on pCO(2) was more than twice as important as temperature, and contributions of other effects were relatively small. Furthermore, satellite observations demonstrate that the spring phytoplankton bloom had a delayed effect on summer pCO(2) but that the influence of this biological event varied regionally; it was more significant on the continental slope, with a later bloom, than that on the shelf with an early bloom. Overall, the MeSAA algorithm was not only able to estimate pCO(2) in the Bering Sea for the first time, but also provided a quantitative analysis of the contribution of various processes that influence pCO(2).

Geology

Ager, T. A., & Phillips, R. L. (2008). Pollen Evidence for Late Pleistocene Bering Land Bridge Environments from Norton Sound, Northeastern Bering Sea, Alaska. *Arctic, Antarctic, and Alpine Research,* 40(3), 451-461. https://doi.org/10.1657/1523-0430(07-076)[ager]2.0.Co;2

After more than half a century of paleoenvironmental investigations, disagreements persist as to the nature of vegetation type and climate of the Bering land bridge (BLB) during the late Wisconsin (Sartan) glacial interval. Few data exist from sites on the former land bridge, now submerged under the Bering and Chukchi Seas. Two hypotheses have emerged during the past decade. The first, based on pollen data from Bering Sea islands and adjacent mainlands of western Alaska and Northeast Siberia, represents the likely predominant vegetation on the Bering land bridge during full-glacial conditions: graminoid-herb-willow tundra vegetation associated with cold, dry winters and cool, dry summer climate. The second hypothesis suggests that dwarf birch-shrub-herb tundra formed a broad belt across the BLB, and that mesic vegetation was associated with cold, snowier winters and moist, cool summers. As a step towards

resolving this controversy, a sediment core from Norton Sound, northeastern Bering Sea was radiocarbon dated and analyzed for pollen content. Two pollen zones were identified. The older, bracketed by radiocarbon ages of 29,500 and 11,515 14C yr BP, contains pollen assemblages composed of grass, sedge, wormwood, willow, and a variety of herb (forb) taxa. These assemblages are interpreted to represent graminoid-herb-willow tundra vegetation that developed under an arid, cool climate regime. The younger pollen zone sediments were deposited about 11,515 14C yr BP, when rising sea level had begun to flood the BLB. This younger pollen zone contains pollen of birch, willow, heaths, aquatic plants, and spores of sphagnum moss. This is interpreted to represent a Lateglacial dwarf birch-heath-willow-herb tundra vegetation, likely associated with a wetter climate with deeper winter snows, and moist, cool summers. This record supports the first hypothesis, that graminoid-herb-willow tundra vegetation extended into the lowlands of the BLB during full glacial conditions of the late Wisconsin.

Derkachev, A. N., Ponomareva, V. V., Portnyagin, M. V., Gorbarenko, S. A., Nikolaeva, N. A., Malakhov, M. I., . . . Liu, Y. G. (2018). Widespread Tephra Layers in the Bering Sea Sediments: Distal Clues to Large Explosive Eruptions from the Aleutian Volcanic Arc. *Bulletin of Volcanology,* 80(11). https://doi.org/10.1007/s00445-018-1254-9

Tephra layers within marine sediments provide information on past explosive eruptions, which is especially important in the case of remote island arcs where data on proximal pyroclastic deposits can be scarce. Three Alaska-Aleutian tephras (labeled Br2, SR2, and SR4) were found in the late Pleistocene-Holocene sediments of the Bering Sea (north Pacific). We fingerprint glass from these tephras with the help of single-shard electron microprobe and LA-ICP-MS analyses and provide microprobe data on minerals from two of these tephras. The large compositional variability of the Alaska-Aleutian volcanoes permits the use of ratios of highly incompatible trace elements (Ba/Nb, Th/Nb, Th/La, La/Nb) for identification of distal tephra sources by comparison of these ratios in tephra glass and proximal bulk rock analyses. This method, along with mapped tephra dispersal, has allowed us to link tephras under study to Aniakchak, Semisopochnoi, and Okmok volcanoes, respectively. Our results indicate that tephra Br2 was derived from the 3.6ka Aniakchak II caldera-forming eruption (Alaska, USA). This is the first ever finding of the Aniakchak II tephra in Bering Sea sediments, which permits enlargement of its tephra volume and eruption magnitude to 100km(3) and 6.8, respectively. Tephra SR2, dated at 12.2ka, is likely associated with a post-glacial caldera on the Semisopochnoi Island, Aleutians (USA). Tephra SR4 (dated at 64.5ka), likely was derived from an earlier undocumented eruption from Okmok volcano (Aleutians). All three regionally spread tephra layers are valuable isochrones, which can be used for correlating and dating of Bering Sea sediments.

Zimmermann, M., & Prescott, M. (2018). Bathymetry and Canyons of the Eastern Bering Sea Slope. *Geosciences,* 8(5). https://doi.org/10.3390/geosciences8050184

We created a new, 100 m horizontal resolution bathymetry raster and used it to define 29 canyons of the eastern Bering Sea (EBS) slope area off of Alaska, USA. To create this bathymetry surface we proofed, edited, and digitized 18 million soundings from over 200 individual sources. Despite the vast size (~1250 km long by ~3000 m high) and ecological significance of the EBS slope, there have been few hydrographic-quality charting cruises conducted in this area, so we relied mostly on uncalibrated underway files from cruises of convenience. The lack of hydrographic quality surveys, anecdotal reports

of features such as pinnacles, and reliance on satellite altimetry data has created confusion in previous bathymetric compilations about the details along the slope, such as the shape and location of canyons along the edge of the slope, and hills and valleys on the adjacent shelf area. A better model of the EBS slope will be useful for geologists, oceanographers, and biologists studying the seafloor geomorphology and the unusually high productivity along this poorly understood seafloor feature.

Marine Culture Heritage

Dixon, J. E., & Monteleone, K. (2014). Gateway to the Americas: Underwater Archeological Survey in Beringia and the North Pacific. In *Prehistoric Archaeology on the Continental Shelf.* A. Evans, J. Flatman, & N. Flemming (Eds.). New York, NY: Springer https://doi.org/10.1007/978-1-4614-9635-9_6

Understanding the archaeology of the Bering Land Bridge and adjacent regions is essential to reconstruct past cultural relationships and exchanges between Asia and North America. It is in this region the two continents come closest together, and where they were connected in the past by a land bridge. During the last Ice Age when sea level was lower, plants, animals, and people inhabited the continental shelves that are now below sea level. Beneath the cold ocean water is a “lost world” that may contain the tangible evidence of ancient human habitation. However, underwater archaeology in this vast area is preliminary with only three scientific studies conducted in 35 years. Since the first underwater survey was conducted in the Bering Sea in 1976 (Dixon, A predictive model for the distribution of archaeological sites on the Bering Continental Shelf, 1979), there have been significant improvements in technology, geologic data essential for modeling, and navigational aids for underwater archaeological survey.

Physics

Ladd, C., Stabeno, P. J., & O'Hern, J. E. (2012). Observations of a Pribilof Eddy. *Deep-Sea Research Part I-Oceanographic Research Papers,* 66, 67-76. https://doi.org/10.1016/j.dsr.2012.04.003

Eddies along the eastern shelf-break of the Bering Sea play an important role in the physics, chemistry, and biology of the region. Eddy activity in this region is particularly strong near the major shelf-break canyons during the spring months, likely influencing the spring bloom. Spring eddy activity is negatively correlated with the North Pacific Index, a measure of the strength of the Aleutian Low. A strong Aleutian Low (negative NPI) is related to a strong sub-polar gyre, suggesting that spin-up of the gyre results in more eddy activity in this region. In situ data from an eddy sampled near Pribilof Canyon in 1997 suggest that these eddies can carry water from the outer shelf into the basin. Drifters rotating around the eddy at different radii exhibited differing rotation periods suggesting that the eddy was not rotating in solid body rotation. Thus horizontal exchange of water within the eddy may result in the excess nutrients and fresher water within the core of the eddy exchanging with the basin over time, influencing chlorophyll-a distributions throughout the summer months.

Section XII: Bering Sea, Chukchi Sea

Biology

Chernova, N. V., Voskoboinikova, O. S., Kudryavtseva, O. Y., Orlova, S. Y., Maznikova, O. A., & Orlov, A. M. (2019). Taxonomic Status of the Okhotsk Lumpsucker *Eumicrotremus ochotonensis* (Cyclopteridae, Cottoidei) with Redescription of *E. derjugini*. *Journal of Ichthyology,* 59(3), 289-306. https://doi.org/10.1134/s0032945219030032

The species status is justified for the Okhotsk lumpsucker Eumicrotremus ochotonensis based on the morphological characters. The differences from the closely related species E. derjugini inhabiting the Arctic Ocean are given. Two species were redescribed basing on type series, their diagnoses were clarified, and the lectotypes were designated. Intraspecific variability is discussed using new materials from the Barents, Kara, Laptev, and Okhotsk seas. The two species differ markedly in a complex of morphological features (shape of the submerged dorsal fin, proportions of the body, number and location of bony plaques) and characteristics of biology (spawning season). The modern disjunction of the ranges of E. ochotonensis and E. derjugini covers the Bering, East Siberian, and Chukchi seas. Sequence analysis of the cytochrome oxidase (COI) gene fragment of mtDNA revealed differences in the haplotypic diversity of the two species. Weak genetic divergence between species indicates a relatively recent isolation of E. derjugini and confirms its status of the evolutionary young species.

Oxtoby, L. E., Horstmann, L., Budge, S. M., O'Brien, D. M., Wang, S. W., Schollmeier, T., & Wooller, M. J. (2017). Resource Partitioning between Pacific Walruses and Bearded Seals in the Alaska Arctic and Sub-Arctic. *Oecologia,* 184(2), 385-398. https://doi.org/10.1007/s00442-017-3883-7

Climate-mediated changes in the phenology of Arctic sea ice and primary production may alter benthic food webs that sustain populations of Pacific walruses (Odobenus rosmarus divergens) and bearded seals (Erignathus barbatus). Interspecific resource competition could place an additional strain on ice-associated marine mammals already facing loss of sea ice habitat. Using fatty acid (FA) profiles, FA trophic markers, and FA stable carbon isotope analyses, we found that walruses and bearded seals partitioned food resources in 2009-2011. Interspecific differences in FA profiles were largely driven by variation in non-methylene FAs, which are markers of benthic invertebrate prey taxa, indicating varying consumption of specific benthic prey. We used Bayesian multi-source FA stable isotope mixing models to estimate the proportional contributions of particulate organic matter (POM) from sympagic (ice algal), pelagic, and benthic sources to these apex predators. Proportional contributions of FAs to walruses and bearded seals from benthic POM sources were high [44 (17-67)% and 62 (38-83)%, respectively] relative to other sources of POM. Walruses also obtained considerable contributions of FAs from pelagic POM sources [51 (32-73)%]. Comparison of delta C-13 values of algal FAs from walruses and bearded seals to those from benthic prey from different feeding groups from the Chukchi and Bering seas revealed that different trophic pathways sustained walruses and bearded seals. Our findings suggest that (1) resource partitioning may mitigate interspecific competition, and (2) climate change impacts on Arctic food webs may elicit species-specific responses in these high trophic level consumers.

Stone, R. P., Lehnert, H., & Hoff, G. R. (2019). Inventory of the Eastern Bering Sea Sponge Fauna, Geographic Range Extensions and Description of Antho Ridgwayi Sp. Nov. *Zootaxa,* 4567(2). https://doi.org/10.11646/zootaxa.4567.2.2

A total of 493 sponges were collected with a bottom trawl during annual groundfish stock assessment surveys in the eastern Bering Sea in 2013, 2015, and 2016 to build an inventory of species in this largely unexplored region. We report here principally on the demosponge fauna collected during those surveys because identifications of hexactinellids are incomplete. We identified 42 unique demosponge taxa from the collection including geographical range extensions for 30 species; seven are new records for the Pacific Ocean. The collection also included three species new to science; two have been previously described (Plicatellopsis borealis Lehnert Stone 2017, Spongosorites beringensis Lehnert Stone 2017) and Antho ridgwayi sp. nov. described here. The new species differed from all northern hemisphere congeners in the complements and sizes of spicules. We document that the region is more species rich than previously suspected, particularly the continental slope where the majority of hexactinellid sponges are located.

Chemistry

Huang, D. K., Lin, J., Du, J. Z., & Yu, T. (2020). The Detection of Fukushima-Derived Radiocesium in the Bering Sea and Arctic Ocean Six Years after the Nuclear Accident. *Environmental Pollution,* 256, 7. https://doi.org/10.1016/j.envpol.2019.113386

After the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident, radionuclides released by this event were observed in the Pacific Ocean. Models predicted that these radionuclides would be transported to the Bering Sea; however, limited evidence currently reveals the transportation of these radionuclides to the Arctic Ocean. Here, we provide the first direct observation showing that FDNPP-derived Cs-134 and Cs-137 were present in subarctic regions and the Arctic Ocean (Chukchi Sea) in 2017. Furthermore, we conclude that these radionuclides were transported from the Pacific Ocean into the Bering and Chukchi Seas by ocean currents. Additionally, the Cs-137 activity concentrations in the Bering Sea exceed those in all previous reports. Due to the continuous leaking of radionuclides from the FDNPP, we hypothesize that FDNPP-derived radionuclides will be continuously transported to the Arctic Ocean in the next several years. Our results suggest that though far away from Fukushima, the accident-derived anthropogenic radionuclides also influenced the Arctic Ocean by ocean currents.

Physics

Danielson, S. L., Weingartner, T. J., Hedstrom, K. S., Aagaard, K., Woodgate, R., Curchitser, E., & Stabeno, P. J. (2014). Coupled Wind-Forced Controls of the Bering-Chukchi Shelf Circulation and the Bering Strait Throughflow: Ekman Transport, Continental Shelf Waves, and Variations of the Pacific-Arctic Sea Surface Height Gradient. *Progress in Oceanography,* 125, 40-61. https://doi.org/10.1016/j.pocean.2014.04.006

We develop a conceptual model of the closely co-dependent Bering shelf, Bering Strait, and Chukchi shelf circulation fields by evaluating the effects of wind stress over the North Pacific and western Arctic using atmospheric reanalyses, current meter observations, satellite-based sea surface height (SSH)

measurements, hydrographic profiles, and numerical model integrations. This conceptual model suggests Bering Strait transport anomalies are primarily set by the longitudinal location of the Aleutian Low, which drives oppositely signed anomalies at synoptic and annual time scales. Synoptic time scale variations in shelf currents result from local wind forcing and remotely generated continental shelf waves, whereas annual variations are driven by basin scale adjustments to wind stress that alter the magnitude of the along-strait (meridional) pressure gradient. In particular, we show that storms centered over the Bering Sea excite continental shelf waves on the eastern Bering shelf that carry northward velocity anomalies northward through Bering Strait and along the Chukchi coast. The integrated effect of these storms tends to decrease the northward Bering Strait transport at annual to decadal time scales by imposing cyclonic wind stress curl over the Aleutian Basin and the Western Subarctic Gyre. Ekman suction then increases the water column density through isopycnal uplift, thereby decreasing the dynamic height, sea surface height, and along-strait pressure gradient. Storms displaced eastward over the Gulf of Alaska generate an opposite set of Bering shelf and Aleutian Basin responses. While Ekman pumping controls Canada Basin dynamic heights (Proshutinsky et al., 2002), we do not find evidence for a strong relation between Beaufort Gyre sea surface height variations and the annually averaged Bering Strait throughflow. Over the western Chukchi and East Siberian seas easterly winds promote coastal divergence, which also increases the along-strait pressure head, as well as generates shelf waves that impinge upon Bering Strait from the northwest.

Kaltin, S., & Anderson, L. G. (2005). Uptake of Atmospheric Carbon Dioxide in Arctic Shelf Seas: Evaluation of the Relative Importance of Processes That Influence PCO(2) in Water Transported over the Bering-Chukchi Sea Shelf. *Marine Chemistry,* 94(1-4), 67-79. https://doi.org/10.1016/j.marchem.2004.07.010

The uptake of atmospheric carbon dioxide in the water transported over the Bering-Chukchi shelves has been assessed from the change in carbon-related chemical constituents. The calculated uptake of atmospheric CO2 from the time that the water enters the Bering Sea shelf until it reaches the northern Chukchi Sea shelf slope (similar to 1 year) was estimated to be 86 +/- 22 g C m(-2) in the upper 100 m. Combining the average uptake per m(3) with a volume flow of 0.83 x 10(6) m(3) s(-1) through the Bering Strait yields a flux of 22x10(12) g C year(-1). We have also estimated the relative contribution from cooling, biology, freshening, CaCO3 dissolution, and denitrification for the modification of the seawater PCO2 over the shelf The latter three had negligible impact on PCO2 compared to biology and cooling. Biology was found to be almost twice as important as cooling for lowering the pCO(2) in the water on the Bering-Chukchi shelves. Those results were compared with earlier surveys made in the Barents Sea, where the uptake of atmospheric CO2 was about half that estimated in the Bering-Chukchi Seas. Cooling and biology were of nearly equal significance in the Barents Sea in driving the flux Of CO2 into the ocean. The differences between the two regions are discussed. The loss of inorganic carbon due to primary production was estimated from the change in phosphate concentration in the water column. A larger loss of nitrate relative to phosphate compared to the classical Delta N/Delta P ratio of 16 was found. This excess loss was about 30% of the initial nitrate concentration and could possibly be explained by denitrification in the sediment of the Bering and Chukchi Seas.

Section XIII: Central Gulf of Alaska

Biology

Abookire, A. A. (2006). Reproductive Biology, Spawning Season, and Growth of Female Rex Sole (Glyptocephalus zachirus) in the Gulf of Alaska. *Fishery Bulletin,* 104(3), 350-359. Retrieved from https://spo.nmfs.noaa.gov/content/reproductive-biology-spawning-season-and-growth-female-rex-sole-glyptocephalus-zachirus-gulf

Rex sole (Glyptocephalus zachirus) have a wide distribution throughout the North Pacific, ranging from central Baja California to the western Bering Sea. Although rex sole are an important species in the commercial trawl fisheries off the U.S. West Coast, knowledge of their reproductive biology is limited to one study off the Oregon coast where ovaries were analyzed with gross anatomical methods. This study was initiated to determine reproductive and growth parameters specific to rex sole in the Gulf of Alaska (GOA) stock. Female rex sole (n=594) ranging in total length from 166 to 552 mm were collected opportunistically around Kodiak Island, Alaska, from February 2000 to October 2001. All ovaries were analyzed by using standard histological criteria to determine the maturity stage. Year-round sampling of rex sole ovaries confirmed that rex sole are batch spawners and have a protracted spawning season in the GOA that lasts at least eight months, from October to May; the duration of the spawning season and the months of spawning activity are different from those previously estimated. Female rex sole in the GOA had an estimated length at 50% maturity (ML50) of 352 mm, which is greater than the previously estimated ML50 at southern latitudes. The maximum age of collected female rex sole was 29 years, and the estimated age at 50% maturity (MA(50)) in the GOA was 5.1 years. The von Bertalanffy growth model for rex sole in the GOA was significantly different from the previously estimated model for rex sole off the Oregon coast. This study indicated that there are higher growth rates for rex sole in the GOA than off the Oregon coast and that there are differences in length at maturity and similarity in age at maturity between the two regions.

Abookire, A. A., & Bailey, K. M. (2007). The Distribution of Life Cycle Stages of Two Deep-Water Pleuronectids, Dover Sole (Microstomus pacificus) and Rex Sole (Glyptocephalus zachirus), at the Northern Extent of Their Range in the Gulf of Alaska. *Journal of Sea Research,* 57(2-3), 198-208. https://doi.org/10.1016/j.seares.2006.08.004

Dover sole (Microstomus pacificus) and rex sole (Glyptocephalus zachirus) are both commercially valuable, long-lived pleuronectids that are distributed widely throughout the North Pacific. While their ecology and life cycle have been described for southern stocks, few investigations have focused on these species at higher latitudes. We synthesized historical research survey data among critical developmental stages to determine the distribution of life cycle stages for both species in the northern Gulf of Alaska (GOA). Bottom trawl survey data from 1953 to 2004 (25 519 trawls) were used to characterize adult distribution during the nonspawning and spawning seasons, ichthyoplankton data from 1972 to 2003 (10776 tows) were used to determine the spatial and vertical distribution of eggs and larvae, and small-meshed shrimp trawl survey data from 1972 to 2004 (6536 trawls) were used to characterize areas utilized by immature stages. During the non-spawning season, adult Dover sole and rex sole were widely distributed from the inner shelf to outer slope. While both species concentrated on the continental

slope to spawn, Dover sole spawning areas were more geographically specific than rex sole. Although spawned in deep water, eggs of both species were found in surface waters near spawning areas. Dover sole larvae did not appear to have an organized migration from offshore spawning grounds toward coastal nursery areas, and our data indicated facultative settling to their juvenile habitat in winter. Rex sole larvae progressively moved cross-shelf toward shore as they grew from April to September, and larvae presumably settled in coastal nursery areas in the autumn. In contrast with studies in the southern end of their range, we found no evidence in the GOA that Dover or rex sole have pelagic larval stages longer than nine months;, however, more sampling for large larvae is needed in winter offshore of the continental shelf as well as sampling for newly settled larvae over the shelf to verify an abbreviated pelagic larval stage for both species at the northern end of their range..

Abookire, A. A., & Macewicz, B. J. (2003). Latitudinal Variation in Reproductive Biology and Growth of Female Dover Sole (Microstomus pacificus) in the North Pacific, with Emphasis on the Gulf of Alaska Stock. *Journal of Sea Research,* 50(2-3), 187-197. https://doi.org/10.1016/s1385-1101(03)00062-5

Dover sole (Microstomus pacificus) have a wide distribution throughout the North Pacific, ranging from southern Baja California (26degreesN) to the Gulf of Alaska (GOA, 59degreesN). Prior to this study, our understanding of Dover sole reproductive biology was limited to the stock off the US west coast. This study was initiated to determine the length and age at maturity for Dover sole in the GOA. We also compared the length at maturity and growth rate across latitudes to test the hypothesis that individuals near the northern extent of their range (GOA stock) mature at a larger size than individuals in the southern stock off California and Oregon. Female Dover sole (n = 273) ranging in length from 198-663 mm were collected opportunistically around Kodiak Island, Alaska, (55-59degreesN) from February 2000 to October 2001, with sampling concentrated in the months February-April, June-July, and October-November. All ovaries were examined to determine the maturity stage using standard histological criteria. The spawning season of Dover sole in the GOA spanned at least 4 months, from February to May. Dover sole in the GOA matured at a larger size than those off California and Oregon, with an estimated length at 50% maturity (ML50) of 439 mm. At the same fish length that nearly 100% of Dover sole from California and Oregon waters are mature, Dover sole in the GOA are just beginning to mature. The estimated age at 50% maturity (MA(50)) for female Dover sole in the GOA was 6.7 years and was similar to the MA(50) for cohorts at more southern latitudes. We attribute the latitudinal variation in ML50, combined with the similar MA(50) across latitudes, to spatial differences in growth rates.

Bailey, K. M., Ciannelli, L., Bond, N. A., Belgrano, A., & Stenseth, N. C. (2005). Recruitment of Walleye Pollock in a Physically and Biologically Complex Ecosystem: A New Perspective. *Progress in Oceanography,* 67(1-2), 24-42. https://doi.org/10.1016/j.pocean.2005.06.001

Walleye pollock (Theragra chalcogramma) is a commercially important marine fish in the Gulf of Alaska that has provided a natural experimental system to study many features of the recruitment process. We review recruitment of pollock in the Gulf of Alaska in the conceptual framework of a complex system. In this perspective, high frequency, or activating, events during egg and larval life introduce variability to the dynamics of the population, whereas lower frequency constraining processes tend to promote broader patterns. This view is supported by both simple population and complex statistical models that

capture the trends and general patterns in the time series of recruitment. Consequences of this view of recruitment are discussed in terms of forecasting strategies.

Castellote, M., Small, R. J., Mondragon, J., Jenniges, J., & Skinner, J. (2016). *Seasonal Distribution of Foraging Behavior of Cook Inlet Belugas Based on Acoustic Monitoring.* Retrieved from https://repository.library.noaa.gov/view/noaa/17323

Information on the seasonal distribution and foraging behavior of beluga whales in Cook Inlet, Alaska, was obtained through passive acoustic monitoring during 2008-2013, at the following 13 locations: North Eagle Bay, Eagle River Mouth, South Eagle Bay, Six Mile, Point MacKenzie, Cairn Point, Fire Island, Little Susitna, Beluga River, Trading Bay, Kenai River, Tuxedni Bay, and Homer Spit. At each location, custom designed low-profile acoustic moorings were deployed, each with an Ecological Acoustic Recorder (EAR), which monitored for the low frequency (0-12.5 kHz) beluga social signals, and a Cetacean and Porpoise Detector (C-POD) that monitored higher frequency (20-160 kHz) beluga echolocation signals. Monitoring both social and echolocation signals maximized beluga detections, which we summarized within two seasons based on the ice phenology in Cook Inlet: 'summer', the ice-free period of May to October; and 'winter', the freezing to melting period of November to April.

Coletti, H. A., Bodkin, J. L., Monson, D. H., Ballachey, B. E., & Dean, T. A. (2016). Detecting and Inferring Cause of Change in an Alaska Nearshore Marine Ecosystems. *Ecosphere,* 7, e01489. https://doi.org/10.1002/ecs2.1489

Community composition, species abundance, and species distribution are expected to change while monitoring ecosystems over time, and effective management of natural resources requires understanding mechanisms contributing to change. Marine ecosystems in particular can be difficult to monitor, in part due to large, multidimensional spatial scales and complex dynamics. However, within the temperate marine ecosystems, the nearshore food web is reasonably well described. This food web is ecologically and socially important, spatially constrained, and has been the focus of extensive experimental research that describes the underlying mechanisms important to system dynamics. Here, we describe a monitoring program initiated in 2006 that focuses on the nearshore benthic food web in the Gulf of Alaska, whose design anticipates potential causes of ecosystem change to improve rigor, resolution, and confidence in understanding the mechanisms underlying change. We established 15 long-term monitoring sites across more than 1000 km of coastline, including 10 within two national parks and 5 within Prince William Sound, area of the 1989 Exxon Valdez oil spill. The program evaluates six ecological indicators and more than 200 species that range from primary producers to top-level consumers, and is designed to examine both bottom-up and top-down dynamics. Employing a design that allows broad spatial inference and selecting species with direct food-web linkages, we demonstrate the ability of our monitoring program to simultaneously detect change and assess potential mechanisms underlying that change. Detecting change and understanding mechanisms can help guide management and conservation policy. Specifically, we provide an example focusing on the sea otter (Enhydra lutris) that illustrates how (1) analytical methods are used to evaluate changes on various scales and infer potential mechanisms of change, (2) food-web linkages can enhance the understanding of changes and their effects, and (3) data can be used to inform management.

Conrath, C. L., & Conners, M. E. (2014). Aspects of the Reproductive Biology of the North Pacific Giant Octopus (Enteroctopus dofleini) in the Gulf of Alaska. *Fishery Bulletin,* 112(4), 253-260. https://doi.org/10.7755/fb.112.4.2

In 2011, octopuses in the Gulf of Alaska were removed from the "other species" group and are now managed by the North Pacific Fishery Management Council as a complex that includes all octopus species within this region. Management of this complex includes the specification of annual catch limits and overfishing limits. Understanding the life history of octopuses is important for establishment of appropriate management strategies. The North Pacific giant octopus (Enteroctopus dofleini) is the most abundant octopus species found on the continental shelf and dominates the commercial catch of octopuses within the Gulf of Alaska. Specimens of the North Pacific giant octopus were obtained from charter operations, commercial fishermen, and scientific surveys within the Gulf of Alaska. This species has a protracted reproductive cycle and peak spawning occurs from winter to early spring months. In the Gulf of Alaska, this species matures at weights from 10 to 20 kg; weight at 50% maturity is 13.7 kg (95% confidence interval [CI]=12.5-15.5 kg) for females and 14.2 kg (95% CI=12.6-15.9 kg) for males. Estimates of fecundity for this species range from 41,600 to 239,000 eggs per female and average fecundity is estimated at 106,800 eggs per female. Fecundity was positively related to the weight of the female (n=33, P<0.001). Determination of reproductive parameters is necessary to assess the vulnerability of octopuses within this region to overfishing and to establish appropriate management strategies for this species group within the Gulf of Alaska.

Conrath, C. L., Rooper, C. N., Wilborn, R. E., Knoth, B. A., & Jones, D. T. (2019). Seasonal Habitat Use and Community Structure of Rockfishes in the Gulf of Alaska. *Fisheries Research,* 219. https://doi.org/10.1016/j.fishres.2019.105331

Research is needed to determine the seasonal importance of high-relief habitats, particularly those containing biotic structures to rockfishes within the Gulf of Alaska. We examined the density and community structure of commercially important rockfishes in low-relief, high-relief, and biotic habitats in the spring, summer, and winter seasons at three sites in the central Gulf of Alaska using stereo drop cameras and bottom trawls. The fish community structure within all three sites was dominated by dusky rockfish (Sebastes variabilis), northern rockfish (S. poiyspinis), Pacific ocean perch (S. alums), and harlequin rockfish (S. variegates). There was no effect of season on community structure and density of rockfish in the study area. While there were local differences in fish density and community structure, rockfish densities throughout the study areas were higher in complex than bare habitats. Significant differences in densities between high-relief and biotic habitats were not found and the additional value of structure-forming invertebrates was not proven. Juvenile rockfish were also associated with high-relief habitat, particularly complex boulder habitat. This study advances our knowledge of seasonal habitat preferences of commercially important rockfish species with the Gulf of Alaska and emphasizes the need to consider these preferences in surveying and managing these species.

Ebert, D. A., Smith, W. D., & Cailliet, G. M. (2008). Reproductive Biology of Two Commercially Exploited Skates, *Raja binoculata* and *R. rhina*, in the Western Gulf of Alaska. *Fisheries Research,* 94(1), 48-57. https://doi.org/10.1016/j.fishres.2008.06.016

This study provides the first detailed information on the reproductive biology of two large and abundant eastern North Pacific Ocean skate species: big skate (Raja binoculata) and longnose skate (Raja rhina). Skates were collected in the western Gulf of Alaska during 2005 and 2006 after a targeted fishery for these two species developed around Kodiak Island, Alaska; both species are also taken as by-catch to other fisheries. A total of 307 females (20.1-183.3 cm TL) and 138 males (19.5-143.7 cm TL) R. binoculata, and 354 females (18.1-145.0 cm TL) and 318 males (21.1-135.8 cm TL) R. rhina were collected. Female R. binoculata were found to attain first (e.g., smallest individual) maturity at 125.8 cm TL and 50% at 148.6 cm TL Males were found to attain first and 50% maturity at 124.0 and 119.2 cm TL, respectively. No gravid female R. binoculata, with egg cases in utero, were encountered during the study. Female R. rhino were found to attain first and 50% maturity at 102.2 and 113.1 cm TL, respectively. Gravid female R. rhino, with egg cases in utero, were recorded throughout the sampling period. Males attained first maturity at 101.0 cm TL and 50% maturity at 102.9 cm TL Histological analysis did not reveal significant changes in spermatocyst production for either species during the sampling period. Both species appear to be reproductively active year-round as no seasonal cycle was evident. This study provides new and essential information on the reproductive biology of these two commercially targeted skate species.

Efird, T. P., & Konar, B. (2014). Habitat Characteristics Can Influence Fish Assemblages in High Latitude Kelp Forests. *Environmental Biology of Fishes,* 97(11), 1253-1263. https://doi.org/10.1007/s10641-013-0211-x

Kelp forests are patchy fish-associated habitats, which can vary greatly in their size, foundation species, and several physical habitat attributes. The structure of fish assemblages can vary with these characteristics and with the location of the assemblage within the forest, i.e. edges versus interiors. This study quantified the biological and physical heterogeneity within different sized kelp forests and identified which factors are important in structuring the associated fish assemblages. Fish and habitat surveys were conducted at the edge and interiors of ten kelp forests of varying sizes in Kachemak Bay, south-central Alaska. Fish assemblage structure was not correlated with the species composition of surface canopy forming foundation kelps (Nereocystis leutkeana and Eualaria fistulosa) or with kelp forest size. Instead, it correlated with the abundances of two understory foundation kelps (Agarum clathratum and Saccharina latissima), substratum rugosity, and water depth. Together these benthic attributes explained 53.6 % of the fish assemblage variability. Additionally, significantly different fish assemblages were found at edge compared to interior locations with the relative abundance of seven species (Artedius fenestralis, Ammodytes hexapterus, Blepsias cirrhosis, Gadus macrocephalus, Hexagrammos stelleri, Pholis laeta, and Sebastes melanops) explaining 91.4 % of the variability. This study highlights the importance of habitat characteristics such as understory foundation species, substratum rugosity, water depth and location within a patch on the variability of fish assemblages in high latitude kelp forests.

Evans, W., Mathis, J. T., Ramsay, J., & Hetrick, J. (2015). On the Frontline: Tracking Ocean Acidification in an Alaskan Shellfish Hatchery. *Plos One,* 10(7), e0130384. https://doi.org/10.1371/journal.pone.0130384

The invasion of anthropogenic carbon dioxide (CO2) into the ocean is shifting the marine carbonate system such that saturation states of calcium carbonate (CaCO3) minerals are decreasing, and this is having a detrimental impact on early life stages of select shellfish species. The global, secular decrease in CaCO3 saturation states is occurring on top of a backdrop of large natural variability in coastal settings; progressively shifting the envelope of variability and leading to longer and more frequent exposure to adverse conditions. This is a great concern in the State of Alaska, a high-latitude setting vulnerable to rapid changes in the marine carbonate system, where an emerging shellfish industry plans major growth over the coming decades. Currently, the Alutiiq Pride Shellfish Hatchery (APSH) in Seward, Alaska is the only hatchery in the state, and produces many shellfish species with early life stages known to be sensitive to low CaCO3 saturation states. Here we present the first land-based OA measurements made in an Alaskan shellfish hatchery, and detail the trends in the saturation state of aragonite (Ωarag), the more soluble form of CaCO3, over a 10-month period in the APSH seawater supply. These data indicate the largest changes are on the seasonal time scale, with extended periods of sub-optimal Ωarag levels (Ωarag < 1.5) in winter and autumn associated with elevated water column respiration and short-lived runoff events, respectively. The data pinpoint a 5-month window of reprieve with favorable Ωarag conditions above the sub-optimal Ωarag threshold, which under predicted upper-bound CO2 emissions trajectories is estimated to close by 2040. To date, many species in production at APSH remain untested in their response to OA, and the data presented here establish the current conditions at APSH as well as provide a framework for hatchery-based measurements in Alaska. The current and expected conditions seen at APSH are essential to consider for this developing Alaskan industry.

Gillikin, D. P., Lorrain, A., Navez, J., Taylor, J. W., Keppens, E., Baeyens, W., & Dehairs, F. (2005). Strong Biological Controls on Sr/Ca Ratios in Aragonitic Marine Bivalve Shells. *Geochemistry Geophysics Geosystems,* 6. https://doi.org/10.1029/2004gc000874

It is well known that skeletal remains of carbonate secreting organisms can provide a wealth of information about past environments. Sr/Ca ratios have been successfully used as a temperature proxy in corals and sclerosponges. Previous work on aragonitic bivalve shells has not been conclusive but suggests a major control of growth rate on Sr/Ca ratios. As many studies have used bivalve growth rates to determine temperature, we tested if Sr/Ca ratios could predict temperature through its relationship with growth rate. Shells from the two species of clams from the same family (veneroidea) studied here, Saxidomus giganteus and Mercenaria mercenaria, show vastly different seasonal Sr/Ca profiles. A strong relationship between average annual Sr/Ca ratios and annual growth rate was found in S. giganteus shells from both Washington (R-2 = 0.87) and Alaska (R-2 = 0.64), USA, but not in M. mercenaria shells from North Carolina, USA. Furthermore, the Sr/Ca-growth rate relationship was also evident upon a more detailed inspection of subannual growth rates in S. giganteus (R-2 = 0.73). Although there were significant positive correlations between Sr/Ca ratios and temperature in S. giganteus shells, the correlations were weak (0.09 < R-2 < 0.27), and thus Sr/Ca ratios cannot be used as a reliable temperature proxy in these species of aragonitic bivalves. It is clear from this study that Sr/Ca ratios are not under thermodynamic control in either clam species, since thermodynamics predict a negative correlation between Sr/Ca ratios and temperature in aragonite. This points toward dominance of biological processes in the regulation of Sr2+. This is also reflected by the largely differing Sr/Ca partition

coefficients (D-Sr) in these shells (D-Sr approximate to 0.25), when compared to inorganic, coral, and sclerosponge studies (D-Sr approximate to 1), all of which show a negative dependence of Sr/Ca on temperature. We suggest that caution be taken when using Sr/Ca in any biogenic aragonite as a temperature proxy when the D-Sr greatly deviates from one, as this indicates the dominance of biological controls on Sr/Ca ratios.

Heikoop, J. M., Hickmott, D. D., Risk, M. J., Shearer, C. K., & Atudorei, V. (2002). Potential Climate Signals from the Deep-Sea Gorgonian Coral *Primnoa resedaeformis*. *Hydrobiologia,* 471, 117-124. https://doi.org/10.1023/a:1016505421115

The deep-sea gorgonian coral Primnoa resedaeformis has an arborescent skeleton composed of both calcite and a horn-like structural protein called gorgonin. We have investigated potential climate records in corals from Alaska, the eastern seaboard of Canada and the United States, and a Southern Ocean (Pacific sector) seamount. Temperatures at these sites range from 4 to similar to10degreesC. delta(18)O values of the calcite show strong evidence for isotopic disequilibrium. Extraction of delta(18)O paleotemperatures is therefore not straightforward. Sr/Ca data, analyzed by Secondary Ion Mass Spectrometry (SIMS), suggest that temperature might be a control on calcite Sr/Ca in Primnoa resedaeformis, but that growth-related kinetic effects could also be important. Based on previous C-14, delta(13)C and delta(15)N measurements, it has been suggested that particulate organic matter (POM) from the surface is an important carbon source to the polyps and the gorgonin fraction of the Primnoa skeleton. delta(15)N and delta(13)C of polyps and gorgonin show similar regional differences to delta(15)N and delta(13)C of surface POM. Polyps and contemporaneous gorgonin correlate strongly for both delta(13)C and delta(15)N. The influence of nutrient isotopic composition and climate and productivity variations on the isotopic composition of surface POM may therefore be recorded in gorgonin layers. These corals have very long lifespans (several centuries). The potential exists, therefore, to obtain extended records of surface productivity, deep ocean temperature and chemistry of value to climatologists and fisheries managers.

Hinckley, S., Stockhausen, W. T., Coyle, K. O., Laurel, B. J., Gibson, G. A., Parada, C., . . . Ladd, C. (2019). Connectivity between Spawning and Nursery Areas for Pacific Cod (Gadus macrocephalus) in the Gulf of Alaska. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 165, 113-126. https://doi.org/10.1016/j.dsr2.2019.05.007

We present the results of a study of the connectivity between Pacific cod spawning and nursery areas, and settlement of Pacific cod in the Gulf of Alaska. This work was conducted to address the hypothesis that spatial and temporal patterns of recruitment are related to variability in connectivity between spawning and nursery areas. To examine this hypothesis, we developed a Lagrangian, biophysical, individual-based model of Pacific cod early life history and dispersal using the Dispersal Model for Early Life Stages (DisMELS) framework. This model is driven by currents and scalars such as temperature from a version of the Regional Oceanographic Model System (ROMS) developed for the Gulf of Alaska. Results of our study show connectivity patterns predicted by the model that agree with our understanding (based on genetic analyses) that there is a high degree of localized retention in Pacific cod. The results indicate that the Shumagin Islands and Prince William Sound regions may serve as important collectors of Pacific cod recruits from upstream spawning areas. We also find correlations between individual-

based model outputs and several large-scale climate indicators that appear to show settlement in several important nursery areas, and recruitment overall, are positively affected by slower gyre circulation in the Gulf of Alaska. We hypothesize that this is due to enhancement of retention, settlement in the Shumagin Island region, and reduction of transport of young cod out of the Gulf of Alaska to the southwest.

Jaecks, T., Bond, M. H., & Quinn, T. P. (2016). Can Dietary Reliance on Pacific Salmon Eggs Create Otolith Sr/Ca Signatures That Mimic Anadromy in Resident Salmonids? *Environmental Biology of Fishes,* 99(2-3), 237-247. https://doi.org/10.1007/s10641-016-0470-4

Many aspects of the ecology, growth, life history, and population dynamics of fishes differ between anadromous populations and those residing exclusively in freshwater habitats. Analysis of the elemental composition of otoliths (ear stones) is commonly used to indicate the migration history of individuals, relying on the differences in ambient concentrations of calcium, strontium, and barium and their subsequent incorporation into calcified structures. Dietary contribution to otolith chemistry is often overlooked, but in this study we report results consistent with the possibility that reliance on food resources derived from the ocean via Pacific salmon can produce otolith Sr/Ca ratios suggesting anadromy in freshwater resident fish. Dolly Varden, Salvelinus malma, from the Iliamna River, Alaska feed very heavily on eggs and other tissues from sockeye salmon, Oncorhynchus nerka, and their otoliths had Sr/Ca ratios typical of fish making seasonal migrations to marine waters but the Ba/Ca ratios were consistent with residence in fresh water. Water samples from the river provided no indication that the elevated Sr concentrations came from the river. A simulation of otolith chemistry resulting from Sr incorporation from both water and diet across a range of published values in salmonids indicates that a diet of salmon eggs and tissues can produce marine Sr/Ca ratios while fish remain in fresh water. Without experimental evidence such as a controlled diet study these results are suggestive but not conclusive. Nevertheless, they send a cautionary note that in some cases heavy reliance on marine-derived food sources might affect otolith microchemistry, creating an appearance of anadromy in fish that did not leave fresh water.

Johnson, S. W., Thedinga, J. F., & Neff, A. D. (2009). Invasion by Saffron Cod *Eleginus gracilis* into Nearshore Habitats of Prince William Sound, Alaska, USA. *Marine Ecology Progress Series,* 389, 203-212. https://doi.org/10.3354/meps08226

We recently identified saffron cod Eleginus gracilis as a dominant fish species in near-shore habitats (<5 m deep, <20 m offshore) of western Prince William Sound (PWS), Alaska, USA. Saffron cod have not been previously reported in PWS, and their capture suggests that fish community structure has changed in nearshore habitats. Nearly 16 000 saffron cod were captured in 49 of 95 beach seine hauls at 8 locations in western PWS in 2006 and 2007. Saffron cod accounted for 32% of the total fish catch (49 060 fish, 45 species). Abundance of saffron cod differed by season and habitat type; catch was greater in summer and fall than in spring, and fish were captured almost exclusively in eelgrass Zostera marina habitat. Most saffron cod captured were Age-0; based on age from otoliths, mean size of Age-0 fish increased from 70 mm total length (TL) (n = 8) in July to 108 mm TL (n = 21) in September. Age-0 saffron cod consumed predominantly pelagic fauna (oikopleurans), whereas fish aged >= 1 targeted predominantly epibenthic fauna (polychaetes and crustaceans). Most saffron cod left the nearshore

area by late summer; of 1002 fish that were fin-clipped and released at 1 sampling location (eelgrass) in July 2007, only 2 were recaptured in late August 2007. Reasons for the sudden and dramatic increase in the abundance of saffron cod in western PWS are unclear; possible ecological implications, however, include competition for food and space and increased predation risk to commercially important and forage fish species.

Konar, B., Iken, K., & Edwards, M. (2009). Depth-Stratified Community Zonation Patterns on Gulf of Alaska Rocky Shores. *Marine Ecology-an Evolutionary Perspective,* 30(1), 63-73. https://doi.org/10.1111/j.1439-0485.2008.00259.x

Vertical zonation patterns have been considered ubiquitous in intertidal ecosystems but questions remain about their generality for individual taxonomic groups and over broad spatial scales, and whether they continue into adjacent shallow subtidal habitats. Taxon richness, invertebrate abundance, and macroalgal biomass were examined in the summer of 2003 along a vertical gradient in the rocky intertidal and shallow subtidal habitats around Kodiak Island, Kachemak Bay, and Prince William Sound, all within the Gulf of Alaska. Replicate samples of benthic organisms were taken in the high (similar to 7 m), mid (similar to 4 m) and low (similar to 0 m) intertidal (relative to MLLW), and at 1, 5, 10 and 15 m water depths at three sites in each region, and identified to the lowest possible taxonomic level. Our primary goals were to assess (1) how estimates of taxon richness, invertebrate abundance, and macroalgal biomass vary among intertidal heights and subtidal depths and (2) how general these patterns are when considered across the Gulf of Alaska. Our results show that when all invertebrates were considered together, most of the variation in taxon richness was accounted for by differences among depths (i.e. intertidal heights and subtidal depths) (similar to 51%), and among replicate samples within each depth (similar to 26%). Little to none of the variation was accounted for by differences among sites within each region (similar to 1%) or among regions themselves (similar to 0%). When considered across the Gulf of Alaska, total taxon richness and organism abundance were greatest in the low intertidal/shallow subtidal and decreased with increasing height/depth. When separated by phylum and examined together with macroalgae, variation in abundance and/or biomass among depths was significant and accounted for most of the variability. Differences among regions and sites within each region were not significant and accounted for little to none of the variance. Because the pattern of zonation varied among sites within each region, it reduced the generality of a single zonation pattern for the Gulf of Alaska. Likewise, when community composition was compared among depths, geographic regions and sites within each region using multivariate analyses, vertical zonation patterns were evident at a regional scale, but high variability in these patterns among sites within each region reduced the generality of these patterns.

Li, K., Doubleday, A. J., Galbraith, M. D., & Hopcroft, R. R. (2016). High Abundance of Salps in the Coastal Gulf of Alaska During 2011: A First Record of Bloom Occurrence for the Northern Gulf. *Deep Sea Research Part II: Topical Studies in Oceanography,* 132, 136-145. https://doi.org/10.1016/j.dsr2.2016.04.009

Atypical high abundances of two salp species occurred in the coastal Gulf of Alaska during 2011. Salpa aspera dominated numerically in aggregate form during spring, and became uncommon during summer, while Cyclosalpa bakeri increased from low during spring to high abundance during summer. Both

species were absent, or nearly so, by fall. C. bakeri abundance was positively correlated to surface temperature in spring and summer, and both species abundances were negatively correlated to chlorophyll a. The proportion of aggregate forms of both species was higher than that of solitary forms during spring and summer. The length–frequency of S. aspera aggregate individuals ranged primarily from 10 to 50 mm, and solitary forms reached 130 mm, while C. bakeri aggregates were 10–25 mm, with solitary forms up to 75 mm. Estimated biomass of S. aspera was 0.35±0.64 mg C m−3 in southeastern Alaska during spring then decreased to 0.03±0.12 mg C m−3 during summer. Estimated biomass of C. bakeri was 0.03±0.06 mg C m−3 over the entire sampling domain during spring, then rose to 0.15±0.25 mg C m−3 during summer. The volume of water filtered daily by S. aspera was estimated to be up to 17% of the 200 m water column at some stations during spring, but only up to ~3.5% during summer. Substantially higher grazing impact was possible if animals were largely confined to the surface mixed layer (typically 20–30 m thick). The average volume filtrated was higher during spring for S. aspera, but for C. bakeri it was higher during summer. We propose that the combined effect of the northward transport of seed populations, their rapid biomass increase through asexual reproduction, and the high clearance rate of salps contributed to atypically low chlorophyll a in the Gulf of Alaska during spring and summer of 2011. This unusual event impacted ecosystem function during 2011, and might be expected to increase in frequency as the Gulf continues to respond to climate variations.

Long, W. C., Swiney, K. M., Harris, C., Page, H. N., & Foy, R. J. (2013). Effects of Ocean Acidification on Juvenile Red King Crab (Paralithodes camtschaticus) and Tanner Crab (Chionoecetes bairdi) Growth, Condition, Calcification, and Survival. *Plos One,* 8(4), e60959-e60959. https://doi.org/10.1371/journal.pone.0060959

Ocean acidification, a decrease in the pH in marine waters associated with rising atmospheric CO2 levels, is a serious threat to marine ecosystems. In this paper, we determine the effects of long-term exposure to near-future levels of ocean acidification on the growth, condition, calcification, and survival of juvenile red king crabs, Paralithodes camtschaticus, and Tanner crabs, Chionoecetes bairdi. Juveniles were reared in individual containers for nearly 200 days in flowing control (pH 8.0), pH 7.8, and pH 7.5 seawater at ambient temperatures (range 4.4-11.9 °C). In both species, survival decreased with pH, with 100% mortality of red king crabs occurring after 95 days in pH 7.5 water. Though the morphology of neither species was affected by acidification, both species grew slower in acidified water. At the end of the experiment, calcium concentration was measured in each crab and the dry mass and condition index of each crab were determined. Ocean acidification did not affect the calcium content of red king crab but did decrease the condition index, while it had the opposite effect on Tanner crabs, decreasing calcium content but leaving the condition index unchanged. This suggests that red king crab may be able to maintain calcification rates, but at a high energetic cost. The decrease in survival and growth of each species is likely to have a serious negative effect on their populations in the absence of evolutionary adaptation or acclimatization over the coming decades.

McMahon, K. W., Williams, B., Guilderson, T. P., Glynn, D. S., & McCarthy, M. D. (2018). Calibrating Amino Acid Delta C-13 and Delta N-15 Offsets between Polyp and Protein Skeleton to Develop Proteinaceous Deep-Sea Corals as Paleoceanographic Archives. *Geochimica Et Cosmochimica Acta,* 220, 261-275. https://doi.org/10.1016/j.gca.2017.09.048

Compound-specific stable isotopes of amino acids (CSI-AA) from proteinaceous deep-sea coral skeletons have the potential to improve paleoreconstructions of plankton community composition, and our understanding of the trophic dynamics and biogeochemical cycling of sinking organic matter in the Ocean. However, the assumption that the molecular isotopic values preserved in protein skeletal material reflect those of the living coral polyps has never been directly investigated in proteinaceous deep-sea corals. We examined CSI-AA from three genera of proteinaceous deep-sea corals from three oceanographically distinct regions of the North Pacific: Primnoa from the Gulf of Alaska, Isidella from the Central California Margin, and Kulamanamana from the North Pacific Subtropical Gyre. We found minimal offsets in the delta C-13 values of both essential and non-essential AAs, and in the delta N-15 values of source AAs, between paired samples of polyp tissue and protein skeleton. Using an essential AA delta C-13 fingerprinting approach, we show that estimates of the relative contribution of eukaryotic microalgae and prokaryotic cyanobacteria to the sinking organic matter supporting deep-sea corals are the same when calculated from polyp tissue or recently deposited skeletal tissue. The delta N-15 values of trophic AAs in skeletal tissue, on the other hand, were consistently 3-4% lower than polyp tissue for all three genera. We hypothesize that this offset reflects a partitioning of nitrogen flux through isotopic branch points in the synthesis of polyp (fast turnover tissue) and skeleton (slow, unidirectional incorporation). This offset indicates an underestimation, albeit correctable, of approximately half a trophic position from gorgonin protein-based deep-sea coral skeleton. Together, our observations open the door for applying many of the rapidly evolving CSI-AA based tools developed for metabolically active tissues in modern systems to archival coral tissues in a paleoceanographic context.

Muller, J., Romero, O., Cowan, E. A., McClymont, E. L., Forwick, M., Asahi, H., . . . Stoner, J. (2018). Cordilleran Ice-Sheet Growth Fueled Primary Productivity in the Gulf of Alaska, Northeast Pacific Ocean. *Geology,* 46(4), 307-310. https://doi.org/10.1130/g39904.1

Fertilization of the ocean by eolian dust and icebergs is an effective mechanism to enhance primary productivity. In particular, high-nutrient, low-chlorophyll (HNLC) areas where phytoplankton growth is critically iron-limited, such as the subarctic Pacific Ocean and the Southern Ocean, are proposed to respond to increases in bioavailable Fe supply with enhanced phytoplankton productivity and carbon export to the seafloor. While Fe-fertilization from dust is widely acknowledged to explain a higher export production during glacial periods in the Southern Ocean, paleoceanographic records supporting links between productivity and eolian dust and/or icebergs in the North Pacific are scarce. By combining independent proxies indicative of ice-sheet dynamics and ocean productivity from a single marine sedimentary record (Integrated Ocean Drilling Program [IODP] Site U1417), we present a comprehensive data set of phytoplankton response to different fertilization mechanisms in the subarctic northeast Pacific between 1.5 and 0.5 Ma, including the Mid Pleistocene Transition. Importantly, the timing of the fertilization events is more strongly controlled by local ice-sheet extent than by glacial-interglacial climate variability. Our findings indicate that fertilization by glacigenic debris results in productivity events in HNLC areas adjacent to ice sheets, and that this mechanism may represent an important, yet rarely considered, driver of phytoplankton growth.

O'Neel, S., Hood, E., Bidlack, A. L., Fleming, S. W., Arimitsu, M. L., Arendt, A., . . . Pyare, S. (2015). Icefield-to-Ocean Linkages across the Northern Pacific Coastal Temperate Rainforest Ecosystem. *Bioscience,* 65(5), 499-512. https://doi.org/10.1093/biosci/biv027

Rates of glacier mass loss in the northern Pacific coastal temperate rainforest (PCTR) are among the highest on Earth, and changes in glacier volume and extent will affect the flow regime and chemistry of coastal rivers, as well as the nearshore marine ecosystem of the Gulf of Alaska. Here we synthesize physical, chemical and biological linkages that characterize the northern PCTR ecosystem, with particular emphasis on the potential impacts of glacier change in the coastal mountain ranges on the surface-water hydrology, biogeochemistry, coastal oceanography and aquatic ecology. We also evaluate the relative importance and interplay between interannual variability and long-term trends in key physical drivers and ecological responses. To advance our knowledge of the northern PCTR, we advocate for cross-disciplinary research bridging the icefield-to-ocean ecosystem that can be paired with long-term scientific records and designed to inform decisionmakers.

Pinchuk, A. I., Coyle, K. O., & Hopcroft, R. R. (2008). Climate-Related Variability in Abundance and Reproduction of Euphausiids in the Northern Gulf of Alaska in 1998-2003. *Progress in Oceanography,* 77(2-3), 203-216. https://doi.org/10.1016/j.pocean.2008.03.012

Interannual variability in abundance of the dominant euphausiids Thysanoessa inermis, Thysanoessa spinifera and Euphausia pacifica was studied in the northern Gulf of Alaska during the production season from 1998 to 2003. T. inermis abundance increased significantly over the shelf from 1998 to 2002, the abundance of T. spinifera (which also inhabits the shelf) did not change, while the abundance of 11 pacifica (usually common on the outer shelf) declined in 2001. Based on the incidence of spermatophores on the females, reproduction of T. inermis occurred during April in all years, and was extended through May in 2000-2002. The major spawning of T. spinifera and E pacifica occurred from April through July, and from late May through August, respectively. The spawning of T inermis and T spinifera appeared to be closely related to the spring diatom bloom on the inner shelf, while the spawning of E. pacifica occurred later in season, when the temperature of the mixed layer increased. A strong increase in abundance of T. inermis, associated with the extended colder phase in the North Pacific, indicates that progressive cooling in 1999-2002 may have resulted in greater reproductive success of the early spawning T. inermis on the inner shelf.

Pinchuk, A. I., & Hopcroft, R. R. (2007). Seasonal Variations in the Growth Rates of Euphausiids (Thysanoessa inermis, T-spinifera, and Euphausia pacifica) from the Northern Gulf of Alaska. *Marine Biology,* 151(1), 257-269. https://doi.org/10.1007/s00227-006-0483-1

The euphausiids Thysanoessa inermis (Kroyer 1846), Thysanoessa spinifera (Holmes 1900), and Euphausia pacifica (Hansen 1911) are key pelagic grazers and also important prey for many commercial fish species in the Gulf of Alaska (GOA). To understand the role of the euphausiids in material flows in this ecosystem their growth rates were examined using the instantaneous growth rate (IGR) technique on the northern GOA shelf from March through October in 2001-2004. The highest mean molting increments (over 5% of uropod length increase per molt) were observed during the phytoplankton bloom on the inner shelf in late spring for coastal T. inermis, and on the outer shelf in summer for T.

spinifera and more oceanic E. pacifica, suggesting tight coupling with food availability. The molting rates were higher in summer and lower in spring, for all species and were strongly influenced by temperature. Mean inter-molt periods calculated from the molting rates, ranged from 11 days at 5 degrees C to 6 days at 8 degrees C, and were in agreement with those measured directly during long-term laboratory incubations. Growth rate estimates depended on euphausiid size, and were close to 0 in early spring, reaching maximum values in May (0.123 mm day(-1) or 0.023 day(-1) for T. inermis) and July (0.091 mm day(-1) or 0.031 day(-1) for T. spinifera). The growth rates for E. pacifica remained below 0.07 mm day(-1) (0.016 day(-1)) throughout the season. The relationship between T. inermis weight specific growth rate (adjusted to 5 degrees C) and ambient chlorophyll-a concentration fit a Michaelis-Menten curve (r(2) = 0.48) with food saturated growth rate of 0.032 day(-1) with half saturation occurring at 1.65 mg chl-a m(-3), but such relationships were not significant for T. spinifera or E. pacifica.

Rooper, C. N., & Martin, M. H. (2012). Comparison of Habitat-Based Indices of Abundance with Fishery-Independent Biomass Estimates from Bottom Trawl Surveys. *Fishery Bulletin,* 110(1), 21-35. Retrieved from https://spo.nmfs.noaa.gov/content/comparison-habitat-based-indices-abundance-fishery-independent-biomass-estimates-bottom-0

Rockfish species are notoriously difficult to sample with multispecies bottom trawl survey methods. Typically, biomass estimates have high coefficients of variation and can fluctuate outside the bounds of biological reality from year to year. This variation may be due in part to their patchy distribution related to very specific habitat preferences. We successfully modeled the distribution of five commercially important and abundant rockfish species. A two-stage modeling method (modeling both presence-absence and abundance) and a collection of important habitat variables were used to predict bottom trawl survey catch per unit of effort. The resulting models explained between 22% and 66% of the variation in rockfish distribution. The models were largely driven by depth, local slope, bottom temperature, abundance of coral and sponge, and measures of water column productivity (i.e., phytoplankton and zooplankton). A year-effect in the models was back-transformed and used as an index of the time series of abundance. The abundance index trajectories of three of five species were similar to the existing estimates of their biomass. In the majority of cases the habitat-based indices exhibited less interannual variability and similar precision when compared with stratified survey-based biomass estimates. These indices may provide for stock assessment models a more stable alternative to current biomass estimates produced by the multispecies bottom trawl survey in the Gulf of Alaska.

Rugh, D. J., Mahoney, B. A., & Smith, B. K. (2004). *Aerial Surveys of Beluga Whales in Cook Inlet Alaska, between June 2001 and June 2002.* Retrieved from https://repository.library.noaa.gov/view/noaa/18274

The National Marine Fisheries Service (NMFS) has conducted aerial surveys of the beluga population in Cook Inlet, Alaska, each June and/or July since 1993. Results from 1993 to 2000 were published in Rugh et al. (2000a). The current document is a collection of field reports for the subsequent years, from 2001 to 2004. Surveys were done 5-12 June 2001 (55 flight hours; 29.3 hours good effort), 4-11 June 2002 (45 flight hours; 24.4 hours good effort), 31 May -12 June 2003 (61 flight hours; 30.5 hours good effort), and 2-9 June 2004 (45 flight hours; 19.0 hours good effort). All surveys were flown in an Aero Commander (twinengine, high-wing aircraft) at a target altitude of 244 m (800 ft) and speed of 185 km/hour (100

knots), consistent with previous surveys. Tracklines were flown 1.4 km from shore along coastal areas around the entire Inlet, including islands, and offshore transects were designed to run the length of Cook Inlet or cross it, minimizing overlap within each season as well as between years. These searches effectively covered 25% to 31% of the entire Inlet in each of the 4 years, but nearly 100% of the coastal areas were surveyed each year. In particular, most of the upper Inlet, where belugas have been found consistently, was surveyed five to six times each year. Paired, independent observers searched on the coastal (left) side of the plane, where virtually all beluga sightings occur, while a single observer searched on the right. A computer operator/data recorder was also on the left side. After finding beluga groups, a series of aerial passes allowed four primary observers to each make four or more independent counts of every group, (i.e., typically 16 aerial counts for each group). In addition, whale groups were videotaped for later analysis and more precise counts iv in the laboratory. During these surveys, only two belugas were seen in lower Cook Inlet (south of East and West Foreland), none were seen in the upper Inlet south of North Foreland and Point Possession, but many were seen in the Susitna Delta (33%), Knik Arm (31%), and Turnagain Arm/Chickaloon Bay (36%). The annual sums of medians from aerial counts provide a quick index of relative abundance, not corrected for estimates of whales missed and assuming there may be some exchange of whales between areas. Annual index counts have not changed appreciably from 1998 to 2004 (192, 217, 184, 210, 181, 174, and 187, respectively), but these counts are lower than those made from 1993 to 1997 (302, 276, 322, 287, and 261, respectively). These annual medians mirror the abundance estimates that have been corrected for missed whales (653, 491, 594, 440, 347, 367, 435, 386, 313, 357, and 366 for the years 1994-2004, respectively).

Shelden, K. E. W., Rugh, D. J., Goetz, K. T., Sims, C. L., Vate Brattstrom, L., Mocklin, J. A., . . . Hobbs, R. C. (2013). *Aerial Surveys of Beluga Whales, Delphinapterus Leucas, in Cook Inlet Alaska, June 2005 to 2012.* Retrieved from https://repository.library.noaa.gov/view/noaa/4581

NOAA Fisheries has conducted aerial surveys of the beluga population in Cook Inlet, Alaska, each June and/or July since 1993. Results from 1993 to 2000 and 2001 to 2004 were published previously. The current document is a compilation of data from field reports for the subsequent years, from 2005 to 2012.

Surveys during these years occurred 31 May-9 June 2005 (54.5 flight hours), 6-15 June 2006 (58.4 flight hours), 7-15 June 2007 (47.2 flight hours), 3-12 June 2008 (47.7 flight hours), 2-9 June 2009 (39.4 flight hours), 1-10 June 2010 (48.4 flight hours), 31 May-9 June 2011 (47.0 flight hours), and 29 May-7 June 2012 (53.0 flight hours). All surveys were flown in twin-engine, high-wing aircraft (i.e., an Aero Commander or Twin Otter) at a target altitude of 244 m (800 ft) and speed of 185 km/hour (100 knots), consistent with NOAA Fisheries' surveys of Cook Inlet conducted in previous years. Tracklines were flown 1.4 km from the shoreline along the entire Cook Inlet coast, including islands. Offshore transects were designed to run the length of Cook Inlet or in a sawtooth pattern across the inlet, minimizing overlap within each season, as well as between years. These aerial surveys effectively covered 25% to 34 % of the total surface area of Cook Inlet in each of the 8 years and nearly 100% of the coastline (with the exception of 2007: 71%). In particular, most of the upper inlet, north of the Forelands where beluga whales are consistently found, was surveyed five to six times each year.

Paired, independent observers searched on the coastal side of the plane, where virtually all beluga sightings occur, while a single observer searched on the offshore side. A computer operator/data recorder periodically monitored distance from the shoreline (1.4 km) with a clinometer (angle 10 °). After finding beluga groups, a series of aerial passes allowed all four observers to each make four or

more independent counts of every group, (i.e., typically 16 counts of each group conducted during 8 passes). In addition, whale groups were video recorded for later analysis and more precise counts in the laboratory.

Stevens, C. H. (2008). Permian Colonial Rugose Corals from the Wrangellian Terrane in Alaska. *Journal of Paleontology,* 82(5), 1043-1050. https://doi.org/10.1666/07-101.1

Wrangellia was one of the first described and probably the most widely known of the North American Cordilleran terranes. On the basis of Triassic stratigraphy (Jones et al., 1977) and paleomagnetism (Hillhouse, 1977), the name Wrangellia was proposed for large areas of outcrop in Alaska, British Columbia, and Oregon (Fig. 1).

Wilborn, R., Conrath, C. L., Knoth, B., & Rooper, C. N. (2017). Results from the Underwater Camera Survey of the 49 Fathom Pinnacle and Snakehead Bank Sites near Kodiak Island, Alaska. In *AFSC Processed Report 2017-06*. Retrieved from [No URL available]

The distribution of federally managed fish species in the Gulf of Alaska and identification of essential fish habitat is poorly understood. Several commercially important fish species are associated with rocky substrates which is also ideal habitat for structure-forming invertebrates such as coral and sponge. However, it is not known whether the additional complexity of rocky substrates with structure-forming invertebrates increases fish abundance or if bare, rocky substrate alone (e.g., boulders) attracts similar numbers of fishes. Two sites were selected off of Kodiak Island in the Gulf of Alaska and 40 underwater camera transects were deployed to assess benthic habitat and fish density. The data extracted from the images included substrate classifications as well as coral, sponge, and fish counts and identification.

Williams, B. C., Kruse, G. H., & Dorn, M. W. (2016). Interannual and Spatial Variability in Maturity Of Walleye Pollock *Gadus chalcogrammus* and Implications for Spawning Stock Biomass Estimates in the Gulf of Alaska. *Plos One,* 11(10), 19. https://doi.org/10.1371/journal.pone.0164797

Catch quotas for walleye pollock Gadus chalcogrammus, the dominant species in the groundfish fishery off Alaska, are set by applying harvest control rules to annual estimates of spawning stock biomass (SSB) from age-structured stock assessments. Adult walleye pollock abundance and maturity status have been monitored in early spring in Shelikof Strait in the Gulf of Alaska for almost three decades. The sampling strategy for maturity status is largely characterized as targeted, albeit opportunistic, sampling of trawl tows made during hydroacoustic surveys. Trawl sampling during pre-spawning biomass surveys, which do not adequately account for spatial patterns in the distribution of immature and mature fish, can bias estimated maturity ogives from which SSB is calculated. Utilizing these maturity data, we developed mixed-effects generalized additive models to examine spatial and temporal patterns in walleye pollock maturity and the influence of these patterns on estimates of SSB. Current stock assessment practice is to estimate SSB as the product of annual estimates of numbers at age, weight at age, and mean maturity at age for 1983-present. In practice, we found this strategy to be conservative for a time period from 2003-2013 as, on average, it underestimates SSB by a 4.7 to 11.9% difference when compared to our

estimates of SSB that account for spatial structure or both temporal and spatial structure. Inclusion of spatially explicit information for walleye pollock maturity has implications for understanding stock reproductive biology and thus the setting of sustainable harvest rates used to manage this valuable fishery.

Chemistry

Dong, S. J., Berelson, W. M., Rollins, N. E., Subhas, A. V., Naviaux, J. D., Celestian, A. J., . . . Adkins, J. F. (2019). Aragonite Dissolution Kinetics and Calcite/Aragonite Ratios in Sinking and Suspended Particles in the North Pacific. *Earth and Planetary Science Letters,* 515, 1-12. https://doi.org/10.1016/j.epsl.2019.03.016

The lack of consensus on CaCO3 dissolution rates and calcite to aragonite production and export ratios in the ocean poses a significant barrier for the construction of global carbon budgets. We present here a comparison of aragonite dissolution rates measured in the lab vs. in situ along a transect between Hawaii and Alaska using a C-13 labeling technique. Our results show a general agreement of aragonite dissolution rates in the lab versus in the field, and demonstrate that aragonite, like calcite, shows a non-linear response of dissolution rate as a function of saturation state (Omega). Total carbon fluxes along the N. Pacific transect in August 2017, as determined using sediment traps, account for 11 similar to 23 weight % of total mass fluxes in the upper 200 m, with a PIC (particulate inorganic carbon) /POC (particulate organic carbon) mole ratio of 0.2 similar to 0.6. A comparison of fluxes at depths of 100 m and 200 m indicates that 30 similar to 60% PIC dissolves between these depths with 20 similar to 70% attenuation in POC fluxes. The molar ratio of PIC to POC loss is 0.29. The simultaneous loss of PIC and POC in the upper 200 m potentially indicates PIC dissolution driven by organic matter respiration, or metazoan/zooplankton consumption. The calcite/aragonite ratio in trap material is significantly lower in the subtropical gyre than in the subarctic gyre. Aragonite fluxes vary from 0.07 to 0.38 mmol m(-2) day(-1) at 100 m, and 0.06 to 0.24 mmol m(-2) day(-1) at 200 m along the North Pacific transect, with no specific trend over latitude. The identification of suspended PIC mineral phases by Raman spectroscopy shows the presence of aragonite below 3000 m in the subtropical gyre, but none in the subpolar gyre. These multiple lines of evidence suggest that predictions based on a strictly thermodynamic view of aragonite dissolution, combined with measured aragonite fluxes, underestimate observed alkalinity excess and measured PIC attenuation in sinking particles. Our measured aragonite flux combined with our inorganic dissolution rate only account for 9% and 0.2% of the excess alkalinity observed in the North Pacific (Feely et al., 2004), assuming aragonite sinking rates of 1 m day(-1) and 100 m day(-1), respectively. However, respiration-driven dissolution or metazoan/zooplankton consumption, indicated by the simultaneous attenuation of PIC and POC in sediment traps, is able to generate the magnitude of dissolution suggested by observed excess alkalinity.

Evans, W., Mathis, J. T., Winsor, P., Statscewich, H., & Whitledge, T. E. (2013). A Regression Modeling Approach for Studying Carbonate System Variability in the Northern Gulf of Alaska. *Journal of Geophysical Research: Oceans,* 118(1), 476-489. https://doi.org/10.1029/2012JC008246

The northern Gulf of Alaska (GOA) shelf experiences carbonate system variability on seasonal and annual time scales, but little information exists to resolve higher frequency variability in this region. To resolve this variability using platforms-of-opportunity, we present multiple linear regression (MLR)

models constructed from hydrographic data collected along the Northeast Pacific Global Ocean Ecosystems Dynamics (GLOBEC) Seward Line. The empirical algorithms predict dissolved inorganic carbon (DIC) and total alkalinity (TA) using observations of nitrate (NO3?), temperature, salinity and pressure from the surface to 500?m, with R2s?>?0.97 and RMSE values of 11?µmol?kg?1 for DIC and 9?µmol?kg?1 for TA. We applied these relationships to high-resolution NO3? data sets collected during a novel 20?h glider flight and a GLOBEC mesoscale SeaSoar survey. Results from the glider flight demonstrated time/space along-isopycnal variability of aragonite saturations (Ωarag) associated with a dicothermal layer (a cold near-surface layer found in high latitude oceans) that rivaled changes seen vertically through the thermocline. The SeaSoar survey captured the uplift to <100?m of dense, high-pCO2 waters at the shelf break that had been forced by the passage of a Yakutat eddy. During this event, the aragonite saturation horizon (depth where Ωarag?=?1) shoaled to a previously unseen depth in the northern GOA. This work is similar to recent studies aimed at predicting the carbonate system in continental margin settings, albeit demonstrates that a NO3?-based approach can be applied to high-latitude data collected from platforms capable of high-frequency measurements.

Hansard, S. P., Vermilyea, A. W., & Voelker, B. M. (2010). Measurements of Superoxide Radical Concentration and Decay Kinetics in the Gulf of Alaska. *Deep-Sea Research Part I-Oceanographic Research Papers,* 57(9), 1111-1119. https://doi.org/10.1016/j.dsr.2010.05.007

Numerous laboratory studies have shown that superoxide radical (O-2(-)) can have a profound influence on the redox speciation of dissolved metals, especially copper, manganese, and iron. We made direct measurements of O-2(-) concentrations and decay kinetics in seawater samples collected from the Gulf of Alaska, using the recently developed method of methyl Cypridina luciferin analog (MCLA) chemiluminescence. Concentrations ranged from <0.02 to similar to 0.6 nmol L-1, with higher concentrations typically observed in the upper 1-10 m of the water column. Pseudo-first-order decay rate coefficients ranged 0.002-0.02 s(-1), and confirm that even in the open ocean, uncatalyzed dismutation is not the major fate of O-2(-). Calculated O-2(-) production rates varied from <1 to similar to 20 nmol L-1 h(-1) and appear to be primarily of biological origin. These results represent the first direct measurements of O-2(-) concentrations in a non-tropical region, and are broadly similar to recently published findings for the eastern equatorial Pacific, suggesting that biological production of O-2(-) may be a common feature of the ocean's surface waters. Our study was also the first to examine the reproducibility of measurements of in situ O-2(-) concentrations and decay coefficients. Subsurface samples collected using GO-FLO bottles exhibited a systematic increase in concentration and decay rate coefficient with time, a possible artifact that should be considered in future studies. In contrast, measurements conducted using "fish" samples under low or no light conditions were found to be reliably reproducible, and demonstrated substantial rates of biological O-2(-) production.

Schroth, A. W., Crusius, J., Chever, F., Bostick, B. C., & Rouxel, O. J. (2011). Glacial Influence on the Geochemistry of Riverine Iron Fluxes to the Gulf of Alaska and Effects of Deglaciation. *Geophysical Research Letters,* 38(16). https://doi.org/10.1029/2011GL048367

Riverine iron (Fe) derived from glacial weathering is a critical micronutrient source to ecosystems of the Gulf of Alaska (GoA). Here we demonstrate that the source and chemical nature of riverine Fe input to the GoA could change dramatically due to the widespread watershed deglaciation that is underway. We

examine Fe size partitioning, speciation, and isotopic composition in tributaries of the Copper River which exemplify a long-term GoA watershed evolution from one strongly influenced by glacial weathering to a boreal-forested watershed. Iron fluxes from glacierized tributaries bear high suspended sediment and colloidal Fe loads of mixed valence silicate species, with low concentrations of dissolved Fe and dissolved organic carbon (DOC). Iron isotopic composition is indicative of mechanical weathering as the Fe source. Conversely, Fe fluxes from boreal-forested systems have higher dissolved Fe concentrations corresponding to higher DOC concentrations. Iron colloids and suspended sediment consist of Fe (hydr)oxides and organic complexes. These watersheds have an iron isotopic composition indicative of an internal chemical processing source. We predict that as the GoA watershed evolves due to deglaciation, so will the source, flux, and chemical nature of riverine Fe loads, which could have significant ramifications for Alaskan marine and freshwater ecosystems.

Siedlecki, S. A., Pilcher, D. J., Hermann, A. J., Coyle, K., & Mathis, J. (2017). The Importance of Freshwater to Spatial Variability of Aragonite Saturation State in the Gulf of Alaska. *Journal of Geophysical Research-Oceans,* 122(11), 8482-8502. https://doi.org/10.1002/2017jc012791

High-latitude and subpolar regions like the Gulf of Alaska (GOA) are more vulnerable than equatorial regions to rising carbon dioxide (CO2) levels, in part due to local processes that amplify the global signal. Recent field observations have shown that the shelf of the GOA is currently experiencing seasonal corrosive events (carbonate mineral saturation states , <1), including suppressed in response to ocean acidification as well as local processes like increased low-alkalinity glacial meltwater discharge. While the glacial discharge mainly influences the inner shelf, on the outer shelf, upwelling brings corrosive waters from the deep GOA. In this work, we develop a high-resolution model for carbon dynamics in the GOA, identify regions of high variability of , and test the sensitivity of those regions to changes in the chemistry of glacial meltwater discharge. Results indicate the importance of this climatically sensitive and relatively unconstrained regional freshwater forcing for variability in the nearshore. The increase was nearly linear at 0.002 per 100 mu mol/kg increase in alkalinity in the freshwater runoff. We find that the local winds, biological processes, and freshwater forcing all contribute to the spatial distribution of and identify which of these three is highly correlated to the variability in . Given that the timing and magnitude of these processes will likely change during the next few decades, it is critical to elucidate the effect of local processes on the background ocean acidification signal using robust models, such as the one described here.

Wu, J., Aguilar-Islas, A., Rember, R., Weingartner, T., Danielson, S., & Whitledge, T. (2009). Size-Fractionated Iron Distribution on the Northern Gulf of Alaska. *Geophysical Research Letters,* 36(11). https://doi.org/10.1029/2009GL038304

Concentrations of soluble (<0.025 ?m), dissolved (<0.4 ?m) and total (unfiltered) iron (Fe) were measured over the continental shelf and slope of the northern Gulf of Alaska (GoA) during spring-summer. Large cross-shelf gradients of surface water Fe concentrations were observed in these productive shelf waters during both seasons. Most of the particulate (>0.4 ?m) and colloidal (0.025?0.4 ?m) Fe size fractions were removed from surface waters within the inner and mid shelf. As a result the contribution of soluble Fe to the total Fe concentration increased from the inner shelf to the shelf break/slope waters. Surface water dissolved Fe concentrations on the northern GoA continental slope

were higher than those previously observed in the central GoA gyre. Variations in surface water Fe concentrations from spring through summer appear to result from the changes in freshwater discharge and physical processes on the shelf.

Zindorf, M., Marz, C., Wagner, T., Gulick, S. P. S., Strauss, H., Benowitz, J., . . . La Rosa, M. (2019). Deep Sulfate-Methane-Transition and Sediment Diagenesis in the Gulf of Alaska (IODP Site U1417). *Marine Geology,* 417. https://doi.org/10.1016/j.margeo.2019.105986

Sediment samples from the Gulf of Alaska (GOA, IODP Expedition 341, Site U1417) have been analyzed to understand present and past diagenetic processes that overprint the primary sediment composition. No Sulfate-Methane Transition Zone (SMTZ) was observed at the zone of sulfate depletion, but a > 200 m thick sulfate- and methane-free sediment interval occurred between the depth of sulfate depletion (similar to 200 m) and the onset of methanogenesis (similar to 440 m). We suggest that this apparent gap in biogeochemical processing of organic matter is caused by anaerobic oxidation of methane fueled by sulfate which is released during dissolution of barites at the upper boundary of the methane rich layer. Beneath the methanogenic zone, at similar to 650 m depth, pore-water sulfate concentrations increase again, indicating sulfate supply from greater depth feeding into a deep, inverse SMTZ. A likely explanation for the availability of sulfate in the deep sub-seafloor at U1417 is the existence of a deep aquifer related to plate bending fractures, which actively transports sulfate-rich water to, and potentially along, the interface between sediments and oceanic crust. Such inverse diagenetic zonations have been previously observed in marine sediments, but have not yet been linked to subduction-related plate bending. With the discovery of a deep inverse SMTZ in an intra-oceanic plate setting and the blocking of upward methane diffusion by sulfate released from authigenic barite dissolution, Site U1417 provides new insights into sub-seafloor pore-fluid and gas dynamics, and their implications for global element cycling and the deep biosphere.

Geology

Holden, K. D. (Cartographer). (1980). Isopach Map of Upper Holocene Marine Sediments, Outer Continental Shelf, Shelikof Strait Alaska. Retrieved from [No URL available]

No abstract available.

Hoose, P. J., Holden, K. D., & Lybeck, L. (Cartographer). (1980). Isopach of Holocene Marine Sediments, Outer Continental Shelf, Shelikof Strait Alaska. Retrieved from [No URL available]

No abstract available.

Hoose, P. J., & Whitney, J. (Cartographer). (1980). Map Showing Selected Geologic Features of Outer Continental Shelf, Shelikof Strait Alaska. Retrieved from [No URL available]

No abstract available.

Lay, T., Ye, L. L., Bai, Y. F., Cheung, K. F., & Kanamori, H. (2018). The 2018 M-W 7.9 Gulf of Alaska Earthquake: Multiple Fault Rupture in the Pacific Plate. *Geophysical Research Letters,* 45(18), 9542-9551. https://doi.org/10.1029/2018gl079813

A major (MW 7.9) intraplate earthquake ruptured the Pacific plate seaward of the Alaska subduction zone near Kodiak Island on 23 January 2018. The aftershock seismicity is diffuse, with both NNW- and ENE-trending distributions, while long-period point source moment tensors have near-horizontal compressional and tensional principal strain axes and significant non-double-couple components. Backprojections from three large-aperture networks indicate sources of short-period radiation not aligned with the best double-couple fault planes. A suite of finite-fault rupture models with one to four faults was considered, and a four-fault model, dominated by right-lateral slip on an SSE trending, westward-dipping fault, is compatible with most seismic, GPS, and tsunami data. However, the precise geometry, timing, and slip distribution of the complex set of faults is not well resolved. The sequence appears to be the result of intraplate stresses influenced by slab pull, the 1964 Alaska earthquake, and collision of the Yakutat terrane in northeastern Alaska. Plain Language Summary On 23 January 2018 a very large earthquake, with magnitude 7.8, ruptured in the Pacific plate southwest of the Alaskan subduction zone. There are multiple indications of complex faulting for this event: The point source moment tensor is not consistent with a single fault rupture; the aftershock distribution is diffuse, with nearly orthogonal trends in seismicity; the aftershock mechanisms are diverse; backprojections of short-period seismic waves show complex patterns of high-frequency energy release not on a single plane; and teleseismic waveforms are complex. Inversions of the teleseismic signals for a variety of models with from one to four different faults being allowed provide slip models that are used to predict regional GPS observations from Alaska along with deepwater tsunami recordings from seafloor pressure sensors at Deep-ocean Assessment and Reporting of Tsunamis (DART) stations. The primary rupture occurred on a fault trending SSE, dipping to the west, and several nearly perpendicular faults appear to have ruptured as well, but the limited spatial extent of the rupture makes it difficult to resolve the details of the faulting.

St John, K. E. K., & Cowan, E. A. (2000). Terrestrial Gypsum from Alaska and Greenland in Glacially Influenced Marine Sediments. *Sedimentary Geology,* 136(1-2), 43-58. https://doi.org/10.1016/s0037-0738(00)00083-x

Gypsum grains were identified in Miocene-Pleistocene sediment cores from two deep-water ODP sites, Site 918 off the SE Greenland margin and Site 887 in the Gulf of Alaska, and in Holocene sediment cores from shallow-water localities in Disenchantment Bay and Muir Inlet in southern Alaska. Although initial morphologic and textural observations suggested a complex system in which the gypsum may have had more than one origin, quantitative sulfur isotope analyses of the gypsum provide evidence of its detrital nature. delta(34)S values in gypsum from southern Alaska range between +0.0 and +7.1 parts per thousand. Gypsum has delta(34)S values between -27.1 and -27.5 parts per thousand in the Gulf of Alaska and values between -28.5 and +0.2 parts per thousand off the SE Greenland margin. All of these

isotopic signatures are too highly depleted in delta(34)S to have precipitated from seawater, present or past. In addition there is no significant change in delta(34)S values for gypsum crystals with differing physical characteristics (abraded vs. unabraded) from the same stratigraphic horizon, suggesting all the gypsum is detrital regardless of the degree of abrasion. The isotopic and physical evidence, in combination with the onshore geology the environmental setting, and site characteristics of the gypsum-bearing marine localities, lead us to propose that the ultimate source of the gypsum is precipitation from freeze-induced terrestrial sediment or soil brines. Furthermore the combined evidence suggests that the subsequent occurrence of gypsum in glacimarine sediments results from ice-rafting (by icebergs or sea ice) of the frozen regolith and/or, in the proximal glacimarine setting of southern Alaska, very rapid burial via turbidity currents.

Thrasher, G. P. (Cartographer). (1979). Geologic Map of the Kodiak Outer Continental Shelf, Western Gulf of Alaska. Retrieved from [No URL available]

No abstract available.

Thurston, D. K. (1985). Offshore Evidence of Glaciations in Lower Cook Inlet, Alaska. *AAPG Bulletin,* 69(4), 681. https://doi.org/10.1306/AD4627A4-16F7-11D7-8645000102C1865D

The Lower Cook Inlet is a northeast-trending tidal embayment of the North Pacific Ocean located in south-central Alaska between the Alaska-Aleutian Ranges on the west and the Chugach and Kenai Mountains on the east. Five major Pleistocene glaciations have been documented for the region. The first three glaciations completely filled the Cook Inlet trough, truncating Tertiary strata and creating an inlet-wide angular unconformity. In the last two glaciations, ice coalesced across the southern part of the inlet only, impounding fresh water from the north in a large proglacial lake.

Thurston, D. K., & Choromanski, D. R. (1994). Quarternary Geology of Lower Cook Inlet, Alaska. *ICAM Proceedings*. Retrieved from https://pebbleprojecteis.com/documents/library

Lower Cook Inlet is a northeast trending tidal embayment of the North PacificOcean located in south central Alaska between the Alaska-Aleutian Range on the west and the Chugach Range on the east. Five major glaciations are recorded for the region during the pleistocene. The first three completely filled Cook Inlet trough, truncating Tertiary bedrock and creating an inlet-side angular unconformity. In the last two glaciations, ice coalesced only across the southern part of the inlet possibly creating a dam to water flowing from the north. Interpretation of marine high-resolution seismic reflection data reveal many glacial and related features both on the seabottom and buried beneath Holocene marine sediments. Seabottom features identified include wave-cut benches, outwash fans, sand waves, megaripples, sand ribbons, lag deposits, and ice-rafted boulders forming comet marks. Subbottom features include terminal, lateral, and ground moraines, glacio-fluvial, glacio-marine, and lacustrine deposits, drainage channels and tunnel valleys, eskers, outwash fans, and sand waves. The seafloor may be divided into four morphological provinces separated by the 60, 120, and 190 m isobath contour lines. The deeper two provinces are predominantly an expression of ice-erosional morphology and reflect

marine depostional conditions, whereas the shallower two provinces are expressions of ice-depositional morphology and reflect non-marine and marine sedimentary environments. The morphology of the seafloor and the features described are almost all the result of depositional and erosional processes during the last two glaciations and subsequent modification by high velocity tidal currents and marine deposition.

Turner, R. F., Lynch, M. B., Conner, T. A., Hallin, P. J., Hoose, P. J., Martin, G. C., . . . Adams, A. J. (1987). *Geological and Operational Summary, Kodiak Shelf Stratigraphic Test Wells, Western Gulf of Alaska.* Retrieved from https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Resource_Evaluation/Geological_and_Geophysical_Data_Acquisition/MMS87_0109KodiakShelfTestWells.pdf

Title 30, Code of Federal Regulations (CFR), paragraph 251.14, stipulates that geological data and processed geological information obtained from Deep Stratigraphic Test (DST) wells drilled on the Outer Continental Shelf (OCS) be made available for public inspection 60 calendar days after the issuance of the first Federal lease within 50 nautical miles of the well site or 10 years after completion of the well if no lease is issued. Six DST wells (often called COST wells) were drilled on the Kodiak shelf in support of proposed Lease Sale 46 (fig. 1). three in 1976 and three in 1977. The first series of wells, the KSST No. 1, KSST No. 2, and KSST No. 4A wells, was drilled by Exploration Services Company, Inc. (ESCI), to shallow depths and obtained relatively limited data. These data were made available for public inspection after 10 years, as required by CFR 251.14, but no formal report was issued at the time. The second series of Kodiak shelf wells, the KSSD No. 1, KSSD No. 2, and KSSD No. 3 wells, was drilled in 1977 by Sun Oil Company. These wells were drilled to much greater depths and acquired far more data. The last well was completed in October 1977. MMS interpretations of the data from all six wells are released in this report. Lease Sales 46, 61, and 99 have all been cancelled. No lease sale for the Kodiak shelf area is scheduled in the current 5-year Oil and Gas Leasing Program.

Whitney, J., & Holden, K. D. (Cartographer). (1980). Bathymetric Map of the Outer Continental Shelf of Shelikof Strait, Alaska. Retrieved from [No URL available]

No abstract available.

Whitney, J., Holden, K. D., & Lybeck, L. (Cartographer). (1980). Isopach Map of Quarternary Glacial-Marine Sediments, Outer Continental Shelf, Shelikof Strait Alaska. Retrieved from [No URL available]

No abstract available.

Whitney, J., Thurston, D. K., Bouma, A. H., & Hampton, M. A. (1979). *Lower Cook Inlet, Alaska: Do Those Large Sand Waves Migrate?* Paper presented at the Offshore Technology Conference. https://www.onepetro.org/conference-paper/OTC-3484-MS

The seafloor of Lower Cook Inlet (LCI), Alaska, contains approximately 85U sq. km of small and large sand waves (wavelengths 50-600 m and heights 2-14 m) and other bedforms. Approximately half this sand-wave area was 1eased in the 1977 Federal sale of tracts for oil and gas exploration. At present strong bottom currents are causing pipeline-maintenance problems in the upper Cook Inlet petroleum-producing area. Although the bottom currents in lower Cook Inlet are weaker, possible migration of the large sand waves there must be considered before making any seafloor installation, particularly pipelines.

In 1973, a private company collected high-resolution seismic baseline data that covered the LCI sand-wave field. In 1977 and 1978 the U.S. Geological Survey resurveyed several of these lines using the same accurate "Mini-Ranger" navigation system. Side-scan sonar, Uniboom, and 3.5 kHz seismic reflection records were obtained for comparison with the 1973 data, which were obtained using comparable seismic equipment. The side-scan sonar was indispensable, as comparing profiles alone was inadequate. Even when the transverse ship-track offsets between surveys were as much as 50-100 m, the sonographs allowed worthwhile comparisons.

Conclusions based on the comparison of the two surveys are: (1) The lower Cook Inlet sand-wave field appears to have been quite stable for the last 5 years along the segmerits studied. No movements greater than 10 m per year were detected. (2) A large number of the megaripp1e patterns and associations with the sand waves also show no measurable changes. (3) Either the rates and modes of change of a vast majority of sand waves and megaripples are not readily detectable with the techniques and time period employed, or they respond to periodic catastrophic phenomena that did not occur during this 5-year study period. Possibly some of the LCI sand waves are relict. (4) Some of the nonchanging sand-wave associations are in areas where strong bottom currents appear to be active.

Wong, F. L. (1984). Heavy Minerals in Surficial Sediments from Lower Cook Inlet, Alaska. *Geo-Marine Letters,* 4, 25-30. https://doi.org/10.1007/BF02237970

Amphiboles, orthopyroxenes, and clinopyroxenes dominate the heavy mineral suite of surficial sediments in lower Cook Inlet, Alaska. Sources for these sediments include the igneous arc terrane of the northeast Alaska Range, reworked intrabasinal sediments, and local drainages in lower Cook Inlet. The distribution of these deposits is a reflection of both the tidal currents and the prevailing southerly net movement from the head of Cook Inlet. The heavy mineral studies concur with similar findings from gravel analyses, clay mineral investigations, and quartz microtexture observations.

Management

Punt, A. E., Foy, R. J., Dalton, M. G., Long, W. C., & Swiney, K. M. (2015). Effects of Long-Term Exposure to Ocean Acidification Conditions on Future Southern Tanner Crab (Chionoecetes bairdi) Fisheries Management. *ICES Journal of Marine Science,* 73(3), 849-864. https://doi.org/10.1093/icesjms/fsv205

Demographic models of pre- and post-recruitment population dynamics were developed to account for the effects of ocean acidification on biological parameters that affect southern Tanner crab (Chionoecetes bairdi) larval hatching success and larval and juvenile survival. Projections of stock biomass based on these linked models were used to calculate biological and economic reference points on which fisheries management advice is based and thus provide fisheries managers with strategic advice on the likely long-term consequences of ocean acidification. The models utilized information for southern Tanner crab in the eastern Bering Sea. This information included the monitoring data on which conventional size-structured stock assessments are based, as well as the functional relationships that determine survival based on experiments that evaluated the consequences of ocean acidification over the next 100–200 years on crab larval hatching success, larval survival, and the survival of juvenile crab. The results highlighted that juvenile survival had the largest effect (~20% decrease over 75 years) on biological and economic reference points, while hatching success, particularly if density dependence occurs after hatching, and larval survival have smaller effects (<10% decrease). Catch and profits would be expected to decrease by >50% in 20 years if natural mortality is affected by ocean acidification. Additional laboratory data on oocyte and embryo development leads to large changes in biological reference points depending on the timing of ocean acidification effects relative to natural mortality. The results highlight the need for experiments to evaluate the longer term physiological effects of ocean acidification on multiple life history stages and to measure indices that directly inform population dynamics models to evaluate future management scenarios.

Minerals Management Service, Alaska OCS Region. (1995). *Cook Inlet Planning Area, Oil and Gas Lease Sale 149.* Retrieved from [No URL available]

No abstract available.

Marine Culture Heritage

United States Coast Guard. (2017). *Possible Downed Aircraft Remote Operated Vehicle Survey.* Retrieved from [No URL available]

No abstract available.

Bureau of Ocean Energy Management, Alaska OCS Region. (2016). *Cook Inlet Planning Area, Oil and Gas Lease Sale 244.* Retrieved from https://www.boem.gov/Cook-Inlet-Lease-Sale-244-Final-EIS-Volume-1/

The purpose of the Proposed Action is to offer certain OCS blocks located in Federal waters of Cook Inlet that may contain economically recoverable oil and gas resources. The need for the Proposed Action is to further the orderly development of OCS resources in accordance with the Outer Continental Shelf Lands Act of 1953 (OCSLA) (43 U.S.C. 1331 et seq.). Lease Sale 244 may lead to oil and gas development and production in the OCS of Cook Inlet. Oil serves as the feedstock for liquid hydrocarbon products including gasoline, aviation and diesel fuel, and various petrochemicals. Natural gas from Cook Inlet provides heat to Anchorage, Kenai Peninsula, and Mat-Su area homes and businesses, and more than 80% of the electricity for communities from Homer to Talkeetna is generated from Cook Inlet natural gas (AOGA, 2015); it is an important power source and raw material for domestic industries engaged in the manufacture or formulation of fertilizers, pharmaceuticals, plastics, and packaging. Oil and gas from the Cook Inlet OCS could help meet the Nation's energy needs and lessen the need for imports.

Minerals Management Service, Alaska OCS Region. (1995). *Cook Inlet Planning Area, Oil and Gas Lease Sale 149.* Retrieved from https://www.boem.gov/About-BOEM/BOEM-Regions/Alaska-Region/Environment/Environmental-Analysis/95_0066_voll.aspx

No abstract available.

Minerals Management Service, Alaska OCS Region. (2003). *Cook Inlet Planning Area, Oil and Gas Lease Sales 191 and 199.* Retrieved from https://www.boem.gov/About-BOEM/BOEM-Regions/Alaska-Region/Environment/Environmental-Analysis/CIsV3.aspx

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Shearer, G. B. (1977). Cultural Resources Assessments Atlantic Richfield Co. Retrieved from [No URL available].

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Physics

Brown, J., & Fiechter, J. (2012). Quantifying Eddy-Chlorophyll Covariability in the Coastal Gulf of Alaska. *Dynamics of Atmospheres and Oceans,* 55-56, 1-21. https://doi.org/10.1016/j.dynatmoce.2012.04.001

Many analyses of the interaction between ocean physics and biology in the Coastal Gulf of Alaska (CGOA) resolve chlorophyll variability separately from eddy-induced circulation, but eddy-chlorophyll

covariability has not received much attention. The present research quantified eddy-chlorophyll interaction from the covariability of observed chlorophyll and eddy kinetic energy (EKE) in the CGOA for 1998-2002. Analyses with coupled empirical orthogonal functions (CoEOFs) showed that covariability between the two fields resulted in strongly coupled modes a feature absent from standard-EOF analyses. Timescales of covariability were also incorporated into the analyses. The temporal evolution of each CoEOF mode was decomposed with the cross-wavelet power spectrum, and instances of covariability for synoptic timescales (2-6 months) were attributed to eddy-chlorophyll interaction. Further analyses in the present research included CoEOF decomposition for the output of a coupled physical-biological model in the CGOA. Model-observation comparisons with CoEOFs offer a new and important way to evaluate coupled models for eddy-chlorophyll interaction across multiple temporal and spatial scales. Implications for cross-shelf transport and spatiotemporal sampling for both observation and model data fields are also discussed.

Halverson, M. J., Belanger, C., & Gay, S. M. (2013). Seasonal Transport Variations in the Straits Connecting Prince William Sound to the Gulf of Alaska. *Continental Shelf Research,* 63, S63-S78. https://doi.org/10.1016/j.csr.2012.06.017

Exchange of water between Prince William Sound and the Gulf of Alaska has a significant impact on its circulation and biological productivity. Current meter records from moored instruments in the two major straits connecting Prince William Sound to the Gulf of Alaska are analyzed to characterize the seasonal variations in water exchange. Eight individual deployments, each lasting for about 6 months, were made during the years 2005-2010. Two moorings were placed across each passage to account for horizontal flow variability. Monthly averaged, depth-integrated transport in winter is characterized by a strong barotropic inflow through Hinchinbrook Entrance and outflow through Montague Strait. The transport through each passage can reach 0.2 Sv, which could replenish the volume of Prince William Sound in as little as 3 months. Depth-integrated transport is weaker and more variable in direction in summer than in winter, implying that Prince William sound is not always a simple flow-through system. Monthly transports range between -0.05 and 0.08 Sv in each passage, and the corresponding flushing times exceed 1 year. The flow through both passages is highly baroclinic in the summer, so that the layer transport can be significant. For example, the deep inflow through Hinchinbrook Entrance can reach 0.05 Sv, which would flush the deep regions of Prince William Sound (> 400 m) in only 23 days. The transport imbalance between Montague Strait and Hinchinbrook Entrance cannot be accounted for by considering other terms in a volume budget such as local freshwater input, meaning the imbalance is mostly a result of under-resolving the cross-strait flow variability. The magnitude of the monthly mean depth-integrated transport through Montague Strait and Hinchinbrook Entrance depends non-linearly on the shelf winds. Strong downwelling conditions, characteristic of the winter, drive inflow through Hinchinbrook Entrance, which is balanced by outflow through Montague Strait. Weak downwelling or upwelling conditions, characteristic of the summer, allow deep water from below the shelf break to flow in through Hinchinbrook Entrance.

Higman, B., Shugar, D. H., Stark, C. P., Ekstrom, G., Koppes, M. N., Lynett, P., . . . Loso, M. (2018). The 2015 Landslide and Tsunami in Taan Fiord, Alaska. *Scientific Reports,* 8, 12. https://doi.org/10.1038/s41598-018-30475-w

Glacial retreat in recent decades has exposed unstable slopes and allowed deep water to extend beneath some of those slopes. Slope failure at the terminus of Tyndall Glacier on 17 October 2015 sent 180 million tons of rock into Taan Fiord, Alaska. The resulting tsunami reached elevations as high as 193 m, one of the highest tsunami runups ever documented worldwide. Precursory deformation began decades before failure, and the event left a distinct sedimentary record, showing that geologic evidence can help understand past occurrences of similar events, and might provide forewarning. The event was detected within hours through automated seismological techniques, which also estimated the mass and direction of the slide - all of which were later confirmed by remote sensing. Our field observations provide a benchmark for modeling landslide and tsunami hazards. Inverse and forward modeling can provide the framework of a detailed understanding of the geologic and hazards implications of similar events. Our results call attention to an indirect effect of climate change that is increasing the frequency and magnitude of natural hazards near glaciated mountains.

Mordy, C. W., Stabeno, P. J., Kachel, N. B., Kachel, D., Ladd, C., Zimmermann, M., . . . Doyle, M. J. (2019). Patterns of Flow in the Canyons of the Northern Gulf of Alaska. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 165, 203-220. https://doi.org/10.1016/j.dsr2.2019.03.009

The continental shelf around Kodiak Island is incised with numerous submarine canyons, which play an important role in the cross-shelf transport of heat, salt, and nutrients, and the transport of ichthyoplankton of deep-spawning fish from the slope region into the shallow nursery grounds surrounding Kodiak Island. To explore the pathways and variability of flow, and the extent of tidal mixing within the canyons, moorings were placed in the Chiniak, Barnabas, and Amatuli troughs, and off the shelf from Resurrection Bay (Seward Line) and the Kenai Peninsula (Gore Point). In the troughs, intensified flow was evident near the trough walls, and flow was directed by bathymetry with inflow along the upstream (northern) side and outflow along the downstream (southern) side. The presence of mesoscale eddies in the gulf had no unique influence on currents or salinity in the troughs. Tidal mixing was strongest in Chiniak Trough, and this introduced cold, nutrient-rich bottom waters into the upper water column. Intensified bottom flow associated with the Alaskan Coastal Current was evident along the Seward Line and Gore Point, and directed toward the Kennedy-Stevenson Entrances, which are also regions of strong tidal mixing. Observations of tidal mixing were consistent with model results and satellite images showing cooler, phytoplankton-rich water in summer in the nursery grounds that surround Kodiak Island. Patterns of flow within the troughs and in Shelikof Strait were consistent with the springtime advance of ichthyoplankton across the shelf.

Stabeno, P. J., Bell, S., Cheng, W., Danielson, S., Kachel, N. B., & Mordy, C. W. (2016). Long-Term Observations of Alaska Coastal Current in the Northern Gulf of Alaska. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 132, 24-40. https://doi.org/10.1016/j.dsr2.2015.12.016

The Alaska Coastal Current is a continuous, well-defined system extending for 1700 km along the coast of Alaska from Seward, Alaska to Samalga Pass in the Aleutian Islands. The currents in this region are examined using data-collected at > 20 mooring sites and from > 400 satellite-tracked drifters. While not

continuous, the mooring data span a 30 year period (1984-2014). Using current meter data collected at a dozen mooring sites spread over four lines (Seward, Gore Point, Kennedy and Stevenson Entrances, and the exit to Shelikof Strait) total transport was calculated. Transport was significantly correlated with alongshore winds, although the correlation at the Seward Line was weak. The largest mean transport in the Alaska Coastal Current occurred at Gore Point (1.4 x 10(6) m(3) s(-1) in winter and 0.6 x 10(6) m(3) S-1 in summer), with the transport at the exit to Shelikof Strait (1.3 x 10(6) m(3) s(-1) in winter and 0.6 x 10(6) m(3) S-1 in summer) only slightly less. The transport was modified at the Seward Line in late summer and fall by frontal undulations associated with strong river discharge that enters onto the shelf at that time of year. The interaction of the Alaska Coastal Current and tidal currents with shallow banks in the vicinity of Kodiak Archipeligo and in Kennedy-Stevenson Entrance results in mixing and prolonged primary production throughout the summer.

Section XIV: Chukchi Sea

Biology

Beatty, W. S., Lemons, P. R., Sethi, S. A., Everett, J., Lewis, C. J., Olsen, J. B., . . . Wenburg, J. K. (2019). *Estimating Pacific Walrus Abundance and Demographic Rates from Geentic Mark-Recapture.* Retrieved from https://www.boem.gov/sites/default/files/boem-newsroom/Library/Publications/2019/BOEM_2019-059.pdf

In 2013, the U.S. Fish and Wildlife Service initiated a genetic mark-recapture project to estimate Pacific walrus abundance, survival, and reproductive rates. Based on a series of simulations, we identified sample size goals that could generate an abundance estimate with a coefficient of variation of 0.25 after the fifth year (i.e. 2017). We conducted successful cruises that met these overall sample size goals from 2013–2016. Consequently, the walrus genetic mark-recapture project was initially developed as a five-year project to evaluate the efficacy of a long-term monitoring program. In addition to the genetic mark-recapture project, the U.S. Fish and Wildlife Service also conducted a Pacific walrus age structure survey in 2016. Data from age structure surveys have been used in numerous peer-reviewed manuscripts (Taylor and Udevitz 2015, Taylor et al. 2017), and age structure surveys currently represent the best available method to collect demographic information on the Pacific walrus. The overall objectives of this study were to (a) estimate walrus population abundance using genetic mark-recapture, (b) estimate walrus survival and reproductive rates. Specifically, the objectives for our sampling in 2017 were (a) collect additional biopsy samples for the walrus genetic mark-recapture project to increase sample sizes and precision of parameter estimates (b) collect a sample of the standing age structure.

Connell, P. E., Michel, C., Meisterhans, G., Arrigo, K. R., & Caron, D. A. (2018). Phytoplankton and Bacterial Dynamics on the Chukchi Sea Shelf During the Spring-Summer Transition. *Marine Ecology Progress Series,* 602, 49-62. https://doi.org/10.3354/meps12692

Climate warming is exerting significant change on the physical properties of the Arctic Ocean, which in turn has marked consequences for the biology of the region. The Chukchi Sea is notable for its species richness as a consequence of a nutrient-rich shelf region that supports substantial primary production. However, little is known about the carbon transformations at the base of the food web in the Chukchi Sea, and in particular the relative amounts of primary production that are transferred directly to higher trophic levels or remineralized within the microbial loop. We measured microbial standing stocks (bacteria to microplankton), phytoplankton growth and mortality rates, and bacterial production and mortality rates at 10 stations in the Chukchi Sea and Bering Strait during the spring-summer transition. Our study revealed that protistan grazers consumed substantially more phytoplankton carbon than bacterial carbon. Phytoplankton growth rates were variable, but at times considerable (range: -0.06 to 0.71 d(-1)), with protistan grazers consuming an average of 46% of the daily primary production. Heterotrophic protists exerted significant grazing pressure on phytoplankton despite low environmental temperatures. Bacterial production and mortality rates were low (generally <1 mu g C 1(-1) d(-1)) and at times in balance, but overall bacterial production exceeded mortality. This study improves our understanding of carbon cycling in the Chukchi Sea during the spring-summer transition, demonstrating a significant transfer of primary production to heterotrophic protists at that time of year.

Ershova, E., Hopcroft, R., Kosobokova, K., Matsuno, K., Nelson, R. J., Yamaguchi, A., & Eisner, L. (2015). Long-Term Changes in Summer Zooplankton Communities of the Western Chukchi Sea, 1945–2012. *Oceanography,* 28(3), 100-115. https://doi.org/10.5670/oceanog.2015.60

The Chukchi Sea pelagic ecosystem, which is finely tuned to the region's seasonal ice formation and retreat, has been undergoing dramatic oceanographic change related to shifting sea ice cover and increasing temperatures over the last decades. We examine historical data sets on zooplankton communities in the central Chukchi Sea during the time period 1946 to 2012. Analysis is confounded by differences between years in terms of spatial coverage, seasonal variability, and methodology; nonetheless, trends remain detectable when a sufficient number of study years is compiled. In addition to high levels of interannual variability, we demonstrate that there have been significant increases in zooplankton biomass and abundance in recent years compared to historical studies, along with shifting distribution ranges for several key species. This signal is most pronounced for the copepods, particularly Calanus glacialis, which appears to be indirectly benefiting from warming of the region. While summer zooplankton communities of the Chukchi Sea have been primarily Bering-Pacific in character for as long as records exist, continuing warming and ice loss are increasing the influence of Bering-Pacific fauna within the Chukchi region.

Ershova, E. A., Questel, J. M., Kosobokova, K., & Hopcroft, R. R. (2017). Population Structure and Production of Four Sibling Species of Pseudocalanus spp. In the Chukchi Sea. *Journal of Plankton Research,* 39(1), 48-64. https://doi.org/10.1093/plankt/fbw078

Copepods of the genus Pseudocalanus are important members of zooplankton communities in temperate and polar shelf regions, but few studies have focused on their species-specific biology due to the very subtle morphological differences between the species. We assess the distribution, population structure and production of four co-occurring species of Pseudocalanus across the Chukchi Sea during 2004, 2009 and 2012. Our approach used a combination of microscopic identification and species-specific polymerase chain reaction to discriminate between the species. Currently, the arctic P. acuspes dominates the genus (50-90%), with the relative distribution of species closely linked to water mass distribution and variations in physical properties, making Pseudocalanus important indicators of water mass origin. Although the temperate P. newmani had a significant presence throughout the Chukchi Sea, its stage distribution suggests that they recruit poorly in cold waters. Direct temperature-manipulation experiments further suggest that the reproductive activity of the two temperate species is inhibited at low temperatures, while the arctic P. acuspes exhibits reduced fitness and lower reproductive capacity when temperatures are increased to 10 degrees C. Our results suggest that shifting oceanographic patterns and climate warming will have unequal impact on this genus, arising from species-specific differences in life histories and tolerance to environmental conditions.

Logerwell, E., Rand, K., Danielson, S., & Sousa, L. (2018). Environmental Drivers of Benthic Fish Distribution in and around Barrow Canyon in the Northeastern Chukchi Sea and Western Beaufort Sea. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 152, 170-181. https://doi.org/10.1016/j.dsr2.2017.04.012

We investigate the relationships between Arctic fish and their environment with the goal of illustrating mechanisms of climate change impacts. A multidisciplinary research survey was conducted to characterize fish distribution and oceanographic processes in and around Barrow Canyon in the northeastern Chukchi Sea in summer 2013. Benthic fish were sampled with standard bottom trawl survey methods. Oceanographic data were collected at each trawl station. The density of Arctic cod (Boreogadus saida), the most abundant species, was related to bottom depth, salinity and temperature. Arctic cod were more abundant in deep, cold and highly saline water in Barrow Canyon, which was likely advected from the Chukchi Shelf or from the Arctic Basin. We hypothesize that Arctic cod occupied Barrow Canyon to take advantage of energy-rich copepods transported in these water masses. Arctic cod were similarly more abundant in deep, cold and high salinity water in the Beaufort Sea, documented by a comparable multidisciplinary survey conducted in 2008. These linkages between oceanographic variables and benthic fish distribution and abundance suggest that advection, sea-ice dynamics and pelagic-benthic coupling are important for the ecology of benthic Arctic fishes. These processes have been and will likely continue to be impacted by climate change. Our results improve the understanding of the mechanistic linkages between climate change and benthic Arctic fish ecology.

Vate Brattstrom, L., Mocklin, J. A., Crance, J. L., & Friday, N. A. (2019). *Arctic Whale Ecology Study (Arcwest): Use of the Chukchi Sea by Endangered Baleen and Other Whales (Westward Xtension of the Bowfest).* Retrieved from https://www.afsc.noaa.gov/nmml/PDF/ARCWEST_AnnualReport_201601.pdf

Through an Inter-Agency agreement (IAA) between the National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), National Marine Mammal Laboratory (NMML) and the Bureau of Ocean Energy Management (BOEM), NMML is conducting a dedicated multi-year study to determine relationships between dominant currents passing from the Bering Sea into and through the Chukchi Sea and prey resources delivered to the Barrow Arch area (an area of high bowhead whale and prey concentrations between Wainwright and Smith Bay), and to provide information about the dynamic nature of those relationships relative to whale distribution and habitat utilization in the eastern Chukchi and extreme western Beaufort Seas. This study will also provide important baseline data on the occurrence, distribution, and habitat use of large whales in an area that is subject to rapid change in climate and human industrial development. This annual report covers work conducted in 2015, the third year of the study. The major activities during 2015 consisted of planning for and executing the 2015 Arctic Whale Ecology Study (ARCWEST)/Chukchi Acoustics, Oceanography, and Zooplankton Study-extension (CHAOZ-X) cruise, after-season maintenance and testing of the passive acoustic recorders, the processing and analysis of data collected during the 2013 and 2014 cruises, and planning for the final report. The cruise took place on the chartered research vessel F/V Aquila, left Nome, AK on 8 September, and returned to Dutch Harbor, AK on 28 September. Eleven scientists, technicians, and observers from six different laboratories and institutions participated on the ARCWEST cruise. As a result of the work conducted to complete the final report for the Chukchi Acoustics, Oceanography, and Zooplankton Study (CHAOZ), the ARCWEST team has developed the framework of how the ARCWEST data will be integrated to enable multi-disciplinary, synthesis analyses and the

programs to run these analyses have been written. The CHAOZ final report will provide important baseline data to which ARCWEST can compare. The acoustics group is also mid-way through implementing a passive acoustics database (Tethys, Roch et al., 2013), as part of a pilot project with NGDC to archive the data and make it publically accessible.

Chemistry

Pipko, I. I., Semiletov, I. P., Tishchenko, P. Y., Pugach, S. P., & Christensen, J. P. (2002). Carbonate Chemistry Dynamics in Bering Strait and the Chukchi Sea. *Progress in Oceanography,* 55(1-2), 77-94. https://doi.org/10.1016/S0079-6611(02)00071-X

Fall dynamics of the carbonate system in the shallow Chukchi Sea is a result of the interaction between physical and biological processes such as mixing of different water masses, cooling, photosynthesis-respiration. The study area acts as a sink for atmospheric CO2. The general trend in surface pCO(2) distribution is a decrease towards the ice edge, which is determined by the temperature decrease, whereas mesoscale variability of the carbonate parameters is controlled by the interaction between different waters. The calculated September 1996 flux of CO2 from the air into the sea on eastern Chukchi Sea is about 1x10(12) g C.

Geology

Chen, Z. H., Gao, A. G., Liu, Y. G., Sun, H. Q., Shi, X. F., & Yang, Z. S. (2003). Ree Geochemistry of Surface Sediments in the Chukchi Sea. *Science in China Series D-Earth Sciences,* 46(6), 603-611. https://doi.org/10.1007/BF02984538

Analyses of rare earth elements (REEs) in 26 surface sediment samples obtained from the Chukchi Sea were conducted using ICP-MS. In general, REEs are relatively rich in fine-grained sediments and deplete in coarse-grained sediments in the Chukchi Sea although REEs have large concentration spans in different types of sediments. Except that a few samples have weak enrichments of light or heavy REEs, most samples exhibit flat shale-normalized REE pattern, indicating that surface sediments in the Chukchi Sea are composed dominantly of terrigenous components experiencing weak chemical weathering. In terms of REE concentrations and other characteristic parameters, we inferred that sediments on the eastern and western sides of the Chukchi Sea are derived from landmasses of Alaska and Siberia, respectively; the midsouth sediments are possibly related to northward dispersion of the Yukon River materials. The Herald Shoal in the center of the study area is covered with relict sediment, which has large ratios of light-to-heavy REEs (SigmaC(e)/SigmaY ratio) and lacks evident negative Ce anomaly; cerium enrichment is possibly related to manganese transfer under oxidizing conditions in early diagenesis.

Dobson, M. E. (Cartographer). (1989). Bathymetry Map. Retrieved from [No URL available]

No abstract available.

Dobson, M. E. (Cartographer). (1989). Geologic Features Map. Retrieved from [no URL available.]

No abstract available.

Dobson, M. E. (Cartographer). (1989). Seafloor Features Map. Retrieved from [No URL available}

No abstract available.

Dobson, M. E. (Cartographer). (1989). Shallow Sediemnts Isopach Map. Retrieved from [No URL available]

No abstract available.

Dove, D., Polyak, L., & Coakley, B. (2014). Widespread, Multi-Source Glacial Erosion on the Chukchi Margin, Arctic Ocean. *Quaternary Science Reviews,* 92, 112-122. https://doi.org/10.1016/j.quascirev.2013.07.016

Multibeam bathymetry and sub-bottom profiler data acquired in 2011 from R/V Marcus Langseth in a broad grid over the Chukchi Sea margin reveal multiple glacigenic features on the top and slopes of the outer Chukchi Shelf/Rise and adjacent Borderland. Glacial lineations record a complex pattern of erosion likely formed by both local glaciation and far-traveled ice shelves/streams sourced from the Laurentide, and possibly East Siberian ice sheets. Multiple till units and stacked debris flows indicate recurrent glacial grounding events. Composite till wedges of several hundred meters thick extend the shelf edge by 10–20 km in places. Distribution of ice-marginal features on the Chukchi Rise suggests stepwise deglacial retreat towards the shelf, backing up the broad bathymetric trough at the eastern side of the Rise. Glacigenic features other than extensive iceberg scouring cannot be identified above 350-m depth, and no glacigenic bedforms are present on the current-swept shallow shelf. Despite the resulting uncertainty with the southern extent of the glaciation, the data suggest a widespread grounded-ice presence on the northern Chukchi Shelf, which makes it an important, previously underestimated component of the Arctic paleo-glacial system.

Edwards, A. (Cartographer). (1990). Isopach Map of Upper Sediment Unit (Seafloor to Horizon a). Retrieved from [No URL available]

No abstract available.

Edwards, A. (Cartographer). (1990). Water Depth and Seafloor Features Map. Retrieved from [No URL available]

No abstract available.

Hill, J. C., & Driscoll, N. W. (2008). Paleodrainage on the Chukchi Shelf Reveals Sea Level History and Meltwater Discharge. *Marine Geology,* 254(3-4), 129-151. https://doi.org/10.1016/j.margeo.2008.05.018

CHIRP subbottom data collected across the Chukchi shelf, offshore NW Alaska, imaged numerous paleochannels and valleys that appear to have been downcut and incised during sea level falls associated with glacial intervals. In contrast, the two most recent incisions appear to have been formed during the period of sea level rise following the Last Glacial Maximum (LGM). The architecture and infill associated with these two incisions suggests that they were formed by an increase in discharge. These events appear to be unrelated to sea level fluctuations, but rather triggered by climatic variations during the most recent deglaciation (i.e. meltwater discharge). Radiocarbon dates from sediment cores within the southern incised valley suggest that the two episodes of meltwater discharge may correlate with Meltwater Pulse 1-A (similar to 14,000 cal. yr BP) and evidence of iceberg scouring on outer Chukchi shelf (similar to 12,000 to 13,000 cal. yr BP), respectively. Regional transgression across the interfluves on the middle Chukchi shelf appears to postdate the second meltwater discharge and may correlate with Meltwater Pulse 1-B (11,500 cal. yr BP). This evidence suggests that in glacially dominated landscapes, episodes of large discharge to the shelf might be out of phase with the sea level cycle. In addition, the presence of glacial meltwater drainage on the shelf implies a greater volume of continental glaciation during the LGM than previously recognized.

Hill, J. C., Driscoll, N. W., Brigham-Grette, J., Donnelly, J. P., Gayes, P. T., & Keigwin, L. (2017). New Evidence for High Discharge to the Chukchi Shelf since the Last Glacial Maximum. *Quaternary Research,* 68(2), 271-279. https://doi.org/10.1016/j.yqres.2007.04.004

Using CHIRP subbottom profiling across the Chukchi shelf, offshore NW Alaska, we observed a large incised valley that measures tens of kilometers in width. The valley appears to have been repeatedly excavated during sea level lowering; however, the two most recent incisions appear to have been downcut during the last sea level rise, suggesting an increase in the volume of discharge. Modern drainage from the northwestern Alaskan margin is dominated by small, low-discharge rivers that do not appear to be large enough to have carved the offshore drainage. The renewed downcutting and incision during the deglaciation and consequent base level rise implies there must have been an additional source of discharge. Paleoprecipitation during deglaciation is predicted to be at least 10% less than modern precipitation and thus cannot account for the higher discharge to the shelf. Glacial meltwater is the most likely source for the increased discharge.

Phillips, R. L., & Reiss, T. E. (1985). *Nearshore Geologic Investigations, Point Barrow to Skull Cliff, Northeast Chukchi Sea.* https://doi.org/10.3133/ofr8550

No abstract available.

Thurston, D. K. (2006). [Age and Location of Phillip's Core of Peat in Chukchi]. Retrieved from [No URL available]

No abstract available.

Thurston, D. K., & Theiss, L. A. (1987). *Geologic Report for the Chukchi Sea Planning Area, Alaska.* Retrieved from [No URL available]

The Chukchi Sea Planning Area encompasses approximately 49,000 square miles of the northwestern Alaska continental shelf and is tentatively scheduled for public offering as Lease Sale 109 in early 1988. The planning area lies offshore of the National Petroleum Reserve in Alaska (NPRA), which provides geological and geophysical control for offshore interpretations. Three major stratigraphic sequences are recognized in northwestern Alaska: (1) the Franklinian sequence (Precambrian to MIddle Devonian metasedimetary rocks), which comprises the acoustic and economic basement complex throughout most of norhtern Alaska; (2) the Ellesmerian sequence (Late Devonian to Early Cretaceous), which is composed of northerly sourced clastic and carbonate rocks; and (3) the Brookian sequence (Early Cretaceous to Tertiary), which comprises a clastic wedge that was shed generally northward away from the Brooks Range orogen. The Ellesmerian sequence is separated from the underlying basement by the Ellesmerian unconformity (EU) and from the overlying Brookian sequence by the Lower Creatceous unconformity (PU). The Brookian seismic sequence is subdivided into lower and upper parts by the mid-Brookian unconformity (mBU) of Late Cretaceous (?) to Tertiary age.

Vineyard, T. (Cartographer). (1989). Bathymetry and Seafloor Features Map. Retrieved from [No URL available]

No abstract available.

Vineyard, T. (Cartographer). (1989). Geologic Features Map. Retrieved from [No URL available]

No abstract available.

Vineyard, T. (Cartographer). (1989). Isopach Map. Retrieved from [No URL available]

No abstract available.

Viscosi-Shirley, C., Mammone, K., Pisias, N., & Dymond, J. (2003). Clay Mineralogy and Multi-Element Chemistry of Surface Sediments on the Siberian-Arctic Shelf: Implications for Sediment Provenance and Grain Size Sorting. *Continental Shelf Research,* 23(11-13), 1175-1200. https://doi.org/10.1016/s0278-4343(03)00091-8

Clay mineral and bulk chemical (Si, Al, K, Mg, Sr, La, Ce, Nd) analyses of terrigenous surface sediments on the Siberian-Arctic shelf indicate that there are five regions with distinct, or endmember, sedimentary compositions. The formation of these geochemical endmembers is controlled by sediment provenance and grain size sorting. (1) The shale endmember (Al, K and REE rich sediment) is eroded from fine-grained marine sedimentary rocks of the Verkhoyansk Mountains and Kolyma-Omolon superterrain, and discharged to the shelf by the Lena, Yana, Indigirka and Kolyma Rivers. (2) The basalt endmember (Mg rich) originates from NE Siberia's Okhotsk-Chukotsk volcanic belt and Bering Strait inflow, and is prevalent in Chukchi Sea Sediments. Concentrations of the volcanically derived clay mineral smectite are elevated in Chukchi fine-fraction sediments, corroborating the conclusion that Chukchi sediments are volcanic in origin. (3) The mature sandstone endmember (Si rich) is found proximal to Wrangel Island and sections of the Chukchi Sea's Siberian coast and is derived from the sedimentary Chukotka terrain that comprises these landmasses. (4) The immature sandstone endmember (Sr rich) is abundant in the New Siberian Island region and reflects inputs from sedimentary rocks that comprise the islands. (5) The immature sandstone endmember is also prevalent in the western Laptev Sea, where it is eroded from sedimentary deposits blanketing the Siberian platform that are compositionally similar to those on the New Siberian Islands. Western Laptev can be distinguished from New Siberian Island region sediments by their comparatively elevated smectite concentrations and the presence of the basalt endmember, which indicate Siberian platform flood basalts are also a source of western Laptev sediments. In certain locations grain size sorting noticeably affects shelf sediment chemistry. (1) Erosion of fines by currents and sediment ice rafting contributes to the formation of the coarse-grained sandstone endmembers. (2) Bathymetrically controlled grain size sorting, in which fines preferentially accumulate offshore in deeper, less energetic water, helps distribute the fine-grained shale and basalt endmembers. An important implication of these results is that the observed sedimentary geochemical endmembers provide new markers of sediment provenance, which can be used to track sediment transport, ice-rafted debris dispersal or the movement of particle-reactive contaminants.

Marine Culture Heritage

Barr, B. W., Delgado, J. P., Lawrence, M. S., & Van Tilburg, H. K. (2016). The Search for the 1871 Whaling Fleet of the Western Arctic: Writing the Final Chapter. *International Journal of Nautical Archaeology,* 46(1), 149-163. https://doi.org/10.1111/1095-9270.12205

During 2015, the NOAA Office of National Marine Sanctuaries led a systematic seabed mapping survey along the Arctic coast of Alaska in search of whaling ships abandoned in 1871. The purpose of the expedition was to determine if wreckage from these abandoned ships was still present in the survey area, and, if so, to assess and document its location, status and condition. The project mapped approximately 50 km2 of seabed using sidescan sonar and magnetometry and identified six sites that contained wreckage from at least two whaling ships. Magnetometry data also suggested that additional wreckage may be buried in the seabed.

Elias, S. A., Short, S. K., & Phillips, R. L. (1992). Paleoecology of Late-Glacial Peats from the Bering Land Bridge, Chukchi Sea Shelf Region, Northwestern Alaska. *Quaternary Research,* 38, 371-378. https://doi.org/10.1016/0033-5894(92)90045-K

Insect fossils and pollen from late Pleistocene nonmarine peat layers were recovered from cores from the shelf region of the Chukchi Sea at depths of about 50 m below sea level. The peats date to 11,300−11,000 yr B.P. and provide a limiting age for the regional Pleistocene-Holocene marine transgression. The insect fossils are indicative of arctic coastal habitats like those of the Mackenzie Delta region (mean July temperatures = 10.6–14°C) suggesting that 11,000 yr ago the exposed Chukchi Sea shelf had a climate substantially warmer than modern coastal regions of the Alaskan north slope. The pollen spectra are consistent with the age assignment to the Birch Interval (14,000–9000 yr B.P.). The data suggest a meadow-like graminoid tundra with birch shrubs and some willow shrubs growing in sheltered areas.

University of Alaska Fairbanks (1976). *Bering Land Bridge Cultural Resource Study.* Retrieved from http://alaska.glynx.gina.alaska.edu/catalog/entries/1434-bering-land-bridge-cultural-resource-study

The following report was produced by the University of Alaska Museum, Fairbanks, Alaska, under Contract #08550-CT5-45 with the Bureau of Land Management Outer Continental Shelf Office. The purpose of the research was to identify areas of high archeological probability on Alaska's outer continental shelf and to assess the feasibility of actually detecting submerged archeological sites. The study is to be used as a planning tool by the BLM-OCS office to assure the preservation and management of cultural resources on the outer continental shelf in relation to oil lease activities.

Hoffecker, J. F., & Elias, S. A. (2003). Environment and Archeology in Beringia. *Evolutionary Anthropology: Issues, News, and Reviews,* 12(1), 34-49. https://doi.org/10.1002/evan.10103

The occupation of Beringia remains one of the most complex problems in human paleoecology. This is because of the wide array of variables that are likely to have affected the timing and character of settlement in the now partially submerged land that lies between the Lena and Mackenzie Rivers. At a minimum, these variables include changing sea levels and coastlines, advancing and retreating glaciers, changing fauna and flora (including trees), and evolving human adaptations to high-latitude environments. Humans occupied Beringia during the interval between the end of the Last Glacial Maximum cold peak (ca. 20,000 cal BP) and the beginning of the Holocene (11,600 cal BP), when all of these variables were in an almost constant state of flux.

Hoffecker, J. F., Elias, S. A., O'Rourke, D. H., Scott, G. R., & Bigelow, N. H. (2016). Beringia and the Global Dispersal of Modern Humans. *Evolutionary Anthropology,* 25(2), 64-78. https://doi.org/10.1002/evan.21478

Until recently, the settlement of the Americas seemed largely divorced from the out-of-Africa dispersal of anatomically modern humans, which began at least 50,000 years ago. Native Americans were thought to represent a small subset of the Eurasian population that migrated to the Western Hemisphere less than 15,000 years ago. Archeological discoveries since 2000 reveal, however, that Homo sapiens occupied the high-latitude region between Northeast Asia and northwest North America (that is, Beringia) before 30,000 years ago and the Last Glacial Maximum (LGM). The settlement of Beringia now appears to have been part of modern human dispersal in northern Eurasia. A 2007 model, the Beringian Standstill Hypothesis, which is based on analysis of mitochondrial DNA (mtDNA) in living people, derives Native Americans from a population that occupied Beringia during the LGM. The model suggests a parallel between ancestral Native Americans and modern human populations that retreated to refugia in other parts of the world during the arid LGM. It is supported by evidence of comparatively mild climates and rich biota in south-central Beringia at this time (30,000-15,000 years ago). These and other developments suggest that the settlement of the Americas may be integrated with the global dispersal of modern humans.

Bureau of Ocean Energy Management, & Alaska OCS Region.(2014). *Chukchi Sea Planning Area, Oil and Gas Lease Sale 193.* Retrieved from https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/About_BOEM/BOEM_Regions/Alaska_Region/Environment/Environmental_Analysis/Lease_Sale_193_DraftSSEIS_vol1.pdf

This Draft Second Supplemental Environmental Impact Statement (SEIS) addresses Outer Continental Shelf (OCS) Oil and Gas Lease Sale 193, Chukchi Sea, Alaska... This Draft Second SEIS analyzes the potential environmental effects of potential oil and gas activities associated with Lease Sale 193. This analysis is based on a new exploration and development scenario of 4.3 billion barrels of oil.

McGillivary, P. A. (2005). *Recovering the Lost Treasures of Ipiutak (Pt. Hope), Alaska*. Paper presented at the Oceans 2005, New York. https://doi.org/ 10.1109/OCEANS.2005.1639907

In the 1940s three archaeologists, two Americans and one Danish colleague, began to excavate on the north Alaskan coast at a place called Ipiutak. This site near Pt. Hope, Alaska, was the locale of a proto-Inuit [Eskimo] community active approximately 1500 YPB. The Ipiutak excavations, funded by the Works Projects Administration (WPA), produced an astonishing array of jade and ivory carvings declared the most amazing treasures ever found in the arctic. At the start of WWII the two Americans archaeologists left the Pt. Hope excavations because of the war, leaving the Danish archaeologist to continue and complete the on-site work. One shipment of the artifacts went back to New York to be photographed, but on its' return to Alaska, the ship it was on, an Army barge, sank en route to Juneau. There may have been a second barge from Pt. Hope, loaded with Ipiutak artifacts, lost not far offshore in the shallow ice-infested area of strong currents of the Bering Strait. A portion of the collections apparently ended up in the Danish National Museum, and a portion of these collections remained in the U.S., but a significant portion of the collections are apparently carefully packaged and intact on the seafloor within one or two

shipwrecks. A multi-agency plan to face the significant challenges to the recovery of the Treasures of Ipiutak is presented, along with photographs of some of the treasures known to be on the seafloor.

Rogers, J. S. (2010). *Archaeological Assessment of Geotechnical Cores and Materials, 2011 Statoil Ancillary Activities, Chukchi Sea, Alaska.* Retrieved from https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/About_BOEM/BOEM_Regions/Alaska_Region/Leasing_and_Plans/Plans/2012-06_Statoil_Marine_Archaeology_Report.pdf

This report provides an archaeological assessment of seafloor coring and site survey activities conducted by Statoil USA E&P Inc. (Statoil) contractors Fugro Marine Geosciences in September, 2011, in the Chukchi Sea, Alaska, and describes archaeological analyses of recovered material. This review addresses a Condition of Approval on Statoil's 2011 Ancillary Activities Notice. Coring activities resulted in the recovery of wood fragments, which were subsequently dated to over 40,000 years of age. No cultural resources, of either historic or prehistoric origin, were identified in any of the materials recovered for analysis or in remotesensing data acquired by the site survey and reviewed by the author of this report.

Minerals Management Service, Alaska OCS Region. (2007). *Chukchi Sea Planning Area, Oil and Gas Lease Sale 193 and Seismic Surveying Activities in the Chukchi Sea.* Retrieved from https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/About_BOEM/BOEM_Regions/Alaska_Region/Environment/Environmental_Analysis/2007-026-Vol%20I.pdf

This environmental impact statement (EIS) examines a proposal for oil and gas leasing in the Chukchi Sea and three alternatives to this Proposed Action. This EIS also examines a proposal for exploration seismic survey permitting in 2007 in the proposed sale area and two alternatives for the 2007 seismic surveys. This EIS addresses the potential impacts under the various alternatives and the potential mitigation measures associated with the Proposed Actions for leasing and associated exploration seismic-survey activity. The Proposed Action for the lease sale examined in the EIS is to offer for lease approximately 6,156 whole and partial blocks (about 34 million acres) identified as the program area in the 2002-2007 5-Year Program. The proposed Sale 193 area excludes a 15- to 50-mile(mi-)-wide corridor along the coast, the polynya or Spring Lead System. Water depths in the sale area vary from about 95 feet (ft) to approximately 262 ft. A small portion of the northeast corner of the area deepens to approximately 9,800 ft. The scenario assumed for environmental analysis involves the discovery, development, and production of the first offshore oil field in the Chukchi Sea. The Proposed Action for seismic surveying is to permit both prelease and postlease exploration seismic surveys within the entire proposed Sale 193 area. All permitted seismic surveys would be subject to the standard stipulations for Geological and Geophysical (G&G) permit activities (Sec. II.A.4), the measures to mitigate seismic-surveying effects (Sec. II.B.4.a), and the mitigation and monitoring requirements of the selected alternative (Alternative 6) from the Final Programmatic Environmental Assessment (PEA), Arctic Ocean Outer Continental Shelf Seismic Surveys - 2006, dated June 2006 (USDOI, MMS, 2006a)) (Sec. II.B.4.b).

Thurston, D. K. (2013). *Emails Re: Target in Barrow Canyon*. Retrieved from [No URL available]

No abstract available.

Physics

Fang, Y. C., Potter, R. A., Statscewich, H., Weingartner, T. J., Winsor, P., & Irving, B. K. (2017). Surface Current Patterns in the Northeastern Chukchi Sea and Their Response to Wind Forcing. *Journal of Geophysical Research: Oceans,* 122(12), 9530-9547. https://doi.org/10.1002/2017jc013121

We measured northeastern Chukchi Sea surface currents using high-frequency radar systems (HFR) during the ice-free periods of August to October from 2010–2014. We analyzed these data, along with regional winds, using Self-Organizing Maps (SOM) to develop a set of surface current-wind patterns. Temporal changes in the SOM patterns consist predominantly of two patterns comprising northeastward and southwestward surface currents. A third pattern represents a transitional stage established during the onset of strong northeasterly winds. These patterns are analogous to the first two eigenmodes of an empirical orthogonal function analysis of the HFR data. The first principal component (PC1) is significantly correlated (∼0.8) to that of the winds and is directly related to the time series of SOM-derived patterns. The sign of PC1 changes when the speed of local northeasterly winds exceeds ∼6 m s−1, at which point the northeastward surface currents reverse to the southwest. This finding agrees with previous models and observations that suggest this wind threshold is needed to overcome the pressure gradient between the Pacific and Arctic Oceans. The transitional stage is characterized by alongshore currents bifurcating in the vicinity of Icy Cape and wind-driven Ekman currents north of 71.5°N. Its development is a manifestation of interactions among the poleward pressure gradient, wind stress, and geostrophic flow due to the coastal setdown.

Hirano, D., Fukamachi, Y., Ohshima, K. I., Watanabe, E., Mahoney, A. R., Eicken, H., . . . Tamura, T. (2018). Winter Water Formation in Coastal Polynyas of the Eastern Chukchi Shelf: Pacific and Atlantic Influences. *Journal of Geophysical Research-Oceans,* 123(8), 5688-5705. https://doi.org/10.1029/2017jc013307

Water properties and formation processes of Alaskan Coastal Winter Water (ACWW) over the eastern Chukchi shelf along the Alaska coast, the so-called Barrow Canyon pathway, are examined using data from moorings, atmospheric reanalysis, satellite-derived sea-ice production (SIP), and a numerical tracer experiment. Along this pathway, Pacific Winter Water (PWW) can be modified to produce ACWW through SIP accompanied by production of cold, saline polynya water in the coastal polynyas, upwelling of warm Atlantic Water (AW), and mixing processes on the shelf. Three different types of ACWW are formed: (i) a mixture of AW and PWW, (ii) a mixture of AW and polynya water, and (iii) hypersaline polynya water. The northeasterly winds, correlated with the north-south atmospheric pressure gradient between Beaufort High and Aleutian Low, are common triggers of polynya SIP episodes and AW upwelling in the Barrow Coastal Polynya (BCP). Due to the dual impact of northeasterly winds, PWW modification processes in the BCP are more complicated than what occurs elsewhere in the Chukchi Polynya. The impact of AW upwelling on the ACWW formation is most prominent in the BCP, usually centered along the coast. All types of ACWW are thought to be basically transported westward or northwestward with the Chukchi slope current and/or Beaufort Gyre and finally contribute to

maintenance of the lower halocline layer especially over the Chukchi Borderland, Northwind Ridge, and southern Canada Basin. Even in the Pacific sector of the Arctic Ocean, ACWW properties are strongly influenced by both Atlantic-origin and Pacific-origin waters.

Ikawa, H., & Oechel, W. C. (2011). Air-Sea Co2 Exchange of Beach and near-Coastal Waters of the Chukchi Sea near Barrow, Alaska. *Continental Shelf Research,* 31(13), 1357-1364. https://doi.org/10.1016/j.csr.2011.05.012

Partial pressure of CO2 in equilibrium with sample water (pCO(2)) for the coastal water in the Chukchi Sea was continuously observed in summer, 2008. Average daily CO2 flux calculated from the pCO(2) and gas transfer coefficients ranged from -0.144 to -0.0701 g C m(-2) day(-1) depending on which gas transfer coefficient was used. The pCO(2) before the landfast ice sheets melted appeared to be highly biologically controlled based on the following information: (1) the diurnal pattern of pCO(2) was strongly correlated with Photosynthetic Photon Flux Density (PPFD); (2) high chlorophyll density was observed during periods of peak uptake; and (3) the day-to-day variation in the pCO(2) strongly correlated with the presence or absence of near-shore ice sheets. The lowest pCO(2) of 35 ppm together with the highest PPFD of 1362 mu mol E m(-2) s(-1) observed in the afternoon on June 28 in the presence of sea ice. The very low pCO(2) observed in late June was likely caused by high photosynthetic rates related to high phytoplankton densities typically observed from spring to early summer near the ice edge, and by water low in salinity and CO2 released by melting sea ice early in the season.

Ito, M., Ohshima, K. I., Fukamachi, Y., Hirano, D., Mahoney, A. R., Jones, J., . . . Eicken, H. (2019). Favorable Conditions for Suspension Freezing in an Arctic Coastal Polynya. *Journal of Geophysical Research-Oceans,* 124(12), 8701-8719. https://doi.org/10.1029/2019jc015536

Arctic sea ice incorporates and transports sediment, releasing it back into the water column during the melting season. This process constitutes an important aspect of marine sediment transport and biogeochemical cycling. Sediment incorporation into sea ice is considered to occur mainly through underwater interaction between frazil ice and resuspended sediment, referred to as suspension freezing. However, harsh environmental conditions have greatly limited field observations of this phenomenon. Analysis of mooring data from a coastal polynya in the northeastern Chukchi Sea, in conjunction with coastal ice radar and meteorological data, indicates that suspension freezing is a key mechanism for sediment entrainment into sea ice. During polynya episodes, acoustic backscatter data obtained by an Acoustic Doppler Current Profiler showed the presence of frazil ice from the surface down to 20- to 25-m depth, coinciding with in situ and potential supercooling. Underwater frazil ice persisted over 1 week under windy, turbulent water column conditions. A combination of the turbidity and Acoustic Doppler Current Profiler backscatter data revealed upward sediment dispersion associated with strong currents during the polynya episodes. The fact that frazil ice and resuspended sediment were detected at the same depth and time strongly suggests the interaction between ice crystals and sediment particles, that is, suspension freezing. Plain Language Summary Sea ice incorporates, transports, and releases particulate matter. These processes constitute an important aspect of the biology, biogeochemical cycling, and pollutant transport in polar oceans. Seafloor sediments serve as the most important source of such particulate matter; however, the process of sediment incorporation into sea ice remains poorly explored. We conducted a year-long study of sediment resuspension and

entrainment processes, using underwater sensors deployed in the Chukchi Sea. During winter, wind-driven offshore transport of sea ice created area of open water and newly grown thin ice that persisted for several days, so-called coastal polynya or flaw lead system. Our sensors recorded small ice crystals, so-called frazil ice, that formed in the water column when water temperatures were below freezing point (supercooling). During some of these episodes, sediment was resuspended from the seafloor and dispersed upward by the strong currents, bringing it into water depths at which frazil ice was encountered. Such conditions provide for opportunities that allow frazil ice crystals or aggregates to capture resuspended sediment, a process referred to as suspension freezing. Based on this study, we propose that suspension freezing commonly occurs in shallow Arctic polynyas, serving as a key process of sediment incorporation into sea ice.

Li, M., Pickart, R. S., Spall, M. A., Weingartner, T. J., Lin, P. G., Moore, G. W. K., & Qi, Y. Q. (2019). Circulation of the Chukchi Sea Shelfbreak and Slope from Moored Timeseries. *Progress in Oceanography,* 172, 14-33. https://doi.org/10.1016/j.pocean.2019.01.002

Data from a year-long mooring array across the shelfbreak/upper-slope of the Chukchi Sea are used to describe and quantify the circulation and water masses of the region. The timeseries revealed the year-round existence of the eastward-flowing shelfbreak jet and, seaward of this, the westward-flowing Chukchi Slope Current. In the mean the slope current is estimated to transport 0.57 +/- 0.04 Sv of Pacific water, while the bottom-intensified shelfbreak jet transports 0.009 +/- 0.003 Sv towards Barrow Canyon. The slope current is surface-intensified in summer and fall, and in winter and spring it becomes middepth-intensified, moves shoreward, and weakens. Two extreme states of the circulation were identified: (1) an enhanced slope current and reversed (westward flowing) shelfbreak jet; and (2) a strong eastward-flowing shelfbreak jet and weak slope current. The former state occurs when the wind stress curl on the Chukchi shelf is positive, and the latter state occurs when the curl is negative. A simple theoretical model is used to determine the changes in sea surface height due to such wind stress curl forcing, which is consistent with the observed changes in flow seaward of the shelf both in amplitude and phase via geostrophic set up. Shelfbreak upwelling occurred throughout the year, but there was no correlation between the regional wind conditions and the upwelling. Furthermore, there was no apparent relationship between upwelling and the extreme slope current/shelfbreak jet events. A comparison of water mass signals between the Chukchi slope array and a mooring at the head of Barrow Canyon supports the notion that the slope current is fed by the outflow of Pacific water from the canyon.

Lin, P. G., Pickart, R. S., McRaven, L. T., Arrigo, K. R., Bahr, F., Lowry, K. E., . . . Mordy, C. W. (2019). Water Mass Evolution and Circulation of the Northeastern Chukchi Sea in Summer: Implications for Nutrient Distributions. *Journal of Geophysical Research-Oceans,* 124(7), 4416-4432. https://doi.org/10.1029/2019jc015185

Synoptic and historical shipboard data, spanning the period 1981-2017, are used to investigate the seasonal evolution of water masses on the northeastern Chukchi shelf and quantify the circulation patterns and their impact on nutrient distributions. We find that Alaskan coastal water extends to Barrow Canyon along the coastal pathway, with peak presence in September, while the Pacific Winter Water (WW) continually drains off the shelf through the summer. The depth-averaged circulation under

light winds is characterized by a strong Alaskan Coastal Current (ACC) and northward flow through Central Channel. A portion of the Central Channel flow recirculates anticyclonically to join the ACC, while the remainder progresses northeastward to Hanna Shoal where it bifurcates around both sides of the shoal. All of the branches converge southeast of the shoal and eventually join the ACC. The wind-forced response has two regimes: In the coastal region the circulation depends on wind direction, while on the interior shelf the circulation is sensitive to wind stress curl. In the most common wind-forced state-northeasterly winds and anticyclonic wind stress curl-the ACC reverses, the Central Channel flow penetrates farther north, and there is mass exchange between the interior and coastal regions. In September and October, the region southeast of Hanna Shoal is characterized by elevated amounts of WW, a shallower pycnocline, and higher concentrations of nitrate. Sustained late-season phytoplankton growth spurred by this pooling of nutrients could result in enhanced vertical export of carbon to the seafloor, contributing to the maintenance of benthic hotspots in this region. Plain Language Summary Using data from eight cruises to the Chukchi Sea, along with historical data spanning the period 1981-2017, we find that the warmest Pacific water predominantly follows the coastal pathway adjacent to Alaska, with a peak presence in September, while the coldest water continually drains from the shelf during the summer. The circulation under light winds is characterized by a strong coastal jet and another pathway through the central shelf. The latter pathway veers to the east and flows around both sides of a shoal on the northeast shelf, known as Hanna Shoal, before joining the coastal pathway. This circulation pattern is strongly altered under strong winds. In the most common wind condition, the coastal pathway is reversed and the central pathway extends farther to the north, with exchange between the interior shelf and coastal regions. In September and October, the region southeast of Hanna Shoal is characterized by elevated amounts cold Pacific water and nitrate, in part because of the circulation pattern. Sustained late-season phytoplankton growth spurred by this local pooling of nutrients could result in enhanced vertical export of carbon to the seafloor, contributing to the high benthic biological activity observed in this region.

Martini, K. I., Stabeno, P. J., Ladd, C., Winsor, P., Weingartner, T. J., Mordy, C. W., & Eisner, L. B. (2016). Dependence of Subsurface Chlorophyll on Seasonal Water Masses in the Chukchi Sea. *Journal of Geophysical Research: Oceans,* 121(3), 1755-1770. https://doi.org/10.1002/2015jc011359

During the late summer, phytoplankton in the northeastern Chukchi Sea are typically found in subsurface layers. These layers and their sensitivity to local changes in hydrography and nutrient concentrations are characterized by combining data from a high-resolution towed sampling platform with traditional shipboard observations. The replacement of surface meltwater and deeper nutrient-rich Chukchi Winter Water by northward flowing nutrient-poor Chukchi Summer Water and Remnant Winter Water leads to a net decrease in biomass and smaller phytoplankton. Between 17 and 67% of phytoplankton biomass is contained within the subsurface layers. This estimate is nearly twice as high as previous estimates from sparser shipboard data and suggests subsurface phytoplankton contribute significantly to the net biomass in the Chukchi Sea in late summer.

Pickart, R. S., Nobre, C., Lin, P. G., Arrigo, K. R., Ashjian, C. J., Berchok, C., . . . Vagle, S. (2019). Seasonal to Mesoscale Variability of Water Masses and Atmospheric Conditions in Barrow Canyon, Chukchi Sea. *Deep-Sea Research Part Ii-Topical Studies in Oceanography,* 162, 32-49. https://doi.org/10.1016/j.dsr2.2019.02.003

Twenty-four repeat hydrographic transects occupied across Barrow Canyon from 2010 to 2013 are used to study the seasonal evolution of water masses in the canyon from July-October as well as the occurrence of upwelling. The mean sections revealed that the Alaskan coastal water is mainly confined to the eastern flank of the canyon, corresponding to a region of sloped isopycnals indicative of the surface-intensified Alaskan Coastal Current which advects the water. The Pacific-origin winter water is found at depth, banked against the western flank of the canyon. Its isopycnal structure is consistent with a bottom-intensified flow of this dense water mass out of the canyon. For the months that were sampled, the Alaskan coastal water is most prevalent in August and September, while the coldest winter water is observed in the month of August. It is argued that this newly ventilated winter water is delivered to the canyon via pathways on the central Chukchi Shelf, as opposed to the coastal pathway. Roughly a third of the hydrographic sections were preceded by significant up-canyon winds and hence were deemed to be under the influence of upwelling. During these periods, anomalously salty water is found throughout the eastern flank of the canyon, and, on occasion, Atlantic water fills the deepest part of the section. Using atmospheric reanalysis data, it is shown that upwelling occurs when the Beaufort High is strengthened and the Aleutian Low is deepened. Two modes of storm tracks were identified: northward progressing storms (mode 1) and eastward progressing storms (mode 2), both of which can drive upwelling. Mode 1 is prevalent in July-August, while mode 2 is more common in September-October. These seasonal patterns appear to be dictated by regional variations in blocking highs.

Viscosi-Shirley, C., Pisias, N., & Mammone, K. (2003). Sediment Source Strength, Transport Pathways and Accumulation Patterns on the Siberian-Arctic's Chukchi and Laptev Shelves. *Continental Shelf Research,* 23(11-13), 1201-1225. https://doi.org/10.1016/s0278-4343(03)00090-6

In this study, we estimate sediment source strength and determine sediment transport/accumulation patterns on the Chukchi and Laptev shelves for lithogenic material from several key source regions. In the western Laptev Sea, sediments from the Siberian flood basalt province account for <20% of surface sediments, while detritus from the eastern Laptev's Lena and Yana Rivers constitutes as much as 40% of seafloor sediments. Eastern Laptev Sea sediments similarly reflect inputs from multiple sources; here, however, local inputs from the Lena and Yana Rivers are most prevalent. Chukchi Sea sediments are more homogeneous in composition, with sediments originating from the Okhotsk-Chukotsk volcanic belt and Bering Strait inflow comprising over 60% of surface sediments except near Wrangel Island and along sections of the Siberian coast. In the Chukchi portion of our study area, the dominant sediment dispersal pathways are from the Bering Strait region to the north and from Long Strait to the east, into the central Chukchi Sea. There appears to be comparatively minimal sediment transport parallel to the Siberian coast at our sample sites (> 40 m water depth). In contrast, at our Laptev Sea sites (typically > 20 m water depth) sediments supplied by the Lena and Yana Rivers move primarily eastward/northeastward parallel to the coast, with relatively minimal transport to the west/northwest or north to the central shelf. Good correspondence between sediment accumulation patterns and currents on the Chukchi shelf indicates water circulation is an important sediment transport mechanism in this marginal sea. In the Laptev Sea, a combination of river outflow, cyclonic water circulation and the Siberian Coastal Current controls sediment distribution. We speculate that sediment ice rafting may also affect shelf

sedimentation patterns through a combination of factors. Our findings have implications for the fate of particle reactive contaminants released to the Siberian continental margin.

Section XV: Eastern Bering Sea

Biology

Ainsley, S. M., Ebert, D. A., & Cailliet, G. M. (2011). Age, Growth, and Maturity of the Whitebrow Skate, Bathyraja Minispinosa, from the Eastern Bering Sea. *ICES Journal of Marine Science,* 68(7), 1426-1434. https://doi.org/10.1093/icesjms/fsr072

Skates are a common bycatch in groundfish fisheries in the Bering Sea; however, their life-history characteristics are not well known. The study is the first to investigate the age, growth, and age at maturity of Bathyraja minispinosa. Ages were estimated using sectioned vertebrae and several growth models were compared. The Gompertz model was the best fit and no significant differences were detected between sexes for any model. The maximum age estimated was 37 years, and parameter estimates generated from the three-parameter von Bertalanffy model were k = 0.02 year(-1) and L(infinity) = 146.9 cm total length (TL). Males reached their size at 50% maturity larger than females (70.1 and 67.4 cm, respectively), but no significant differences in the estimated size or age at maturity were found. Whereas B. minispinosa is smaller than many skate species in the eastern Bering Sea, it has a considerably longer estimated lifespan, indicating that size may not be a reliable method of estimating the vulnerability of a rajid species to population declines in the eastern North Pacific.

Goddard, P., Wilborn, R., Rooper, C. N., Williams, K., Towler, R., Sigler, M. F., & Malecha, P. (2016). *Results of the 2014 Underwater Camera Survey of the Eastern Bering Slope and Outer Shelf.* https://doi.org/10.7289/V5/TM-AFSC-313

The results of the 2014 Underwater Camera Survey of the Eastern Bering Sea slope and outer shelf are presented here. The 2014 survey was the first comprehensive underwater camera survey of coral and sponge on the Bering Sea slope and outer shelf conducted by the National Marine Fisheries Service. Two-hundred fifty transects were successfully completed during the survey, which extended north from Bering Canyon to Pervenets Canyon. Transects were randomly selected between Unalaska Island and Pervenets Canyon. Each transect was assigned to one of eight geographical regions. Demersal populations of corals, sponges, sea whips, fishes, and crabs were sampled by drifting a stereo drop camera for 15 minutes at each transect. Survey results presented in this report include fish and crab composition and density, coral, sponge and sea whip density and height, and substrate composition for each transect. The Appendix lists start position, distance towed, swath, mean depth, and mean temperature for each transect completed.

Hoff, G. R. (2016). Identification of Multiple Nursery Habitats of Skates in the Eastern Bering Sea. *Journal of Fish Biology,* 88(5), 1746-1757. https://doi.org/10.1111/jfb.12939

The use of more than a single nursery habitat type is examined for oviparous elasmobranchs using data summarized from studies conducted on the Alaska skate Bathyraja parmifera and the Aleutian skate Bathyraja aleutica in the eastern Bering Sea. The eastern Bering Sea skate species use two discrete areas as nurseries, one for egg deposition and a second for newly emergent juveniles. Egg deposition sites

were located along the outer shelf and upper slope near canyons in the eastern Bering Sea. Newly emergent juveniles were found along the outer and middle shelf for B. parmifera and deep-slope for B. aleutica, suggesting that habitat used by newly emergent juvenile skates is distinct from habitat used for egg deposition and embryo development. In reviewing many studies on oviparous elasmobranchs, similar patterns emerge of habitat use during their early life history. To distinguish these distinct habitats, appropriate terminology is proposed. Egg case nursery is suggested for areas of egg deposition and juvenile nursery is suggested for areas where juveniles aggregate after emergence. Criteria to describe each habitat type are outlined.

Matta, M. E. (2015). Reproductive Biology of the Alaska Skate *Bathyraja parmifera*, with Comments on an Intersexual Individual. *Journal of Fish Biology,* 87(3), 664-678. https://doi.org/10.1111/jfb.12747

A total of 1357 specimens of Alaska skate Bathyraja parmifera were collected in the eastern Bering Sea by fisheries observers and during scientific groundfish surveys from 2003 to 2005. Male and female gonads were examined for maturity stage and seasonal reproductive timing. Based on seasonal reproductive data, including the occurrence of egg cases, ovum size, ovum number, shell-gland width and gonado-somatic index, this species appears to reproduce continually throughout the year. Potential effects of maternal size upon the size and number of mature oocytes were also investigated, with total length having a significant, although weak, influence on both. Morphology of a single intersexual individual encountered during the collection period is also described.

Miller, J. A., DiMaria, R. A., & Hurst, T. P. (2016). Patterns of Larval Source Distribution and Mixing in Early Life Stages of Pacific Cod (Gadus macrocephalus) in the Southeastern Bering Sea. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 134, 270-282. https://doi.org/10.1016/j.dsr2.2014.12.012

Effective and sustainable management depends on knowledge of spawning locations and their relative contributions to marine fish populations. Pacific cod (Gadus macrocephalus) in the southeastern Bering Sea aggregate at discrete spawning locations but there is little information on patterns of larval dispersal and the relative contribution of specific spawning areas to nursery habitats. Age-0 Pacific cod from two cohorts (2006 and 2008) were examined to address the following questions: (1) does size, age, and otolith chemistry vary among known capture locations; (2) can variation in elemental composition of the otolith cores (early larval signatures) be used to infer the number of chemically distinct sources contributing to juvenile recruits in the Bering Sea; and (3) to what extent are juvenile collection locations represented by groups of fish with similar chemical histories throughout their early life history? Hierarchical cluster (HCA) and discriminant function analyses (DFA) were used to examine variation in otolith chemistry at discrete periods throughout the early life history. HCA identified five chemically distinct groups of larvae in the 2006 cohort and three groups in 2008; however, three sources accounted for 80-100% of the juveniles in each year. DFA of early larval signatures indicated that there were non-random spatial distributions of early larvae in both years, which may reflect interannual variation in regional oceanography. There was also a detectable and substantial level of coherence in chemical signatures within groups of fish throughout the early life history. The variation in elemental signatures throughout the early life history (hatch to capture) indicates that otolith chemical analysis could be an

effective tool to further clarify larval sources and dispersal, identify juvenile nursery habitats, and estimate the contributions of juvenile nursery habitats to the adult population within the southeastern Bering Sea.

Miller, R. J., Hocevar, J., Stone, R. P., & Fedorov, D. V. (2012). Structure-Forming Corals and Sponges and Their Use as Fish Habitat in Bering Sea Submarine Canyons. *Plos One,* 7(3), e33885. https://doi.org/10.1371/journal.pone.0033885

Continental margins are dynamic, heterogeneous settings that can include canyons, seamounts, and banks. Two of the largest canyons in the world, Zhemchug and Pribilof, cut into the edge of the continental shelf in the southeastern Bering Sea. Here currents and upwelling interact to produce a highly productive area, termed the Green Belt, that supports an abundance of fishes and squids as well as birds and marine mammals. We show that in some areas the floor of these canyons harbors high densities of gorgonian and pennatulacean corals and sponges, likely due to enhanced surface productivity, benthic currents and seafloor topography. Rockfishes, including the commercially important Pacific ocean perch, Sebastes alutus, were associated with corals and sponges as well as with isolated boulders. Sculpins, poachers and pleuronectid flounders were also associated with corals in Pribilof Canyon, where corals were most abundant. Fishes likely use corals and sponges as sources of vertical relief, which may harbor prey as well as provide shelter from predators. Boulders may be equivalent habitat in this regard, but are sparse in the canyons, strongly suggesting that biogenic structure is important fish habitat. Evidence of disturbance to the benthos from fishing activities was observed in these remote canyons. Bottom trawling and other benthic fishing gear has been shown to damage corals and sponges that may be very slow to recover from such disturbance. Regulation of these destructive practices is key to conservation of benthic habitats in these canyons and the ecosystem services they provide.

Miller, R. J., Juska, C., & Hocevar, J. (2015). Submarine Canyons as Coral and Sponge Habitat on the Eastern Bering Sea Slope. *Global Ecology and Conservation,* 4, 85-94. https://doi.org/10.1016/j.gecco.2015.05.009

Submarine canyons have been shown to positively influence pelagic and benthic biodiversity and ecosystem function. In the eastern Bering Sea, several immense canyons lie under the highly productive "green belt'' along the continental slope. Two of these, Pribilof and Zhemchug canyons, are the focus of current conservation interest. We used a maximum entropy modeling approach to evaluate the importance of these two canyons, as well as canyons in general, as habitat for gorgonian (alcyonacean) corals, pennatulacean corals, and sponges, in an area comprising most of the eastern Bering Sea slope and outer shelf. These invertebrates create physical structure that is a preferred habitat for many mobile species, including commercially important fish and invertebrates. Weshow that Pribilof canyon is a hotspot of structure-forming invertebrate habitat, containing over 50% of estimated high-quality gorgonian habitat and 45% of sponge habitat, despite making up only 1.7% of the total study area. The amount of quality habitat for gorgonians and sponges varied in other canyons, but canyons overall contained more high-quality habitat for structure-forming invertebrates compared to other slope areas. Bottom trawling effort was not well correlated with habitat quality for structure-forming invertebrates, and bottom-contact fishing effort in general, including longlining and trawling, was not particularly

concentrated in the canyons examined. These results suggest that if conserving gorgonian coral habitat is a management goal, canyons, particularly Pribilof Canyon, may be a prime location to do this without excessive impact on fisheries.

Nichol, D. G., Somerton, D. A., & Kotwicki, S. (2017). Movement Rates of Morphometrically Mature Male Snow Crabs, *Chionoecetes opilio* (O. Fabricius, 1788), in the Eastern Bering Sea, Alaska (Brachyura: Oregoniidae). *Journal of Crustacean Biology,* 37(4), 380-388. https://doi.org/10.1093/jcbiol/rux039

Movement rates of morphometrically mature male snow crabs, Chionoecetes opilio, in the eastern Bering Sea, Alaska were estimated for 33 individuals at liberty between 280 and 467 days. Using depth measurements from data storage tags attached to individual crabs, daily across-shelf movement rates were estimated as the daily change in crab depth divided by the slope (i.e., depth/horizontal distance) of the seafloor on which each crab resided each day. Rates and distances were analyzed at different time scales (day, month, year) and general additive models were used to test the significance of factors that could potentially influence the daily rate of movements. Individual crab rates averaged between 0.1 and 1.1 km/day over their time at liberty, with one individual attaining a maximum rate of 8 km/day. Rates varied significantly ($P < 0.05$) with the bottom depth, season (day of year), and the release area. Although overall rates did not vary with crab size, maximum rates were highest among the smallest individuals, two of which (100-102 mm carapace width) traveled approximately 250 km in ten months. Movement rates were highest during spring when travel was directed mostly inshore, and slower during fall and winter when offshore movements occurred. In contrast to other studies that demonstrated decreased snow crab movement rates in cold water (e.g., < 1 degrees C), no temperature effect was found for these males in the eastern Bering Sea. Further research is necessary to determine if factors that act at shorter time scales (< 24 hours), such as tidal currents and light intensity, influence snow crab movements.

Norman, S. A., Goertz, C. E. C., Burek, K. A., Quakenbush, L. T., Cornick, L. A., Romano, T. A., . . . Hobbs, R. C. (2012). Seasonal Hematology and Serum Chemistry of Wild Beluga Whales (Delphinapterus leucas) in Bristol Bay, Alaska, USA. *Journal of Wildlife Diseases,* 48(1), 21-32. https://doi.org/10.7589/0090-3558-48.1.21

We collected blood from 18 beluga whales (Delphinapterus leucas), live-captured in Bristol Bay, Alaska, USA, in May and September 2008, to establish baseline hematologic and serum chemistry values and to determine whether there were significant differences in hematologic values by sex, season, size/age, or time during the capture period. Whole blood was collected within an average of 19 min (range=11–30 min) after the net was set for capture, and for eight animals, blood collection was repeated in a later season after between 80–100 min; all blood was processed within 12 hr. Mean hematocrit, chloride, creatinine, total protein, albumin, and alkaline phosphatase were significantly lower in May than they were in September, whereas mean corpuscular hemoglobin concentration, monocytes, phosphorous, magnesium, blood urea nitrogen, alanine aminotransferase, aspartate aminotransferase, γ-glutamyltranspeptidase, and creatinine kinase were significantly higher. Mean total protein, white blood cell count, neutrophils, and lymphocytes were significantly higher early in the capture period than they were later. No significant differences in blood analyte values were noted between males and females.

Using overall body length as a proxy for age, larger (older) belugas had lower white blood cell, lymphocyte, and eosinophil counts as well as lower sodium, potassium, and calcium levels but higher creatinine levels than smaller belugas. These data provide values for hematology and serum chemistry for comparisons with other wild belugas.

Orr, J. W., Stevenson, D. E., Hanke, G., Spies, I. B., Boutillier, J. A., & Hoff, G. R. (2019). Range Extensions and New Records from Alaska and British Columbia for Two Skates, *Bathyraja spinosissima* and *Bathyraja microtrachys*. *Northwestern Naturalist,* 100(1), 37-47, 11. https://doi.org/10.1898/NWN18-21

Recent deep-water surveys of the continental slope in the Bering Sea and the eastern North Pacific, conducted by the US National Marine Fisheries Service, Alaska Fisheries Science Center, and Fisheries and Oceans Canada, have broadened our understanding of the ichthyofauna in the region. Herein, we report significant new records of 2 species of skates based on morphological and molecular data. For Bathyraja spinosissima, the White Skate, we describe 2 specimens: a neonate male that constitutes a northern range extension for the species to Alaska in the Bering Sea; and an adult male representing a new record for the species in British Columbia. For B. microtrachys, the Fine-spined Skate, we describe 5 males taken in a single haul that represent the 1st record of the species in British Columbia. These specimens had been previously misidentified as B. violacea, the Okhotsk Skate, a species known only from the western Aleutian Islands and the western North Pacific.

Petrik, C. M., Duffy-Anderson, J. T., Mueter, F., Hedstrom, K., & Curchitser, E. N. (2015). Biophysical Transport Model Suggests Climate Variability Determines Distribution of Walleye Pollock Early Life Stages in the Eastern Bering Sea through Effects on Spawning. *Progress in Oceanography,* 138, 459-474. https://doi.org/10.1016/j.pocean.2014.06.004

The eastern Bering Sea recently experienced an anomalously warm period followed by an anomalously cold period. These periods varied with respect to sea ice extent, water temperature, wind patterns, and ocean circulation. The distributions of Walleye Pollock early life stages also differed between periods, with larval stages found further eastward on the shelf in warm years. Statistical analyses indicated that these spatial distributions were more closely related to temperature than to other covariates, though a mechanism has not been identified. The objective of this study was to determine if variable transport could be driving the observed differences in pollock distributions. An individual-based model of pollock early life stages was developed by coupling a hydrodynamic model to a particle-tracking model with biology and behavior. Simulation experiments were performed with the model to investigate the effects of wind on transport, ice presence on time of spawning, and water temperature on location of spawning. This modeling approach benefited from the ability to individually test mechanisms to quantitatively assess the impact of each on the distribution of pollock. Neither interannual variability in advection nor advances or delays in spawning time could adequately represent the observed differences in distribution between warm and cold years. Changes to spawning areas, particularly spatial contractions of spawning areas in cold years, resulted in modeled distributions that were most similar to observations. The location of spawning pollock in reference to cross-shelf circulation patterns is important in determining the distribution of eggs and larvae, warranting further study on the relationship between spawning adults and the physical environment. The different distributions of

pollock early life stages between warm and cold years may ultimately affect recruitment by influencing the spatial overlap of pollock juveniles with prey and predators.

Reum, J. C. P., Blanchard, J. L., Holsman, K. K., Aydin, K., Hollowed, A. B., Hermann, A. J., . . . Punt, A. E. (2020). Ensemble Projections of Future Climate Change Impacts on the Eastern Bering Sea Food Web Using a Multispecies Size Spectrum Model. *Frontiers in Marine Science,* 7, 17. https://doi.org/10.3389/fmars.2020.00124

Characterization of uncertainty (variance) in ecosystem projections under climate change is still rare despite its importance for informing decision-making and prioritizing research. We developed an ensemble modeling framework to evaluate the relative importance of different uncertainty sources for food web projections of the eastern Bering Sea (EBS). Specifically, dynamically downscaled projections from Earth System Models (ESM) under different greenhouse gas emission scenarios (GHG) were used to force a multispecies size spectrum model (MSSM) of the EBS food web. In addition to ESM and GHG uncertainty, we incorporated uncertainty from different plausible fisheries management scenarios reflecting shifts in the total allowable catch of flatfish and gadids and different assumptions regarding temperature-dependencies on biological rates in the MSSM. Relative to historical averages (1994-2014), end-of-century (2080-2100 average) ensemble projections of community spawner stock biomass, catches, and mean body size (+/- standard deviation) decreased by 36% (+/- 21%), 61% (+/- 27%), and 38% (+/- 25%), respectively. Long-term trends were, on average, also negative for the majority of species, but the level of trend consistency between ensemble projections was low for most species. Projection uncertainty for model outputs from ~2020 to 2040 was driven by inter-annual climate variability for 85% of species and the community as a whole. Thereafter, structural uncertainty (different ESMs, temperature-dependency assumptions) dominated projection uncertainty. Fishery management and GHG emissions scenarios contributed little (<10%) to projection uncertainty, with the exception of catches for a subset of flatfishes which were dominated by fishery management scenarios. Long-term outcomes were improved in most cases under a moderate "mitigation" relative to a high "business-as-usual" GHG emissions scenario and we show how inclusion of temperature-dependencies on processes related to body growth and intrinsic (non-predation) natural mortality can strongly influence projections in potentially non-additive ways. Narrowing the spread of long-term projections in future ensemble simulations will depend primarily on whether the set of ESMs and food web models considered behave more or less similarly to one another relative to the present models sets. Further model skill assessment and data integration are needed to aid in the reduction and quantification of uncertainties if we are to advance predictive ecology.

Rooper, C. N., Hoff, G. R., Stevenson, D. E., Orr, J. W., & Spies, I. B. (2019). Skate Egg Nursery Habitat in the Eastern Bering Sea: A Predictive Model. *Marine Ecology Progress Series,* 609, 163-178. https://doi.org/10.3354/meps12809

Alaska skate species utilize localized egg nursery sites along the interface of the continental slope and shelf in the eastern Bering Sea to lay eggs in high densities. These egg nursery sites persist across years and are thought to be related to environmental conditions. The objective of this analysis was to predict the potential habitat of skate egg nursery sites using species distribution models. Skate egg nursery locations (n = 26) for 6 species were identified from bottom trawl survey catches and underwater

camera surveys. Maximum entropy models were developed using 10 environmental variables to predict the probability of suitable skate egg nursery habitat; 7 variables were included in the best model. Potential habitat peaked at seafloor slopes <2 %, in areas of low temperature variability and in areas of high oxygen concentrations. These were the 3 most important variables in the model. Most of the predicted high probability egg nursery suitable habitat for skates was in canyons (e.g. Bering Canyon and the southern arm of Pribilof Canyon) in a relatively narrow band on the upper slope. The most important finding of this modeling study was that there is a limited area of the upper continental slope where conditions would support potential skate egg nursery areas; however, much of the area is unexplored and likely to remain so in the near future. Management actions for important conservation questions can look to modeling studies such as these for guidance in the absence of comprehensive surveys.

Rooper, C. N., Sigler, M. F., Goddard, P., Malecha, P., Towler, R., Williams, K., . . . Zimmermann, M. (2016). Validation and Improvement of Species Distribution Models for Structure-Forming Invertebrates in the Eastern Bering Sea with an Independent Survey. *Marine Ecology Progress Series,* 551, 117-130. https://doi.org/10.3354/meps11703

Species distribution modeling is a useful tool for informing ecosystems management. However, validation of model predictions through independent surveys is rarely attempted in marine environments, which are challenging to study and often contain sensitive habitats. We conducted an underwater camera survey of the eastern Bering Sea slope and outer shelf as an independent test of species distribution modeling of deep-sea corals, sponges and sea whips based on bottom trawl survey data. We also refined model predictions by combining species distribution models based on both bottom trawl and underwater camera survey data. The camera survey also was conducted to determine density and size of the taxa. The trawl model predictions generally were confirmed by the camera observations (area under the receiver-operator curve [AUC] values of 0.63 to 0.73). Combining bottom trawl and camera survey model predictions improved predictive ability (AUC values of 0.74 to 0.90 for camera observations). Corals were distributed in Pribilof Canyon and the slope area to the northwest of the canyon, and colony densities averaged 0.005 ind. m(-2) and ranged from 0 to 0.28 ind. m(-2). The low densities were consistent with the absence of hard substrates for coral attachment in most areas of the eastern Bering Sea. Sponge and sea whip density averaged 0.11 ind. m(-2), with sponge density ranging from 0 to 13.1 and sea whip density ranging from 0 to 8.4 ind. m(-2). Invertebrate heights were generally small, with most taxonomic groups < 20 cm in average height. This type of study is vital to providing the best scientific advice for spatial management of structure-forming invertebrates, so that decisions concerning the protection of these vulnerable communities can be implemented with a clear basis for priorities.

Rooper, C. N., Zimmermann, M., & Spencer, P. D. (2005). Using Ecologically Based Relationships to Predict Distribution of Flathead Sole *Hippoglossoides elassodon* in the Eastern Bering Sea. *Marine Ecology Progress Series,* 290, 251-262. https://doi.org/10.3354/meps290251

This study describes a method for modeling and predicting, from biological and physical variables, habitat use by a commercially harvested groundfish species. Models for eastern Bering Sea flathead sole Hippoglossoides elassodon were developed from 3 relationships describing the response of organism abundance along a resource continua. The model was parameterized for 1998 to 2000 trawl survey data

and tested on 2001 and 2002 data. Catch per unit effort (CPUE) of flathead sole had a curvilinear relationship with depth, peaking at 140 m, a proportional relationship with bottom water temperature, a positive curvilinear relationship with potential cover (invertebrate sheltering organisms such as anemones, corals, sponges, etc.), a negative relationship with increasing mud:sand ratio in the sediment, and an asymptotic relationship with potential prey abundance. The predicted CPUE was highly correlated (r(2) = 0.63) to the observations (1998 to 2000) and the model accurately predicted CPUE (r(2) = 0.58) in the test data set (2001 and 2002). Because this method of developing habitat-based abundance models is founded on ecological relationships, it should be more robust for predicting fish distributions than statistically based models. Thus, the model can be used to examine the consequences of fishing activity (e.g. reduction in sheltering organisms), changes in temperature (e.g. climate effects) and interaction between variables, and can be modified to incorporate new variables as more information is collected about a species.

Sigler, M. F., Rooper, C. N., Hoff, G. R., Stone, R. P., McConnaughey, R. A., & Wilderbuer, T. K. (2015). Faunal Features of Submarine Canyons on the Eastern Bering Sea Slope. *Marine Ecology Progress Series,* 526, 21-40. https://doi.org/10.3354/meps11201

Some of the largest submarine canyons in the world incise the eastern Bering Sea shelf break. Here, we examine whether 5 large canyons (Bering, Pribilof, Zhemchug, Pervenets and Navarin) are faunally distinct features within the eastern Bering Sea. We compiled data from the eastern Bering Sea that included trawl survey data on fish and invertebrate distributions and observations of ocean conditions and benthic habitat. These data were analyzed using multivariate techniques to determine if the canyons are distinguishable from the adjacent continental slope. We found that the 5 canyons are not faunally distinct features of the eastern Bering Sea slope but that the major characteristics structuring fish and invertebrate communities were depth, latitude and sediment rather than submarine canyons. One notable feature of these canyons is that about one quarter of the coral habitat predicted for the eastern Bering Sea slope occurs in Pribilof Canyon, an area that comprises only similar to 10% of the total slope area. The predicted coral habitat also extends westward to the adjacent slope, indicating that this coral habitat concentration is not unique to Pribilof Canyon but rather that it is typical for a larger area (Pribilof Canyon and westward).

Stevenson, D. E., Hoff, G. R., Orr, J. W., Spies, I., & Rooper, C. N. (2019). Interactions between Fisheries and Early Life Stages of Skates in Nursery Areas of the Eastern Bering Sea. *Fishery Bulletin,* 117(1-2), 8-14. https://doi.org/10.7755/fb.117.1.2

From late 2014 through 2017, fishery observers in the North Pacific Observer Program, National Marine Fisheries Service, were trained in the identification and sampling of skate egg cases to investigate the interactions between fisheries and skate nursery areas in the eastern Bering Sea. Trained observers identified and assessed 2887 egg cases in a wide range of fisheries across all gear types, with the majority of egg cases being encountered on vessels targeting deepwater species, such as the arrowtooth flounder (Atheresthes stomias), Greenland halibut (Reinhardtius hippoglossoides), Pacific cod (Gadus macrocephalus), and sablefish (Anoplopoma fimbria). A large proportion of the egg cases identified were reported on boats using bottom trawling gear, but an even greater proportion were reported on longliners. Egg cases identified represent 10 skate taxa. Over half (67%) of them were identified as

Alaska skate (Bathyraja parmifera), and 19% were identified as either Aleutian skate (B. aleutica) or Bering skate (B. interrupta). More than 42% of all the egg cases assessed were viable (contained a living skate); over 50% of egg cases of Alaska skate and of egg cases encountered on longliners were viable. The highest concentrations of egg cases generally were reported near known skate nursery areas, particularly in the Bering, Pribilof, and Pervenets Canyons.

Wilderbuer, T., Stockhausen, W., & Bond, N. (2013). Updated Analysis of Flatfish Recruitment Response to Climate Variability and Ocean Conditions in the Eastern Bering Sea. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 94, 157-164. https://doi.org/10.1016/j.dsr2.2013.03.021

This study provides a retrospective analysis of the relationship between physical oceanography, biology and recruitment of three Eastern Bering Sea flatfish stocks: flathead sole (Hippoglossoides elassodon), northern rock sole (Lepidopsetta polyxystra), and arrowtooth flounder (Atheresthes stomias) during the period 1978-2005. Stock assessment model estimates of recruitment and spawning stock size indicate that temporal patterns in productivity are consistent with decadal scale (or shorter) patterns in climate variability, which may influence marine survival during the early life history phases. Density-dependence (through spawning stock size) was statistically significant in a Ricker stock-recruit model of flatfish recruitment that included environmental terms. Wind-driven advection of northern rock sole and flathead sole larvae to favorable nursery grounds was found to coincide with years of above-average recruitment. Ocean forcing of Bristol Bay surface waters during springtime was mostly on-shelf (eastward) during the 1980s and again in the early 2000s, but was off-shelf (westerly) during the 1990s, corresponding with periods of good and poor recruitment, respectively. Finally, the Arctic Oscillation was found to be an important indicator of arrowtooth flounder productivity. Model results were applied to IPCC (Intergovernmental Panel on Climate Change) future springtime wind scenarios to predict the future impact of climate on northern rock sole productivity and indicated that a moderate future increase in recruitment might be expected because the climate trends favor on-shelf transport but that density-dependence will dampen this effect such that northern rock sole abundance will not be substantially affected by climate change.

Winton, M. V., Natanson, L. J., Kneebone, J., Cailliet, G. M., & Ebert, D. A. (2014). Life History of *Bathyraja trachura* from the Eastern Bering Sea, with Evidence of Latitudinal Variation in a Deep-Sea Skate Species. *Journal of the Marine Biological Association of the United Kingdom,* 94(2), 411-422. https://doi.org/10.1017/s0025315413001525

Although many skates possess life history characteristics that may make them vulnerable to exploitation, the detailed biological information needed to enact effective management schemes is lacking for most species. The objectives of this study were to provide age, growth, and maturity estimates for the roughtail skate, Bathyraja trachura, from the eastern Bering Sea. Maximum age was estimated at 36yr based on band pair counts in vertebral centra. Of the four growth models applied, the logistic model provided the best description of growth (asymptotic total length=911mm; growth coefficient=0.131yr(-1)). There was no evidence of difference in growth between males and females. Females attained maturity at larger sizes and older ages than males. The median size-at-maturity was estimated at 741mm total length (TL) for males and 796mm TL for females; median age-at-maturity was estimated at 21.1yr and 24.7yr for males and females, respectively. The results of this study may

indicate a latitudinal pattern in size and growth, with individuals from the eastern Bering Sea growing more slowly and reaching higher maximum ages than previously reported for specimens collected off the western coast of the continental United States.

Zaleski, M. A. F., & Tamone, S. L. (2014). Relationship of Molting, Gonadosomatic Index, and Methyl Farnesoate in Male Snow Crab (Chionoecetes opilio) from the Eastern Bering Sea. *Journal of Crustacean Biology,* 34(6), 764-772. https://doi.org/10.1163/1937240x-00002271

Snow crabs, Chionoecetes opilio (Fabricius, 1788), have a complex mating system, and understanding their reproductive physiology is paramount to crab fishery management. Mating and molting are inextricably linked, so the energetically demanding molting process may compromise male mating potential for some period prior to and after the molt. Recently molted, new-shell males are targeted preferentially during the commercially valuable eastern Bering Sea (EBS) fishery. Old-shell males, or males that have not molted within the last year, are not as visually appealing, but may have greater reproductive capacity and can contribute disproportionately to the genetic stock. We measured a crustacean reproductive hormone, methyl famesoate (MF), and reproductive fitness, using gonadosomatic index (GSI) as a proxy, in EBS male snow crab to determine differences in reproductive potential between adolescents and adults. We compared these reproductive indices in new- and old-shell males as a broad estimate of the effect of molting biology on reproduction. Circulating MF was significantly higher in new-shell adolescent males compared to old-shell adolescent males and old-shell adult males, suggesting a juvenilizing rather than gonadotropic role for MF in C. opilio. New-shell males had a significantly lower GSI compared to old-shell males for both adolescent and adult males. The lower GSI measured in new-shell adults compared to the significantly higher GSI levels measured in old-shell adults suggests that new-shell males harvested during the commercial fishery lack the reproductive capacity of the old-shelled adults and therefore may not be contributing equally to the population.

Chemistry

Hartwell, S. I., Apeti, A. D., Pait, A. S., Radenbaugh, T., & Britton, R. (2018). Benthic Habitat Contaminant Status and Sediment Toxicity in Bristol Bay, Alaska. *Regional Studies in Marine Science,* 24, 343-354. https://doi.org/10.1016/j.rsma.2018.09.009

A baseline environmental characterization of the northeastern reaches of Bristol Bay, Alaska was conducted using the National Status and Trends' sediment quality triad approach. The study area was subdivided into 6 strata based on geophysical and hydrodynamic patterns (the upper and lower reaches of Nushagak and Kvichak Bays, Dillingham Harbor and the mouth of the Naknek River). Within each stratum, a stratified random sampling approach was used to select sampling sites for infauna and sediment chemistry. Ambient toxicity was assessed at a subset of sites using two bioassays (Microtox (R) and sea urchin fertilization and development). Fish species including, starry flounder (Platichthys stellatus) and rainbow smelt (Osmerus mordax) were collected by trawl for body burden analyses for chemical contaminants. Persistent organic pollutant concentrations were low relative to National Oceanic and Atmospheric Administration (NOAA) sediment quality guidelines (SQG). All metal/metalloid concentrations were below NOAA SQGs except for arsenic which was uniformly above the threshold SQG. Benthic communities were relatively sparse at most locations due to harsh physical oceanographic conditions. Significant chemical toxicity was virtually absent except for selected locations with high

pore-water ammonia levels associated with fish processing plant waste streams. Contaminant body burdens were very low in the fish tested. The fish were generally healthy and non-contaminated.

Mathis, J. T., Cross, J. N., & Bates, N. R. (2011). The Role of Ocean Acidification in Systemic Carbonate Mineral Suppression in the Bering Sea. *Geophysical Research Letters,* 38(19). https://doi.org/10.1029/2011GL048884

Ocean acidification driven by absorption of anthropogenic carbon dioxide (CO2) from the atmosphere is now recognized as a systemic, global process that could threaten diverse marine ecosystems and a number of commercially important species. The change in calcium carbonate (CaCO3) mineral saturation states (Ω) brought on by the reduction of seawater pH is most pronounced in high latitude regions where unique biogeochemical processes create an environment more susceptible to the suppression of Ω values for aragonite and calcite, which are critical to shell building organisms. New observations from the eastern Bering Sea shelf show that remineralization of organic matter exported from surface waters rapidly increases bottom water CO2 concentrations over the shelf in summer and fall, suppressing Ω values. The removal of CO2 from surface waters by high rates of phytoplankton primary production increases Ω values between spring and summer, but these increases are partly counteracted by mixing with sea ice melt water and terrestrial river runoff that have low Ω values. While these environmental processes play an important role in creating seasonally low saturation states, ocean uptake of anthropogenic CO2 has shifted Ω values for aragonite to below the saturation horizon in broad regions across the shelf for at least several months each year. Furthermore, we also report that calcite became undersaturated in September of 2009 in the bottom waters over the shelf. The reduction in CaCO3 mineral saturation states could have profound implications for several keystone calcifying species in the Bering Sea, particularly the commercially important crab fisheries.

Geology

Comer, C. D., Herman, B. M., & Zerwick, S. A. (1987). *Geologic Report for the St. George Basin Planning Area, Bering Sea, Alaska.* Retrieved from https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Resource_Evaluation/Resource_Assessment/MMS87_0030StGeorge.pdf

No abstract available.

Richwine, K. A., Smith, K. R., & McConnaughey, R. A. (2018). *Surficial Sediments of the Eastern Bering Sea Continental Shelf: EBSSED-2 Database Documentation.* Retrieved from https://repository.library.noaa.gov/view/noaa/19258

Sediment grain size is a fundamental property of benthic marine habitats. Its frequency distribution affects basic physical characteristics of the seafloor such as porosity, permeability, and compaction, as well as plant and animal distributions. Previous studies have reported spatial variation of sediment texture on the eastern Bering Sea (EBS) continental shelf. Many of these studies are limited to specific locations, while others characterize larger areas of the continental shelf by averaging relatively sparse

data. The original studies vary in the analytical and descriptive methods used to characterize the sediment samples. The Eastern Bering Sea sediment (EBSSED) database documented here combines the original point data (n = 13,874) in a consistent manner to provide a comprehensive resource for a great variety of research on seafloor habitats of the EBS shelf. The database represents sediment variation over the study area with uncompromised (i.e., original) spatial detail. Two main types of textural data are included: 1) standardized statistics characterizing the grain size distribution of samples with % composition (e.g., gravel, sand, mud) and size-distribution parameters (e.g., mean size) and 2) sample descriptions from more subjective visual/tactile observations establishing size-grade constitutions. Two descriptive fields are added to characterize sample grain size distribution by a single, standardized variable based on the original data. These fields classify samples according to gravel-sand-mud composition using low and high-resolution schemes. The low-resolution scheme (7 classes) is designed to allow unambiguous classifications of nearly all samples (n = 13,742) including those with subjective visual/tactile descriptions. It represents the maximum number of samples according to a single common variable, providing the most spatially detailed data for the study area. The highiii resolution scheme classifies (1,458) samples with detailed granulometric data into 15 textural classes, providing greater detail regarding textural variation.

Minerals Management Service, Alaska OCS Region. (Cartographer). (1984). Prelease Investigation Maps of the North Aleutian Shelf, Outer Continental Shelf, Bering Sea, Alaska. Retrieved from [No URL available]

No abstract available.

Turner, R. F., Martin, G. C., Flett, T. O., & Steffy, D. A. (1985). *Geologic Report for the Navarin Basin Planning Area.* Retrieved from https://www.osti.gov/biblio/6170549-geologic-report-navarin-basin-planning-area-bering-sea-alaska-final-report

The report discusses the geology and petroleum potential of the Navarin Basin planning area. The report presents and integrates new data and interpretations with the data obtained from the Navarin Basin COST No. 1 well, a deep stratigraphic test well. The report discusses the regional geology, petroleum geology, and potential geohazards of the planning area, with emphasis on biostratigraphy, lithostratigraphy, seismic stratigraphy, structural geology and geologic history, exploration history, organic geochemistry, and potential petroleum traps. The report also discusses the shallow geology, geotechnical constraints on offshore exploration and production facilities, the marine weather, and the biota of the area.

Turner, R. F., McCarthy, C. M., Comer, C. D., Larson, J. A., Boln, J. G., Banet Jr., A. C., & Adams, A. J. (1985). *Geological and Operational Summary: St. George Basin Cost No. 1 Well.* Retrieved from https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Resource_Evaluation/Geological_and_Geophysical_Data_Acquisition/MMS84_0016StGeorgeCOST_No1.pdf

No abstract available.

Turner, R. F., McCarthy, C. M., Lynch, M. B., Hoose, P. J., Martin, G. C., Larson, J. A., . . . Adams, A. J. (1988). *Geological and Operational Summary, North Aleutian Shelf Cost No. 1 Well, Bering Sea Alaska.* Retrieved from https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Resource_Evaluation/Geological_and_Geophysical_Data_Acquisition/MMS88_0089NAleutianShelf.pdf

No abstract available.

Management

Hollowed, A. B., Holsman, K. K., Haynie, A. C., Hermann, A. J., Punt, A. E., Aydin, K., . . . Wilderbuer, T. K. (2020). Integrated Modeling to Evaluate Climate Change Impacts on Coupled Social-Ecological Systems in Alaska. *Frontiers in Marine Science,* 6, 18. https://doi.org/10.3389/fmars.2019.00775

The Alaska Climate Integrated Modeling (ACLIM) project represents a comprehensive, multi-year, interdisciplinary effort to characterize and project climate-driven changes to the eastern Bering Sea (EBS) ecosystem, from physics to fishing communities. Results from the ACLIM project are being used to understand how different regional fisheries management approaches can help promote adaptation to climate-driven changes to sustain fish and shellfish populations and to inform managers and fishery dependent communities of the risks associated with different future climate scenarios. The project relies on iterative communications and outreaches with managers and fishery-dependent communities that have informed the selection of fishing scenarios. This iterative approach ensures that the research team focuses on policy relevant scenarios that explore realistic adaptation options for managers and communities. Within each iterative cycle, the interdisciplinary research team continues to improve: methods for downscaling climate models, climate-enhanced biological models, socio-economic modeling, and management strategy evaluation (MSE) within a common analytical framework. The evolving nature of the ACLIM framework ensures improved understanding of system responses and feedbacks are considered within the projections and that the fishing scenarios continue to reflect the management objectives of the regional fisheries management bodies. The multi-model approach used for projection of biological responses, facilitates the quantification of the relative contributions of climate forcing scenario, fishing scenario, parameter, and structural uncertainty with and between models. Ensemble means and variance within and between models inform risk assessments under different future scenarios. The first phase of projections of climate conditions to the end of the 21st century is complete, including projections of catch for core species under baseline (status quo) fishing conditions and two alternative fishing scenarios are discussed. The ACLIM modeling framework serves as

a guide for multidisciplinary integrated climate impact and adaptation decision making in other large marine ecosystems.

MacLean, S. A., Rooper, C. N., & Sigler, M. F. (2017). Corals, Canyons, and Conservation: Science Based Fisheries Management Decisions in the Eastern Bering Sea. *Frontiers in Marine Science,* 4. https://doi.org/10.3389/fmars.2017.00142

When making science matter for conservation, marine conservation practitioners, and managers must be prepared to make the appropriate decision based on the results of the best available science used to inform it. For nearly a decade, many stakeholders encouraged the North Pacific Fishery Management Council to enact protections for deep-sea corals in several canyons in the Eastern Bering Sea slope. In 2014, at the request of the Council, the National Marine Fisheries Service, Alaska Fisheries Science Center conducted a strip-transect survey along the Eastern Bering Sea slope to validate the results of a model predicting the occurrence of deep-sea coral habitat. More than 250,000 photos were analyzed to estimate coral, sponge, and sea whip abundance, distribution, height, and vulnerability to anthropogenic damage. The results of the survey confirmed that coral habitat and occurrence was concentrated around Pribilof Canyon and the adjacent slope. The results also confirmed that the densities of corals in the Eastern Bering Sea were low, even where they occurred. After reviewing the best available scientific information, the Council concluded that there is no scientific evidence to suggest that deep-sea corals in the Eastern Bering Sea slope or canyons are at risk from commercial fisheries under the current management structure, and that special protections for deep-sea corals were not warranted.

Punt, A. E., Poljak, D., Dalton, M. G., & Foy, R. J. (2014). Evaluating the Impact of Ocean Acidification on Fishery Yields and Profits: The Example of Red King Crab in Bristol Bay. *Ecological Modelling,* 285, 39-53. https://doi.org/10.1016/j.ecolmodel.2014.04.017

A stage-structured pre-recruit model was developed to capture hypotheses regarding the impact of ocean acidification on the survival of pre-recruit crab. The model was parameterized using life history and survival data for red king crab (Paralithodes camtschaticus) derived from experiments conducted at the National Marine Fisheries Service Kodiak laboratory. A parameterized pre-recruit model was linked to a post-recruit population dynamics model for adult male red king crab in Bristol Bay, Alaska that included commercial fishery harvest. This coupled population dynamics model was integrated with a bioeconomic model of commercial fishing sector profits to forecast how the impacts of ocean acidification on the survival of pre-recruit red king crab will affect yields and profits for the Bristol Bay red king crab fishery for a scenario that includes future ocean pH levels predictions. Expected yields and profits were projected to decline over the next 50–100 years in this scenario given reductions in pre-recruit survival due to decreasing ocean pH levels over time. The target fishing mortality used to provide management advice based on the current harvest policy for Bristol Bay red king crab also declined over time in response to declining survival rates. However, the impacts of ocean acidification due to reduced pre-recruit survival on yield and profits are likely to be limited for the next 10–20 years, and its effects will likely be masked by natural variation in pre-recruit survival. This analysis is an initial step toward a fully integrated understanding of the impact of ocean acidification on fishery yields and profits, and could be used to focus future research efforts.

Reum, J. C. P., McDonald, P. S., Long, W. C., Holsman, K. K., Divine, L., Armstrong, D., & Armstrong, J. (2019). Rapid Assessment of Management Options for Promoting Stock Rebuilding in Data-Poor Species under Climate Change. *Conservation Biology*, 11. https://doi.org/10.1111/cobi.13427

The development of species recovery plans requires considering likely outcomes of different management interventions, but the complicating effects of climate change are rarely evaluated. We examined how qualitative network models (QNMs) can be deployed to support decision making when data, time, and funding limitations restrict use of more demanding quantitative methods. We used QNMs to evaluate management interventions intended to promote the rebuilding of a collapsed stock of blue king crab (Paralithodes platypus) (BKC) around the Pribilof Islands (eastern Bering Sea) to determine how their potential efficacy may change under climate change. Based on stakeholder input and a literature review, we constructed a QNM that described the life cycle of BKC, key ecological interactions, potential climate-change impacts, relative interaction strengths, and uncertainty in terms of interaction strengths and link presence. We performed sensitivity analyses to identify key sources of prediction uncertainty. Under a scenario of no climate change, predicted increases in BKC were reliable only when stock enhancement was implemented in a BKC hatchery-program scenario. However, when climate change was accounted for, the intervention could not counteract its adverse impacts, which had an overall negative effect on BKC. The remaining management scenarios related to changes in fishing effort on BKC predators. For those scenarios, BKC outcomes were unreliable, but climate change further decreased the probability of observing recovery. Including information on relative interaction strengths increased the likelihood of predicting positive outcomes for BKC approximately 5-50% under the management scenarios. The largest gains in prediction precision will be made by reducing uncertainty associated with ecological interactions between adult BKC and red king crab (Paralithodes camtschaticus). Qualitative network models are useful options when data are limited, but they remain underutilized in conservation.

Physics

Durski, S. M., Kurapov, A., Zhang, J., & Panteleev, G. G. (2016). Circulation in the Eastern Bering Sea: Inferences from a 2-Km-Resolution Model. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 134, 48-64. https://doi.org/10.1016/j.dsr2.2015.02.002

A 2-km-resolution model of the eastern Bering Sea is developed to capture dynamical processes on the scale of the Rossby radius of deformation on tidal to seasonal time scales. The model spans the region from 178 degrees E to the Alaskan coast and from roughly 50 degrees to 66 degrees N, including the Aleutian Islands in the south and the Bering Strait in the north. The high resolution throughout ensures that the mesoscale dynamics of significant subregions of the domain, such as the Aleutian Island passes, Bering Sea slope, and the shelf canyons, are captured simultaneously without the concern for loss of interconnectivity between regions. Simulations are performed for the ice-free season (June-October) of 2009, with tidal and atmospheric forcing. The model compares favorably with observations from AVHRR and Envisat satellites, Argo drifters, and Bering Sea shelf moorings. The mesoscale dynamics of the mixing and exchange flow through the eastern Aleutian Island passes, which exhibit strong diurnal and two-week variability, are well represented. The two-week oscillation in volume flux through the largest of these passes, Amukta Pass, is found to be out of phase with the transport through the neighboring passes (e.g., Seguam and Samalga passes). Mesoscale structure is also found to be ubiquitous along the mixing, front of the cold pool. Structures at the scale of O(20 km) persist and play a role in determining

the pattern of erosion of the water mass as the shelf warms and mixes. On the Bering Sea shelf, tidal motions are dominant, and variability on the horizontal scale of the first-mode internal tide develops (O(30 km)) from the shelf break to the onshore edge of the Bering shelf cold pool.

Section XVI: Eastern Bering Sea, Central Gulf of Alaska

Biology

Ainsley, S. M., Ebert, D. A., & Cailliet, G. M. (2011). A Comparison of Reproductive Parameters of the Bering Skate, Bathyraja Interrupta, from Two Alaskan Large Marine Ecosystems. *Marine and Freshwater Research,* 62(6), 557-566. https://doi.org/10.1071/mf10140

Estimates of size at maturity are crucial to fisheries stock assessments and may change spatially and temporally. This study directly compares life-history characteristics of a skate species in two large marine ecosystems in a region where there is both a directed fishery and considerable skate by-catch in other fisheries. The Bering skate, Bathyraja interrupta, is one of the most common skate species in Alaskan waters, occurring in two large marine ecosystems, the eastern Bering Sea (EBS) and the Gulf of Alaska (GOA), but little is known about its life history. Skates were sampled from both regions between 2004 and 2007. In the GOA, the size at maturity was estimated to be 69 cm total length (TL) for males and 71 cm TL for females, while in the EBS size at maturity was estimated as 70 cm and 72 cm TL for males and females, respectively. Median size at maturity differed by sex but not by region. Our results indicate that B. interrupta shows late maturity, typical of most skate species, suggesting that more detailed monitoring of skate populations and precautionary management is warranted as skate fisheries expand.

Hay, D. E., Rose, K. A., Schweigert, J., & Megrey, B. A. (2008). Geographic Variation in North Pacific Herring Populations: Pan-Pacific Comparisons and Implications for Climate Change Impacts. *Progress in Oceanography,* 77(2-3), 233-240. https://doi.org/10.1016/j.pocean.2008.03.015

We review age-specific growth, recruitment, and population diversity of herring (Clupea pallasi) in the North Pacific. Eastern Pacific herring are smaller, grow slower, and reach a lower asymptotic weight (W-infinity) than western Pacific herring. in the eastern Pacific, there are latitudinal differences in size but this variation is slight compared to east-west differences. The east-west growth differences match geographic patterns of genetic variation between eastern and western Pacific herring described in earlier reports. Both the genetic studies and the growth variation show that virtually all western Pacific herring populations, including those in the Bering Sea, cluster in one group, and all eastern Pacific herring, from cluster in a second group. Population diversity, estimated as the number the Gulf of Alaska to California, of separate populations per degree of latitude, is highest in the mid-ranges (latitudes) of herring distribution but the available supporting data are limited. Recruitment variation, examined by comparing the coefficient of recruitment variation for nine eastern Pacific herring populations, was highest in the Gulf of Alaska and lowest in southern populations. We suggest that the broad geographic differences in herring populations are adaptive, evolving in response to local prey resources, competitive and climate regimes. If so, examination of these differences can provide insight about potential effects of future climate change.

Hirons, A. C., Schell, D. M., & Finney, B. P. (2001). Temporal records of δ13C and δ15N in North Pacific pinnipeds: inferences regarding environmental change and diet. *Oecologia,* 129(4), 591-601. https://doi.org/10.1007/s004420100756

Sea lion and seal populations in Alaskan waters underwent various degrees of decline during the latter half of the twentieth century and the cause(s) for the declines remain uncertain. The stable carbon (13C/12C) and nitrogen (15N/14N) isotope ratios in bone collagen from wild Steller sea lions (Eumetopias jubatus), northern fur seals (Callorhinus ursinus) and harbor seals (Phoca vitulina) from the Bering Sea and Gulf of Alaska were measured for the period 1951–1997 to test the hypothesis that a change in trophic level may have occurred during this interval and contributed to the population declines. A significant change in δ15N in pinniped tissues over time would imply a marked change in trophic level. No significant change in bone collagen δ15N was found for any of the three species during the past 47 years in either the Bering Sea or the Gulf of Alaska. However, the 15N in the Steller sea lion collagen was significantly higher than both northern fur seals and harbor seals. A significant decline in δ13C (almost 2 ‰ over the 47 years) was evident in Steller sea lions, while a declining trend, though not significant, was evident in harbor seals and northern fur seals. Changes in foraging location, in combination with a trophic shift, may offer one possible explanation. Nevertheless, a decrease in δ13C over time with no accompanying change in δ15N suggests an environmental change affecting the base of the foodweb rather than a trophic level change due to prey switching. A decline in the seasonal primary production in the region, possibly resulting from decreased phytoplankton growth rates, would exhibit itself as a decline in δ13C. Declining production could be an indication of a reduced carrying capacity in the North Pacific Ocean. Sufficient quantities of optimal prey species may have fallen below threshold sustaining densities for these pinnipeds, particularly for yearlings and subadults who have not yet developed adequate foraging skills.

Management

Cheung, W. W. L., Brodeur, R. D., Okey, T. A., & Pauly, D. (2015). Projecting Future Changes in Distributions of Pelagic Fish Species of Northeast Pacific Shelf Seas. *Progress in Oceanography,* 130, 19-31. https://doi.org/10.1016/j.pocean.2014.09.003

Marine life is being affected by changes in ocean conditions resulting from changes in climate and chemistry triggered by combustion of fossil fuels. Shifting spatial distributions of fish species is a major observed and predicted impact of these oceanographic changes, and such shifts may modify fish community structure considerably in particular locations and regions. We projected future range shifts of pelagic marine fishes of the Northeast Pacific shelf seas by 2050 relative to the present. We combined published data, expert knowledge, and pelagic fish survey data to predict current species distribution ranges of 28 fish species of the Northeast Pacific shelf seas that occur in the epipelagic zone and are well-represented in pelagic fish surveys. These represent a wide spectrum of sub-tropical to sub-polar species, with a wide range of life history characteristics. Using projected ocean condition changes from three different Earth System Models, we simulated changes in the spatial distribution of each species. We show that Northeast Pacific shelf seas may undergo considerable changes in the structure of its pelagic marine communities by mid-21st century. Ensembles of model projections suggest that the distribution centroids of the studied species are expected to shift poleward at an average rate of 30.1 +/- 2.34 (S.E.) km decade(-1) under the SRES A2 scenario from 2000 to 2050. The projected species range shifts result in a high rate of range expansion of this group of species into the Gulf of Alaska and the Bering Sea. Rate of range contraction of these species is highest at the Aleutian Islands, and in the

California Current Large Marine Ecosystem. We also predict increasing dominance of warmer water species in all regions. The projected changes in species assemblages may have large ecological and socio-economic implications through mismatches of co-evolved species, unexpected trophic effects, and shifts of fishing grounds. These results provide hypotheses of climate change impacts that can be tested using data collected by monitoring programmes in the region.

Physics

Shanmugam, G. (2018). A Global Satellite Survey of Density Plumes at River Mouths and at Other Environments: Plume Configurations, External Controls, and Implications for Deep-Water Sedimentation. *Petroleum Exploration and Development,* 45(4), 640-661. https://doi.org/10.1016/s1876-3804(18)30069-7

The U.S. National Aeronautics and Space Administration (NASA) has archived thousands of satellite images of density plumes in its online publishing outlet called 'Earth Observatory' since 1999. Although these images are in the public domain, there has not been any systematic compilation of configurations of density plumes associated with various sedimentary environments and processes. This article, based on 45 case studies covering 21 major rivers (e.g., Amazon, Betsiboka, Congo [Zaire], Copper, Hugli [Ganges], Mackenzie, Mississippi, Niger, Nile, Rhone, Rio de la Plata, Yellow, Yangtze, Zambezi, etc.) and six different depositional environments (i. e., marine, lacustrine, estuarine, lagoon, bay, and reef), is the first attempt in illustrating natural variability of configurations of density plumes in modern environments. There are, at least, 24 configurations of density plumes. An important finding of this study is that density plumes are controlled by a plethora of 18 oceanographic, meteorological, and other external factors. Examples are: 1) Yellow River in China by tidal shear front and by a change in river course; 2) Yangtze River in China by shelf currents and vertical mixing by tides in winter months; 3) Rio de la Plata Estuary in Argentina and Uruguay by Ocean currents; 4) San Francisco Bay in California by tidal currents; 5) Gulf of Manner in the Indian Ocean by monsoonal currents; 6) Egypt in Red Sea by Eolian dust; 7) U.S. Atlantic margin by cyclones; 8) Sri Lanka by tsunamis; 9) Copper River in Alaska by high-gradient braid delta; 10) Lake Erie by seiche; 11) continental margin off Namibia by upwelling; 12) Bering Sea by phytoplankton; 13) the Great Bahama Bank in the Atlantic Ocean by fish activity; 14) Indonesia by volcanic activity; 15) Greenland by glacial melt; 16) South Pacific Ocean by coral reef; 17) Carolina continental Rise by pockmarks; and 18) Otsuchi Bay in Japan by internal bore. The prevailing trend in promoting a single type of river-flood triggered hyperpycnal flow is flawed because there are 16 types of hyperpycnal flows. River-flood derived hyperpycnal flows are muddy in texture and they occur close to the shoreline in inner shelf environments. Hyperpycnal flows are not viable transport mechanisms of sand and gravel across the shelf into the deep sea. The available field observations suggest that they do not form meter-thick sand layers in deep water settings. For the above reasons, river-flood triggered hyperpycnites are considered unsuitable for serving as petroleum reservoirs in deep-water environments until proven otherwise.

Section XVII: Gulf of Alaska

Biology

Debenham, C., Moss, J., & Heintz, R. (2019). Ecology of Age-0 Arrowtooth Flounder (Atheresthes Stomias) Inhabiting the Gulf of Alaska. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 165, 140-149. https://doi.org/10.1016/j.dsr2.2019.06.004

Age-0 arrowtooth flounder (Atheresthes stomias) were collected from surface waters, throughout the summer months in the Gulf of Alaska. As the most abundant groundfish species in the Gulf of Alaska, arrowtooth flounder are an important ecological component of this ecosystem. While information is available for juvenile and adult arrowtooth flounder, and to some extent the ichthyoplankton life stage and spawning processes, the late-pelagic, post-larval stage of arrowtooth flounder has been the subject of fewer inquiries. This study examined the effects of environmental parameters on age-0 arrowtooth flounder in the pelagic environment. Based on data collected from 2010 to 2013, this study provided information on the abundance, distribution, pelagic duration, size, growth, diet and energy content of age-0 arrowtooth flounder in the Gulf of Alaska. Mean settlement to the benthos occurred at approximately 41 mm standard length, which corresponded to early August. Average energy density was 20.42 +/- 0.07 kJ g(-1) dry mass and showed no change with size, although there were some inter-annual differences that were attributed to changes in temperature and diet composition. This study helps fill critical gaps in the knowledge of the early life history of arrowtooth flounder and how they respond to the biophysical parameters in the Gulf of Alaska.

Diogou, N., Palacios, D. M., Nystuen, J. A., Papathanassiou, E., Katsanevakis, S., & Klinck, H. (2019). Sperm Whale (Physeter macrocephalus) Acoustic Ecology at Ocean Station Papa in the Gulf of Alaska - Part 2: Oceanographic Drivers of Interannual Variability. *Deep-Sea Research Part I-Oceanographic Research Papers,* 150, 14. https://doi.org/10.1016/j.dsr.2019.05.004

Understanding top predator responses to environmental variability is key to assessing potential impacts of global warming on marine ecosystems. However, tracking environmental changes and their effects across multiple trophic levels up to predators can be difficult. Here, we related the interannual (2007-2012) acoustic occurrence of sperm whales (Physeter macrocephalus) at Ocean Station PAPA (OSP), in the offshore Gulf of Alaska (GOA), to environmental drivers within an explicit time-series modeling framework. In a model based on a combination of in-situ and remotely sensed variables, ocean heat content (HC), meridional current (V), eddy kinetic energy (EKE), strength of the permanent pycnocline (maxBVF), sea surface temperature (SST) and SST standard deviation (SSTsd) explained 51% of the variability in sperm whale presence, indicating a positive relationship between sperm whale occurrence and increased ocean heating, vertical stratification, and circulation. Sperm whale detections were anomalously high in summer 2010 and winter 2011, and anomalously low at the end of summer and winter 2008, and spring 2011. Results suggest these strongly anomalous detection events reflect a response to El Nino-Southern Oscillation (ENSO) events, with an 8-month lag. In the study area, El Nino leads to a stronger permanent pycnocline, a weakening of the Alaska Gyre, a northward expansion of the North Pacific Subarctic Frontal Zone, and a prevalence of offshore mesoscale eddies, likely favoring

the abundance of squid and their predator, the sperm whale. The overall results are consistent with a scenario of increasing sperm whale occurrence at high latitudes under increased ocean warming.

Etnoyer, P., & Morgan, L. E. (2005). Habitat-Forming Deep-Sea Corals in the Northeast Pacific Ocean. In *Cold-Water Corals and Ecosystems.* A. Freiwald & J. M. Roberts (Eds.), (pp. 331-343): Springer-Verlag Berlin Heidelberg https://doi.org/10.1007/3-540-27673-4_16

We define habitat-forming deep-sea corals as those families of octocorals, hexacorals, and stylasterids with species that live deeper than 200 m, with a majority of species exhibiting complex branching morphology and a sufficient size to provide substrata or refugia to associated species. We present 2,649 records (name, geoposition, depth, and data quality) from eleven institutions on eight habitatforming deep-sea coral families, including octocorals in the families Coralliidae, Isididae, Paragorgiidae and Primnoidae, hexacorals in the families Antipathidae, Oculinidae and Caryophylliidae, and stylasterids in the family Stylasteridae. The data are ranked according to record quality. We compare family range and distribution as predicted by historical records to the family extent as informed by recent collections aboard the National Oceanic of Atmospheric Administration (NOAA) Office of Ocean Exploration 2002 Gulf of Alaska Seamount Expedition (GOASEX). We present a map of one of these families, the Primnoidae.

We find that these habitat-forming families are widespread throughout the Northeast Pacific, save Caryophylliidae (Lophelia sp.) and Oculinidae (Madrepora sp.), which are limited in occurrence. Most coral records fall on the continental shelves, in Alaska, or Hawaii, likely reflecting research effort. The vertical range of these families, based on large samples (N >200), is impressive. Four families have maximum-recorded depths deeper than 1500 m, and minimum depths shallower than 40 m. Isidid, primnoid, and antipatharian records all exceed 2500 m depth. GOASEX collections are made from each of seven seamounts surveyed, extending the known range of Coralliidae 2500 km northward and the known limits of Isididae 450 km seaward, beyond the continental shelf, to seamounts in the Gulf of Alaska.

Fiechter, J., Broquet, G., Moore, A. M., & Arango, H. G. (2011). A Data Assimilative, Coupled Physical-Biological Model for the Coastal Gulf of Alaska. *Dynamics of Atmospheres and Oceans,* 52(1-2), 95-118. https://doi.org/10.1016/j.dynatmoce.2011.01.002

A data assimilative, coupled physical-biological model for the Coastal Gulf of Alaska (CGOA) is used to investigate the extent to which improvements to oceanic circulation yield improvements to lower trophic level ecosystem predictions, especially in relation to mesoscale variability at the shelfbreak. The ocean circulation component is an implementation of the Regional Ocean Modeling System (ROMS), the lower trophic level ecosystem component is a six-compartment Nutrient-Phytoplankton-Zooplankton-Detritus (NPZD) model with iron limitation, and the data assimilation component is the adjoint-based, four-dimensional variational (4D-Var) system available in ROMS. Assimilated observations consist of weekly satellite sea surface height and temperature, as well as bimonthly in situ temperature and salinity measurements. Simulation results for 1998-2002 indicate that assimilation of physical observations significantly improves the accuracy with which the model reproduces the frequency, duration, and intensity of eddy events along the CGOA shelfbreak. Improvements to oceanic mesoscale processes lead to substantial improvements to the biological response predicted by the NPZD model.

Observed and simulated correlations between eddy kinetic energy and surface chlorophyll concentrations suggest that ecosystem dynamics at the shelfbreak is tied to eddy activity in the northern CGOA (i.e., off the Kenai Peninsula and Kodiak Island). In the southern CGOA (i.e., off the Shumagin Islands), mesoscale processes and ecosystem response at the shelfbreak are uncorrelated, as eddies tend to occur during winter when phytoplankton growth is severely light-limited. Based on observation and control vector impact calculations for physical (eddy kinetic energy) and biological (surface chlorophyll concentrations) processes, improvements to oceanic circulation and ecosystem dynamics are primarily associated with the assimilation of satellite sea surface height observations, and occur mainly through adjustments of the model initial conditions. These similarities in the observation and control vector impacts lend further evidence to the linkages between mesoscale activity and primary production along the CGOA shelfbreak.

Gregr, E. J., & Coyle, K. O. (2009). The Biogeography of the North Pacific Right Whale (Eubalaena japonica). *Progress in Oceanography,* 80(3-4), 188-198. https://doi.org/10.1016/j.pocean.2008.12.004

The eastern North Pacific population of right whales (Eubalaena japonica) is among the most endangered whale populations, with an estimated size of only 10s of individuals. The effectiveness of measures (e.g., protected areas, abundance surveys) intended to promote recovery of this population will be enhanced by understanding its distribution, habitat use, and habitat characteristics. In order to facilitate such understanding, we summarized relevant right whale biology, reviewed the life history of their zooplankton prey species, and related North Pacific oceanography to the production, distribution, and concentration of these prey at three scales of variability. We discuss how ocean processes may drive zooplankton distribution and concentration, and present hypotheses about how prey patches suitable for right whale foraging might be formed. Such hypotheses, combined with available distributional data and descriptions of the ocean environment, would be suitable for predicting potential right whale foraging habitat.

Kamin, L. M., Palof, K. J., Heifetz, J., & Gharrett, A. J. (2014). Interannual and Spatial Variation in the Population Genetic Composition of Young-of-the-Year Pacific Ocean Perch (Sebastes alutus) in the Gulf of Alaska. *Fisheries Oceanography,* 23(1), 1-17. https://doi.org/10.1111/fog.12038

Little is known about the population structure of Alaskan rockfishes, including Pacific ocean perch (POP, Sebastes alutus), and how persistent and variable oceanographic features may influence their structures. Moreover, early life history information is sparse for many species. We used data from 14 microsatellite loci to characterize the genetic structure of young-of-the-year Pacific ocean perch collected during 1998-2003 from the Gulf of Alaska and Bering Sea. Broad-scale geographic variation in genetic structure of the young-of-the-year (F-ST=0.005, P<10(-4)) had similarities to that observed in a previous adult study. The overall correlation between genetic and geographic distance (isolation by distance) was nearly identical to that observed in the adults. Fine-scale geographic divergence was also observed and may be the result of oceanographic circulation features within the Gulf of Alaska. Interannual variation (between cohorts) at locations sampled in more than oneyear is consistent with variable oceanography and fine-scale population structure rather than the influence of a sweepstakes

effect. The similarities of the young-of-the-year with the adults and the pattern of genetic divergence confirm that dispersal of Pacific ocean perch is limited in all life stages.

Koeberle, A. L., Arismendi, I., Crittenden, W., Leer, D., & Noakes, D. L. G. (2020). Fluctuating Asymmetry of Adult Chinook Salmon (Oncorhynchus tshawytscha) Otoliths from Wild and Hatchery Origins. *Aquatic Ecology,* 54(1), 431-446. https://doi.org/10.1007/s10452-019-09733-0

Fluctuating asymmetry is the non-directional deviations from bilateral symmetry and occurs across organisms. Fish otoliths are often used to test for differences in symmetry as otoliths aid in hearing, homing, and balance. Here, we evaluated the symmetry of otolith pairs in adult Chinook Salmon between wild and hatchery-origin stocks. Pacific salmon are economically and ecologically important to the Pacific Northwest, USA. Chinook Salmon are widely distributed throughout the North Pacific Ocean, yet several wild populations are federally listed as endangered or threatened due to depleted stocks, loss of genetic diversity, and hatchery contribution to wild stocks. As such, fishery managers are concerned with the health and condition of hatchery-origin fish and their impacts on wild populations. We included both hatchery and wild-origin Chinook Salmon from the Coast Mountain and Willamette regions in Oregon as well as hatchery populations from southeast Alaska. We evaluated several metrics to test shape variation and symmetry between the left and right sagittal otoliths. We found consistently more asymmetry in otoliths from hatchery origin than wild Chinook Salmon within seven out of eight total metrics. These results could have conservation and management implications as hatchery-origin Chinook Salmon can reduce pressure from wild stocks while continuing to support commercial and recreational industries.

Laurel, B. J., & Rogers, L. A. (2020). Loss of Spawning Habitat and Prerecruits of Pacific Cod During a Gulf of Alaska Heatwave. *Canadian Journal of Fisheries and Aquatic Sciences,* 77(4), 644-650. https://doi.org/10.1139/cjfas-2019-0238

Pacific cod (Gadus macrocephalus) stocks in the Gulf of Alaska experienced steep, unexpected declines following an unprecedented 3-year marine heatwave (i.e., "warm blob") from 2014 to 2016. We contend that stock reproductive potential was reduced during this period, evidenced by a combination of new laboratory data demonstrating narrow thermal hatch success (3-6 degrees C), mechanistic-based models of spawning habitat, and correlations with prerecruit time series. With the exception of single-year El Nino events (1998, 2003), the recent 3-year heatwave (2014-2016) and return to similar conditions in 2019 were potentially the most negative impacts on spawning habitat for Pacific cod in the available time series (1994-2019). Continued warming will likely reduce the duration and spatial extent of Pacific cod spawning in the Gulf of Alaska.

Marks, G. S., LaVigne, M., Hill, T. M., Sauthoff, W., Guilderson, T. P., Roark, E. B., . . . Horner, T. J. (2017). Reproducibility of Ba/Ca Variations Recorded by Northeast Pacific Bamboo Corals. *Paleoceanography,* 32(9), 966-979. https://doi.org/10.1002/2017pa003178

Trace elemental ratios preserved in the calcitic skeleton of bamboo corals have been shown to serve as archives of past ocean conditions. The concentration of dissolved barium (Ba-SW), a bioactive nutrientlike element, is linked to biogeochemical processes such as the cycling and export of nutrients. Recent work has calibrated bamboo coral Ba/Ca, a new Ba-SW proxy, using corals spanning the oxygen minimum zone beneath the California Current System. However, it was previously unclear whether Ba/Ca-coral records were internally reproducible. Here we investigate the accuracy of using laser ablation inductively coupled plasma mass spectrometry for Ba/Ca-coral analyses and test the internal reproducibility of Ba/Ca among replicate radial transects in the calcite of nine bamboo corals collected from the Gulf of Alaska (643-720m) and the California margin (870-2054m). Data from replicate Ba/Ca transects were aligned using visible growth bands to account for nonconcentric growth; smoothed data were reproducible within similar to 4% for eight corals (n=3 radii/coral). This intracoral reproducibility further validates using bamboo coral Ba/Ca for Ba-SW reconstructions. Sections of the Ba/Ca records that were potentially influenced by noncarbonate bound Ba phases occurred in regions where elevated Mg/Ca or Pb/Ca and coincided with anomalous regions on photomicrographs. After removing these regions of the records, increased Ba/Ca-coral variability was evident in corals between similar to 800 and 1500m. These findings support additional proxy validation to understand Ba-SW variability on interannual timescales, which could lead to new insights into deep sea biogeochemistry over the past several centuries.

Penn, K., Wu, D. Y., Eisen, J. A., & Ward, N. (2006). Characterization of Bacterial Communities Associated with Deep-Sea Corals on Gulf of Alaska Seamounts. *Applied and Environmental Microbiology,* 72(2), 1680-1683. https://doi.org/10.1128/aem.72.2.1680-1683.2006

Although microbes associated with shallow-water corals have been reported, deepwater coral microbes are poorly characterized. A cultivation-independent analysis of Alaskan seamount octocoral microflora showed that Proteobacteria (classes Alphaproteobacteria and Gammaproteobacteria), Firmicutes, Bacteroidetes, and Acidobacteria dominate and vary in abundance. More sampling is needed to understand the basis and significance of this variation.

Pirtle, J. L., Shotwell, S. K., Zimmerman, M., Reid, J. A., & Golden, N. (2019). Habitat Suitability Models for Groundfish in the Gulf of Alaska. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 165, 303-321. https://doi.org/10.1016/j.dsr2.2017.12.005

Identifying and quantifying the major ecosystem processes that regulate recruitment strength of commercially and ecologically important fish species is a central goal of fisheries management research. In the Gulf of Alaska (GOA) five groundfish species are of particular interest: sablefish (Anoplopoma fimbria), Pacific cod (Gadus macrocephalus), walleye pollock (Gadus chalcogrammus), arrowtooth flounder (Atheresthes stomias), and Pacific ocean perch (Sebastes alutus). Habitat suitability models (HSM) were developed for the demersal early juvenile stage to inform survival to recruitment for these species, using catch data and seafloor habitat metrics with presence-only models. Regional-scale maps were produced that predict the probability of suitable habitat available in the GOA from settlement through residency in nursery areas. For example, the HSM for sablefish (150-399 mm) described suitable habitat as bathymetrically low-lying areas with low rocky structure within 25-300 m depth. In contrast, the HSM for Pacific ocean perch (50-200 mm) described suitable habitat as bathymetry rises with rocky

structure present on north-south facing slopes within 85-270 m depth. These habitat covariates are useful to refine population estimates for North Pacific groundfish species and to inform life stage-specific definitions of Essential Fish Habitat. This application of MaxEnt models should be applicable for species with low occurrence of spatial data in other marine ecosystems globally.

Puerta, P., Ciannelli, L., Rykaczewski, R. R., Opiekun, M., & Litzow, M. A. (2019). Do Gulf of Alaska Fish and Crustacean Populations Show Synchronous Non-Stationary Responses to Climate? *Progress in Oceanography,* 175, 161-170. https://doi.org/10.1016/j.pocean.2019.04.002

Changes in the abundance and productivity of biological populations in the North Pacific have often been associated with large-scale modes of climate variability. The Pacific Decadal Oscillation (PDO), which describes spatio-temporal variability in North Pacific sea surface temperature (SST), correlates with much of this variability. However, since the late 1980s, the North Pacific Gyre Oscillation (NPGO) has explained an increasing proportion of variance in North Pacific climate properties. Ecological responses to this change in the proportion of variance ascribed to the two climate patterns remain poorly understood. Here, we test the hypothesis that relationships between biological time series and climate covariates (SST and the PDO) differ for nine Gulf of Alaska fish and crustacean populations before and after the late 1980s. Additionally, we evaluate whether non-stationary climate-biology relationships arose synchronously across populations as a community response. We used different formulations of Generalized Additive Models in a population and community context and compared results to the classical approach of aggregated population responses based on Principal Component Analysis (PCA). The results showed that climate-biology relationships weakened or reversed for most populations in the late 1980s, coinciding with the increase in variance of the NPGO. However, these non-stationary responses were highly species-specific and did not arise synchronously as a community response. We show that PCA does not represent community dynamics properly when only few species covary in time and exhibit long-term trends. Therefore, this approach might not be always useful to detect synchronous changes among biological time series as a community response. Novel associations among climate variables and novel climate-biology relationships are expected to become increasingly evident with future climate change, and the recognition of switches between different explanatory variable-response relationships may be critical for successful management of marine resources during transitions to these novel climate states.

Roark, E. B., Guilderson, T. P., Flood-Page, S., Dunbar, R. B., Ingram, B. L., Fallon, S. J., & McCulloch, M. (2005). Radiocarbon-Based Ages and Growth Rates of Bamboo Corals from the Gulf of Alaska. *Geophysical Research Letters,* 32(4). https://doi.org/10.1029/2004gl021919

Deep-sea coral communities have long been recognized by fisherman as areas that support large populations of commercial fish. As a consequence, many deep-sea coral communities are threatened by bottom trawling. Successful management and conservation of this widespread deep-sea habitat requires knowledge of the age and growth rates of deep-sea corals. These organisms also contain important archives of intermediate and deep-water variability, and are thus of interest in the context of decadal to century-scale climate dynamics. Here, we present Delta(14)C data that suggest that bamboo corals from the Gulf of Alaska are long-lived (75-126 years) and that they acquire skeletal carbon from two distinct

sources. Independent verification of our growth rate estimates and coral ages is obtained by counting seasonal Sr/Ca cycles and probable lunar cycle growth bands.

Rooper, C. N., Zimmermann, M., & Prescott, M. M. (2017). Comparison of Modeling Methods to Predict the Spatial Distribution of Deep-Sea Coral and Sponge in the Gulf of Alaska. *Deep-Sea Research Part I-Oceanographic Research Papers,* 126, 148-161. https://doi.org/10.1016/j.dsr.2017.07.002

Deep-sea coral and sponge ecosystems are widespread throughout most of Alaska's marine waters, and are associated with many different species of fishes and invertebrates. These ecosystems are vulnerable to the effects of commercial fishing activities and climate change. We compared four commonly used species distribution models (general linear models, generalized additive models, boosted regression trees and random forest models) and an ensemble model to predict the presence or absence and abundance of six groups of benthic invertebrate taxa in the Gulf of Alaska. All four model types performed adequately on training data for predicting presence and absence, with regression forest models having the best overall performance measured by the area under the receiver-operating-curve (AUC). The models also performed well on the test data for presence and absence with average AUCs ranging from 0.66 to 0.82. For the test data, ensemble models performed the best. For abundance data, there was an obvious demarcation in performance between the two regression-based methods (general linear models and generalized additive models), and the tree-based models. The boosted regression tree and random forest models out-performed the other models by a wide margin on both the training and testing data. However, there was a significant drop-off in performance for all models of invertebrate abundance (similar to 50%) when moving from the training data to the testing data. Ensemble model performance was between the tree-based and regression-based methods. The maps of predictions from the models for both presence and abundance agreed very well across model types, with an increase in variability in predictions for the abundance data. We conclude that where data conforms well to the modeled distribution (such as the presence-absence data and binomial distribution in this study), the four types of models will provide similar results, although the regression-type models may be more consistent with biological theory. For data with highly zero-inflated distributions and non normal distributions such as the abundance data from this study, the tree-based methods performed better. Ensemble models that averaged predictions across the four model types, performed better than the GLM or GAM models but slightly poorer than the tree-based methods, suggesting ensemble models might be more robust to overfitting than tree methods, while mitigating some of the disadvantages in predictive performance of regression methods.

Schwing, F. B., Mendelssohn, R., Bograd, S. J., Overland, J. E., Wang, M. Y., & Ito, S. (2010). Climate Change, Teleconnection Patterns, and Regional Processes Forcing Marine Populations in the Pacific. *Journal of Marine Systems,* 79(3-4), 245-257. https://doi.org/10.1016/j.jmarsys.2008.11.027

Climate change impacts in large marine ecosystems (LMEs) are driven by global climate variability, often communicated over large distances by atmospheric teleconnections, and modified by the dominant local and regional ocean processes. The focus of this paper is to summarize the key processes and features that characterize the major coastal LMEs of the Pacific, as part of a greater effort to understand the role of past and future global climate change in driving (possibly synchronous) fluctuations in marine

populations. The physical setting of five LMEs - the Humboldt Current System (HCS), California Current System (CCS), Gulf of Alaska (GOA), Kuroshio Current System (KCS), and Oyashio Current System (OCS) - and the mechanisms and impacts of climate variability on these systems are described. Because of their pivotal role in linking and perhaps synchronizing climate variability in disparate LMEs, we also review teleconnections and analyze past global atmospheric teleconnections and regional ocean response patterns. The major Pacific eastern boundary current systems, the CCS and HCS, feature similar dominant processes (e.g., coastal upwelling), and share atmospheric forcing from common teleconnection patterns that vary together. Sea level pressure variations forcing the KCS and OCS systems on climate scales, however, are not strongly teleconnected to the CCS and HCS. A common factor analysis of sea surface temperature (SST) within these ecosystems provides an example of how LMEs have responded to past climate variability. All LMEs display a persistent warming tendency since 1900, with multi-decadal fluctuations superimposed. However, SST fluctuations in the western Pacific lag those in the east by about a decade. Global synchrony in climate forcing is modulated by distinct processes within each LME, which reduce the correlation between long-term fluctuations.

Yang, Q., Cokelet, E. D., Stabeno, P. J., Li, L. B., Hollowed, A. B., Palsson, W. A., . . . Barbeaux, S. J. (2019). How "the Blob" Affected Groundfish Distributions in the Gulf of Alaska. *Fisheries Oceanography,* 28(4), 434-453. https://doi.org/10.1111/fog.12422

We investigated the distributional shifts of groundfish in response to anomalous ocean conditions, particularly the recent anomalously warm period (2014-2016; "The Blob"), based on data from ten Gulf of Alaska bottom trawl surveys conducted by the Alaska Fisheries Science Center during 1996-2015. Six groundfish species were considered: Pacific cod (Gadus macrocephalus), arrowtooth flounder (Atheresthes stomias), walleye pollock (Gadus chalcogrammus), Pacific ocean perch (Sebastes alutus), northern rock sole (Lepidopsetta polyxystra), and southern rock sole (Lepidopsetta bilineata). Ontogenetic differences were examined by dividing data for each fish species into size classes. Our study demonstrated that after accounting for size-specific depth preferences, the spatial responses of groundfish to anomalous ocean conditions differed by species and foraging guild in the central Gulf of Alaska. Pacific cod and arrowtooth flounder showed similar responses to ocean warming, but different responses to cooling. In general, Pacific cod moved to deeper depths in warmer years and moved to shallower depths in colder years. Arrowtooth flounder also moved deeper in warmer years. However, in colder years, large arrowtooth flounder (>40 cm) shifted toward shallower depths while smaller-sized fish shifted toward deeper depths. In warmer years, large pollock (>30 cm) moved to deeper waters while smaller pollock (10-20 cm) moved to shallower waters. Pacific ocean perch exhibited an opposite response to thermal changes in habitat compared with Pacific cod and arrowtooth flounder. They moved deeper in colder years, but there was no clear change in depth as a function of size in response to warmer habitat.

Chemistry

Aguilar-Islas, A. M., Seguret, M. J. M., Rember, R., Buck, K. N., Proctor, P., Mordy, C. W., & Kachel, N. B. (2016). Temporal Variability of Reactive Iron over the Gulf of Alaska Shelf. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 132, 90-106. https://doi.org/10.1016/j.dsr2.2015.05.004

The Gulf of Alaska (GoA) shelf is a highly productive regime bordering the nitrate-rich, iron (Fe)-limited waters of the central GoA. The exchange between nitrate-limited, Fe-replete coastal waters and nitrate rich, Fe-deplete offshore waters, amplified by mesoscale eddies, is key to the productivity of the region. Previous summer field studies have observed the partitioning of Fe in the coastal GoA as being heavily dominated by the particulate phase due to the high suspended particulate loads carried by glacial rivers into these coastal waters. Here we present new physico-chemical iron data and nutrient data from the continental shelf of the GoA during spring and late summer 2011. The late summer data along the Seward Line showed variable surface dissolved iron (DFe) concentrations (0.052 nM offshore to 4.87 nM inshore), within the range of previous observations. Relative to available surface nitrate, DFe was in excess (at Fe:C=50 mu mol:mol) inshore, and deficient (at Fe:C= 20 mu ol:mol) offshore. Summer surface total dissolvable iron (TDFe, acidified unfiltered samples) was dominated by the acid-labile particulate fraction over the shelf (with a median contribution of only 3% by DFe), supporting previously observed Fe partitioning in the GoA. In contrast, our spring data from southeast GoA showed TDFe differently partitioned, with surface DFe (0.28-4.91 nM) accounting on average for a much higher fraction (similar to 25%) of the TDFe pool. Spring surface DFe was insufficient relative to available nitrate over much of the surveyed region (at Fe:C=50 mu mol:mol). Organic Fe-binding ligand data reveal excess concentrations of ligands in both spring and summer, indicating incomplete titration by Fe. Excess concentrations of an especially strong-binding ligand class in spring surface waters may reflect in-situ ligand production. Due to anomalous spring conditions in 2011, river flow and phytoplankton biomass during our spring sampling were lower than the expected May average. We argue our samples are likely more representative of early spring pre-bloom conditions, providing an idea of the possible physicochemical partitioning of Fe in coastal GoA waters relevant to initial spring bloom dynamics.

Aguilar-Islas, A. M., Wu, J., Rember, R., Johansen, A. M., & Shank, L. M. (2010). Dissolution of Aerosol-Derived Iron in Seawater: Leach Solution Chemistry, Aerosol Type, and Colloidal Iron Fraction. *Marine Chemistry,* 120(1), 25-33. https://doi.org/10.1016/j.marchem.2009.01.011

Experiments were conducted using a semi-continuous batch protocol to leach iron from aerosol samples. In this procedure, aerosol samples were leached in an all-Teflon flow-through reaction chamber by multiple (3–4) aliquots (~40 mL) of leaching solution per predetermined leaching period. Several types of aerosols and leaching solutions were tested. The percent iron solubility obtained from aerosols collected in two urban regions was lower (~1%) than the solubility from samples collected in the open ocean (6–13%). This regional variability was greater than the variability obtained when leaching the same aerosols using different leaching solutions. A review of field and laboratory studies from the literature also suggests that different types of aerosols produce more variability in aerosol iron solubility estimates than do different leaching protocols. Colloidal iron was the dominant fraction of aerosol derived dissolved iron in all the experiments carried out during this study, suggesting that the dissolution of aerosol iron in seawater is dominated by the colloidal iron fraction.

Cheng, W., Hermann, A. J., Coyle, K. O., Dobbins, E. L., Kachel, N. B., & Stabeno, P. J. (2012). Macro- and Micro-Nutrient Flux to a Highly Productive Submarine Bank in the Gulf of Alaska: A Model-Based Analysis of Daily and Interannual Variability. *Progress in Oceanography,* 101(1), 63-77. https://doi.org/10.1016/j.pocean.2012.01.001

Although the Gulf of Alaska is subjected to intense downwelling through much of the year, during early spring and summer, upwelling due to local wind stress curl can occur over major portions of the shelf, resulting in high production. Satellite observations indicate that shallow banks may have substantially elevated chlorophyll concentrations relative to surrounding waters during much of the summer. We use the Regional Ocean Modeling System (ROMS) and ocean observation data to examine circulation and stratification around Portlock Bank in the Gulf of Alaska, and to explore mechanisms contributing to interannual variability in the supply of iron and nitrate onto the bank in spring and summer. ROMS at 3-km resolution is coupled to a lower trophic level biology model for the Gulf of Alaska; the coupled model is driven by tidal forcing, sub-daily atmospheric forcing, freshwater runoff, and boundary and initial conditions from Simple Ocean Data Assimilation (SODA) products. Hydrographic observations were made as part of six surveys undertaken by the GLOBEC/NEP (Global Ocean Ecosystem Dynamics/Northeast Pacific) program. Modeling results suggest that iron supply to the shallow layer around Portlock Bank is controlled by both advection and vertical diffusion processes, while nitrate supply is dominated by tidally-induced vertical diffusion. Overall, higher chlorophyll concentration in summer around Portlock Bank is attributed to strong vertical mixing, which pumps nutrients onto the bank from the flanks on either side, and from the top of the bank into the euphotic zone. Recirculation attributed to tidal effects increases residence time over the bank, further enhancing potential production, but intense mixing atop the bank in early spring can lead to light limitation of phytoplankton production. We used July 2004 cruise data from Portlock Bank to help verify model results.

Chierici, M., Fransson, A., & Nojiri, Y. (2006). Biogeochemical Processes as Drivers of Surface Fco(2) in Contrasting Provinces in the Subarctic North Pacific Ocean. *Global Biogeochemical Cycles,* 20(1). https://doi.org/10.1029/2004gb002356

The effect of temperature, biological processes, air-sea CO2 exchange and vertical mixing as drivers of the seasonality of the surface water fugacity of CO2 (fCO(2)sw) were studied for the year 2000 in the subarctic North Pacific Ocean. The regional and seasonal variability of the surface water chemistry was studied using an extensive data set on surface water fCO(2) and nutrient concentrations in six contrasting provinces. We observed the largest seasonal amplitude for all parameters in the western provinces (Oyashio and Western Subarctic Gyre, WSG). Our study showed that biological processes and temperature were major controls for the monthly fCO(2)sw change in all provinces. The magnitude and strength of the processes showed large temporal and spatial variability. The WSG showed larger influence by biological processes and vertical mixing than the Alaska gyre (AG), where the effect caused by temperature was larger, implying different forcing of the fCO(2) change in the two gyres. Biological activity, estimated from the monthly nitrate change corrected for addition induced by vertical mixing, resulted in a net annual CO2 loss. The net carbon loss out of the top 50 m driven by biological activity was 3 times higher in the WSG (64 g C m(-2) yr(-1)) than in the AG (23 g C m(-2) yr(-1)). The annual sum of the fCO(2)sw change based on all processes resulted in a CO2 buildup in the surface waters for all provinces. Although the air-sea CO2 exchange was of minor importance relative to the other considered processes (4 to 13%), all provinces showed a net annual uptake of atmospheric CO2 from 1 to 23 g C m(-2) yr(-1) and an average for the whole study area of about 12 (+/- 9) g C m(-2) yr(-1).

Powers, L. C., Babcock-Adams, L. C., Enright, J. K., & Miller, W. L. (2015). Probing the Photochemical Reactivity of Deep Ocean Refractory Carbon (Dorc): Lessons from Hydrogen Peroxide and

Superoxide Kinetics. *Marine Chemistry,* 177, 306-317. https://doi.org/10.1016/j.marchem.2015.06.005

Most marine DOC is thought to be biologically-recalcitrant, especially that in the deep ocean pool (>1000 m). In particular, the deep waters of the North Pacific should contain the most recalcitrant DOC because they do not form locally, with deep DOC having survived long isolation from the surface during global-scale thermohaline circulation. One of the proposed removal pathways involves photochemical reactions when refractory DOC circulates through sunlit surface waters (Mopper et al., 1991). Here, we reevaluate the general photoreactivity of refractory DOC by investigating the photochemical production of two reactive oxygen species (ROS), hydrogen peroxide (H2O2) and superoxide (O-2(-)), using controlled irradiations at sea and in the laboratory. The photoproduction of these two ROS were compared between deep and surface water samples collected in the Gulf of Alaska. For irradiated samples, initial superoxide steady-state concentrations ([O-2(-)](ss)) and first-order decay constants (k(pseudo)) were similar between surface and deep waters, ranging from similar to 1-4 nM and 4-12 x 10(-3) s(-1), respectively. Initial photoproduction rates were comparable between surface and deep waters, ranging from 22-173 nM h(-1) for O-2(-) and from 1-8.3 nM h(-1) for H2O2, indicating that a large portion of photoproduced O-2(-) does not lead to H2O2 formation. In fact, the photoproduction ratio of O-2(-) to H2O2 averaged similar to 4:1 in paired experiments, instead of the 2:1 stoichiometry expected for O-2(-) dismutation to form H2O2. Continued irradiation for up to 48 h showed photoproduced H2O2 to be much lower in deep samples compared to surface samples with accumulation slowing or stopping in deep samples despite both measurable [O-2(-)](ss) and photon absorbance by colored dissolved organic matter (CDOM). These results are consistent with a loss of source material (i.e. CDOM) for O-2(-) photoproduction and a shift to a predominantly oxidative pathway for O-2(-) decay. Low photoproduction rates, loss of O-2(-) continued accumulation with extended radiation, and an apparent loss of 01 source material argues that the deep refractory DOC pool is less photochemically reactive than previously suggested.

van de Flierdt, T., Frank, M., Halliday, A. N., Hein, J. R., Hattendorf, B., Gunther, D., & Kubik, P. W. (2003). Lead Isotopes in North Pacific Deep Water - Implications for Past Changes in Input Sources and Circulation Patterns. *Earth and Planetary Science Letters,* 209(1-2), 149-164. https://doi.org/10.1016/s0012-821x(03)00069-4

The sources of non-anthropogenic Pb in seawater have been the subject of debate. Here we present Pb isotope time-series that indicate that the non-anthropogenic Pb budget of the northernmost Pacific Ocean has been governed by ocean circulation and riverine inputs, which in turn have ultimately been controlled by tectonic processes. Despite the fact that the investigated locations are situated within the Asian dust plume, and proximal to extensive arc volcanism, eolian contributions have had little impact. We have obtained the first high-resolution and high-precision Pb isotope time-series of North Pacific deep water from two ferromanganese crusts from the Gulf of Alaska in the NE Pacific Ocean, and from the Detroit Seamount in the NW Pacific Ocean. Both crusts were dated applying Be-10/Be-9 ratios and yield continuous time-series for the past 13.5 and 9.6 Myr, respectively. Lead isotopes show a monotonic evolution in Pb-206/Pb-204 from low values in the Miocene (less than or equal to 18.57) to high values at present day (greater than or equal to 18.84) in both crusts, even though they are separated by more than 3000 kin along the Aleutian Arc. The variation exceeds the amplitude found in Equatorial Pacific deep water records by about three-fold. There also is a striking similarity in Pb-207/Pb-204 and Pb-208/Pb-204 ratios of the two crusts, indicating the existence of a local circulation cell in the

sub-polar North Pacific, where efficient lateral mixing has taken place but only limited exchange (in terms of Pb) with deep water from the Equatorial Pacific has occurred. Both crusts display well-defined trends with age in Pb-Pb isotope mixing plots, which require the involvement of at least four distinct Pb sources for North Pacific deep water. The Pb isotope time-series reveal that eolian supplies (volcanic ash and continent-derived loess) have only been of minor importance for the dissolved Pb budget of marginal sites in the deep North Pacific over the past 6 Myr. The two predominant sources have been young volcanic arcs, one located in the northeastern part and one located in the northwestern part of the Pacific margin, from where material has been eroded and delivered to the ocean, most likely via riverine pathways.

Geology

Etnoyer, P. (2005). Seamount Resolution in Satellite-Derived Bathymetry. *Geochemistry Geophysics Geosystems,* 6. https://doi.org/10.1029/2004gc000833

I compare satellite-derived global relief data on 13 seamounts in the northeast Pacific Ocean to echosounder-derived multibeam values from the Gulf of Alaska Seamount Expeditions and the West Coast Seamounts and Ridges Multibeam Surveys for peak height, latitude, longitude, and midsection area. I find Smith and Sandwell's (1997) global sea floor topography relatively accurate for peak geoposition but generally deeper than multibeam by 192 m (132 m). Cell size alone can explain 50-90% of peak height variation, suggesting higher-resolution geodetic altimetry could improve the accuracy of these estimates. Nevertheless, midsection areas overlap by 80 +/- 11%. The altimetric technique clearly resolves the presence and general form of numerous unnamed deep seamounts, though predicted seamount peak height estimates for small features may vary from their true depth by up to 50%. These findings support high-end estimates of global seamount abundance since small seamount features (similar to 1200 m relief) revealed by satellite may, in actuality, be quite substantial features (similar to 2500 m relief).

Liu, C. L., Lay, T., Xie, Z. J., & Xiong, X. (2019). Intraslab Deformation in the 30 November 2018 Anchorage, Alaska, M-W 7.1 Earthquake. *Geophysical Research Letters,* 46(5), 2449-2457. https://doi.org/10.1029/2019gl082041

Anchorage, Alaska, was strongly shaken on 30 November 2018 by an M-W 7.1 earthquake that ruptured within the underthrust Pacific plate at depths of from 45 to 65 km. Ground failures occurred in saturated lowlands filled with sediments, producing notable road damage, but there was limited structural damage in Anchorage, only similar to 12 km south of the epicenter. The earthquake has a normal faulting geometry with a shallowly dipping east-west tension axis indicating intraslab deformation, likely between the underthrust Yakutat terrane and adjacent Pacific seafloor. Separate and joint inversions of teleseismic P and SH waves, regional strong ground motions, and GPS static displacements provide a weak preference for a westward steeply dipping rupture plane with up to 2 m of slip distributed over a single slip patch with dimensions of 20x20 km. The similar to 12s long rupture expanded northward. Aftershocks occur at shallower depths than the mainshock slip zone. Plain Language Summary The earthquake that struck on 30 November 2018, causing damage in Anchorage, Alaska, involved a fault rupture within the Pacific plate, which is sinking into the mantle beneath Alaska along the convergence zone between the Pacific and North American plates. Anchorage was seriously damaged during the

great 1964 Alaska earthquake, which had a magnitude of 9.2 and resulted from sudden sliding on the shallow plate boundary; far less damage was produced by the 2018 event, which had a magnitude of 7.1 and involved deeper deformation of the underthrust slab. There is a lateral change in the dip of the sinking plate with the thick, relatively buoyant oceanic plateau called the Yakutat terrane having shallow dip to the east of the earthquake while normal thickness oceanic crust dips more steeply to the west. The 2018 event was located in the central region of the slab distortion. Intraslab events of this type present significant earthquake hazard, but it is difficult to determine their likelihood of occurrence.

Risley, D. E., Martin, G. C., Lynch, M. B., Flett, T. O., Larson, J. A., & Horowitz, W. L. (1992). *Geologic Report for the Gulf of Alaska Planning Area.* Retrieved from https://www.osti.gov/biblio/5913383

The report is a summary of the regional geology, geologic history, petroleum potential, and environmental characteristics of the Gulf of Alaska Planning Area. The geologic interpretations are based on offshore seismic reflection lines, subsurface data obtained from onshore and offshore wells, dredge samples, shallow core holes, and geologic investigations of outcrops onshore. The primary emphasis, however, is on 13 wells drilled offshore between 1975 and 1983. Despite the lack of exploration success thus far, industry interest in the Gulf of Alaska area as a potential petroleum province remains high.

Zimmermann, M., De Robertis, A., & Ormseth, O. (2019). Verification of Historical Smooth Sheet Bathymetry for the Gulf of Alaska - Integrated Ecosystem Research Program. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 165, 292-302. https://doi.org/10.1016/j.dsr2.2018.06.006

We verified the accuracy of interpolated bathymetric surfaces created from historic (1924-2003) National Ocean Service smooth sheet bathymetric soundings and shorelines with single-beam echosounder measurements of seafloor depth obtained in the spring and summer of 2013. Independent comparisons were made at ten inshore locations in the central and eastern Gulf of Alaska as an effort to groundtruth the fish habitat layers provided for NPRB's (North Pacific Research Board) sponsored Gulf of Alaska - Integrated Ecosystem Research Program (GOA-IERP). Ordinary least squares linear regressions determined that the GOA-IERP soundings could successfully predict interpolated smooth sheet bathymetry (gridded or raster surface) at all sites (best R-2 = 1.0), although the oldest smooth sheets from 1924 (R-2 = similar to 0.90) and 1925 (R-2 = similar to 0.80) had the poorest fits. Standardized residuals were geographically clustered at all sites, with larger residuals often observed in areas of rapid depth transition, but >= 93% of residuals at all sites were within two standard deviations. Residual analysis indicates that the standardized residuals increase with depth, slope, distance to nearest smooth sheet sounding, and distance to nearest smooth sheet navigation station. This indicates that errors in navigation were greater farther offshore, interpolations were worse in areas of sparse soundings, and the consequences were more significant in steeper and deeper areas. Overall, we conclude that the smooth sheet bathymetry was successfully ground truthed and useful for fish habitat descriptions.

Management

Baker, M. R., Palsson, W., Zimmermann, M., & Rooper, C. N. (2019). Model of Trawlable Area Using Benthic Terrain and Oceanographic Variables—Informing Survey Design and Habitat Maps in the Gulf of Alaska. *Fisheries Oceanography,* 28(6), 629-657. https://doi.org/10.1111/fog.12442

Bottom trawl surveys provide fishery-independent data on relative abundance and life history parameters for a wide range of marine taxa. Survey data are used to assess species distribution, biological interactions, and ecosystem structure and to manage marine resources. Not all bottom types or oceanographic conditions accommodate this survey method. We applied National Ocean Service hydrographic smooth sheets to evaluate physical attributes associated with habitat available to surveys. Random forests were used to evaluate the relative influence of benthic terrain and oceanographic predictors in determining accessibility to bottom trawl gear. We examined the marginal importance of each predictor, quantified the response gradient, and applied piecewise regression to determine threshold breakpoint values. Thresholds were used to develop predictive maps and distinguish untrawlable habitat at the scale of discrete towpaths and survey stations. Untrawlable habitat was associated with increased complexity in terrain, roughness, slope, surface curvature, substrate coarseness, current, and aspect. Maps of critical thresholds suggest different variables constrain the probability of a successful trawl in the nearshore, shelf, and continental slope. Overlay analysis of the model projection demonstrates the utility of archived smooth sheet data and identifies areas where higher resolution data might improve results. The model and maps produced in this analysis might be used to identify habitats available to and impacted by commercial trawl fisheries, inform the relative availability of various species and habitat types to bottom trawl surveys, evaluate bias in assessment indices and ecosystem metrics derived from survey data, and advance habitat-specific biomass estimates.

Barth, J. A., Allen, S. E., Dever, E. P., Dewey, R. K., Evans, W., Feely, R. A., . . . Wingard, C. E. (2019). Better Regional Ocean Observing through Cross-National Cooperation: A Case Study from the Northeast Pacific. *Frontiers in Marine Science,* 6, 13. https://doi.org/10.3389/fmars.2019.00093

The ocean knows no political borders. Ocean processes, like summertime wind-driven upwelling, stretch thousands of kilometers along the Northeast Pacific (NEP) coast. This upwelling drives marine ecosystem productivity and is modulated by weather systems and seasonal to interdecadal ocean-atmosphere variability. Major ocean currents in the NEP transport water properties such as heat, fresh water, nutrients, dissolved oxygen, pCO(2), and pH close to the shore. The eastward North Pacific Current bifurcates offshore in the NEP, delivering open-ocean signals south into the California Current and north into the Gulf of Alaska. There is a large and growing number of NEP ocean observing elements operated by government agencies, Native American Tribes, First Nations groups, not-for-profit organizations, and private entities. Observing elements include moored and mobile platforms, shipboard repeat cruises, as well as land-based and estuarine stations. A wide range of multidisciplinary ocean sensors are deployed to track, for example, upwelling, downwelling, ocean productivity, harmful algal blooms, ocean acidification and hypoxia, seismic activity and tsunami wave propagation. Data delivery to shore and observatory controls are done through satellite and cell phone communication, and via seafloor cables. Remote sensing from satellites and land-based coastal radar provide broader spatial coverage, while numerical circulation and biogeochemical modeling complement ocean observing efforts. Models span

from the deep ocean into the inland Salish Sea and estuaries. NEP ocean observing systems are used to understand regional processes and, together with numerical models, provide ocean forecasts. By sharing data, experiences and lessons learned, the regional ocean observatory is better than the sum of its parts.

Pichel, W. G., Veenstra, T. S., Churnside, J. H., Arabini, E., Friedman, K. S., Foley, D. G., . . . Li, X. F. (2012). Ghostnet Marine Debris Survey in the Gulf of Alaska - Satellite Guidance and Aircraft Observations. *Marine Pollution Bulletin,* 65(1-3), 28-41. https://doi.org/10.1016/j.marpolbul.2011.10.009

Marine debris, particularly debris that is composed of lost or abandoned fishing gear, is recognized as a serious threat to marine life, vessels, and coral reefs. The goal of the GhostNet project is the detection of derelict nets at sea through the use of weather and ocean models, drifting buoys and satellite imagery to locate convergent areas where nets are likely to collect, followed by airborne surveys with trained observers and remote sensing instruments to spot individual derelict nets. These components of GhostNet were first tested together in the field during a 14-day marine debris survey of the Gulf of Alaska in July and August 2003. Model, buoy, and satellite data were used in flight planning. A manned aircraft survey with visible and IR cameras and a LIDAR instrument located debris in the targeted locations, including 102 individual pieces of debris of anthropogenic or terrestrial origin.

Straub, P. T., Batchelder, H. P., & Weingartner, T. J. (2002). U.S. Globec Northeast Pacific Program: Overview. *Oceanography,* 15(2), 30-35. Retrieved from https://tos.org/oceanography/article/u.s.-globec-northeast-pacific-program-overview

The bountiful natural resources of the Northeast Pacific (NEP) long sustained thriving populations of native peoples. The central importance of salmon, halibut, marine mammals, seabirds and other species to the cultural life of indigenous populations is beautifully represented in the legends and distinctive artwork of this region (Holm, 1965). Today, as human activities strongly affect terrestrial and aquatic ecosystems through harvesting of timber and fishery resources, water use practices, and habitat degradation in this region, the critical importance of understanding how these impacts might interact with further effects of global climate change is abundantly clean The processes underlying the generally high productivity in the nearshore waters of the Northeast Pacific differ in the various subsystems and the effects of climate change can be expected to be manifested in distinctive ways in each (Batchelder et al., this issue; Weingartner et al., this issue). How these changes will affect overall levels of productivity in the Northeast Pacific is a critical question for GLOBEC researchers.

Physics

Auad, G. (2008). Response of the Gulf of Alaska 3d Winter Circulation to Oceanic Climate Shifts: Ecosystem Implications. *Geophysical Research Letters,* 35(2). https://doi.org/10.1029/2007gl031611

Recent measurements of zooplankton biomass and biological productivity in the Gulf of Alaska have raised a number of questions regarding possible linkages between climate and availability of renewable resources. In this article we compare 3 abrupt oceanic regime shifts in the Gulf of Alaska, the 1976-1977 warming shift, the 1998 cooling episode, and the 1998 to 1999 El Ni (n) over tildeo to La Ni (n) over tildea transition, against concomitant changes in biological conditions reported in the literature. After the 1976-1977 warming shift, changes in the Gulf's 3D circulation, i.e., interior upwelling, onshore transport and coastal downwelling, had the same sign as their climatological means, thus providing a candidate explanation to the observed increased productivity of the upper ocean. Warming and cooling transitions have associated with them very different patterns of both horizontal and vertical circulation, where the latter is confirmed to be linked to the wind stress curl variability. Important shifts in the local biology have been reported in the literature (warming of 1976-1997 and El Ni (n) over tildeo to La Ni (n) over tildea transition of 1998-1999) when climatological shifts in our simulated vertical velocities were large; in turn, when they were small, the ecosystem did not show significant changes and this was in part due to the resilience set by the 1976-1977 shift through the strengthening of the GOA's mean 3D circulation.

Coyle, K. O., Hermann, A. J., & Hopcroft, R. R. (2019). Modeled Spatial-Temporal Distribution of Productivity, Chlorophyll, Iron and Nitrate on the Northern Gulf of Alaska Shelf Relative to Field Observations. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 165, 163-191. https://doi.org/10.1016/j.dsr2.2019.05.006

The northern Gulf of Alaska (GOA) shelf is dynamic spatially and temporally. With two major current systems and numerous eddies and meanders, interpretation of field data from ship-based observations at specific times and locations is complicated. We used the Regional Ocean Modeling System (ROMS) with an embedded nutrientphytoplankton-zooplankton (GOANPZ) model to aid in understanding spatial-temporal patterns of productivity, chlorophyll concentration and biomass over the GOA shelf between 132 degrees W and 160 degrees W from 2000 to 2013. Carbon chlorophyll ratios in the model were varied in response to light to alter production-irradiance curves by season to conform to field measurements. Simulations reveal regions of high productivity in March-May on the southeast Alaskan Shelf, and the western inner shelf between Prince William Sound (PWS) and the Shumagin Islands, but with lower productivity on the outer shelf between PWS and western Kodiak. The model produced regions of elevated productivity on the outer shelf of the western GOA during summer and fall. This pattern is driven by circulation affecting the distribution of iron on the western shelf. Simulated productivity on the shelf between 2000 and 2006 was elevated relative to 2007-2013, apparently due to changes in the simulated iron concentration. Correlations indicate that simulated production on the western GOA shelf during March-May can explain up to 65% of the variance in the mean biomass of large copepods from net tows during spring. Simulations suggest that detailed temporal-spatial data on iron concentration and the processes affecting iron are crucial to understanding interannual spatial-temporal differences in magnitudes of production and biomass at lower trophic levels on the GOA shelf.

Donohue, S. M., & Stacey, M. W. (2016). Simulation of the 2014 Anomalous Warming in the Northeast Pacific. *Atmosphere-Ocean,* 54(4), 457-468. https://doi.org/10.1080/07055900.2016.1197096

The Nucleus for European Modelling of the Ocean (NEMO) numerical model was used to simulate the North Pacific Ocean beginning in January 1960. The model had a horizontal resolution of 0.25(o), 46 vertical levels, and employed a spectral nudging assimilation scheme that, unlike standard nudging, nudges only specific frequency and wavenumber bands. This simulation was nudged to the mean and monthly Levitus climatology of potential temperature and salinity. The model was forced with mean monthly winds, net heat flux, and precipitation from the National Centers for Environmental Prediction (NCEP). The simulation was used to study a recent intrusion of much warmer and less saline water than normal from the west into the Gulf of Alaska, beginning in December 2013 and lasting until at least the early summer of 2014. The observed surface temperature anomalies were more than 4 standard deviations above normal. The model reproduced these anomalies in both a qualitative and quantitative manner, reproducing the same scale of anomalies over the region. An anomalous increase in the North Pacific Current (NPC) was found in the model in 2012 and the beginning of 2013, in agreement with observations. This increase in the NPC is associated with the positive phase of the North Pacific Gyre Oscillation. The causes of the temperature anomalies in the Gulf of Alaska could be due to three key factors: (i) an anomalously high, positive, surface heat flux in 2013 over the greater North Pacific; (ii) a significant decrease in the eastward flow of the NPC starting in late 2013 (with an accompanying decrease in cold water advection) after a period of historically strong eastward flow; and (iii) weaker winds throughout most of 2013 accompanied, however, by a shift to stronger northward winds (with an accompanying increase in warm water advection) in late 2013.

Hristova, H. G., Ladd, C., & Stabeno, P. J. (2019). Variability and Trends of the Alaska Gyre from Argo and Satellite Altimetry. *Journal of Geophysical Research-Oceans,* 124(8), 5870-5887. https://doi.org/10.1029/2019jc015231

The interannual variability and trends of the Alaska Gyre and Gulf of Alaska (GOA) circulation are examined using meridional geostrophic transport from Argo temperature and salinity (2004-2017) and altimetric sea surface height (1993-2017). More than half of the top 1,500 m meridional transport variability in the Alaska Gyre is accounted for by a statistical mode strongly correlated with the Pacific Decadal Oscillation (PDO) index, consistent with the PDO exerting a major influence on North Pacific sea surface temperature variability. During a positive phase of the PDO, the zero-transport streamline separating the subtropical from the Alaska Gyre is shifted to the south from its mean position, while more transport is diverted northward, associated with a stronger and larger Alaska Gyre. Additionally, over the 25-year altimetric record there is a linear, increasing trend in strength of the Alaska Gyre (but not in areal extent), accompanied by an increasing trend for the incoming North Pacific Current. The effect of the PDO transport mode on GOA circulation is weak. Temperature and salinity volume averaged for the GOA covary with the PDO index, with warmer and fresher waters during a positive phase. Despite correlated anomalies for temperature, salinity, and northward transport into the GOA, however, geostrophic advection from the south contributes only minimally to the interannual variations of water properties in the GOA. An exception was the marine heat wave of 2013/2014 and its aftermath when temperature advection from the south played a more appreciable role for warming and subsequent cooling of the GOA. Plain Language Summary Variability of the ocean circulation in the

Alaska Gyre is one of the factors influencing the rich ecosystem in the Gulf of Alaska. Improved understanding of the variability and trends of the Alaska Gyre is thus of prime concern, given its biologic and economic implications. Using data from the Global Argo program and satellite altimetry covering the 25-year period from 1993 to 2017, we diagnose the changes in Alaska Gyre structure and transport and how they fit in the larger picture of North Pacific global climate modes, such as the Pacific Decadal Oscillation (PDO). During a positive phase of the PDO, more transport is diverted northward, associated with a stronger and larger Alaska Gyre. Additionally, over the 25-year record the Alaska Gyre has continuously increased in strength (but not in size). While temperature and salinity in the Gulf of Alaska vary with the PDO, with warmer and fresher waters during a positive phase, advection from the south contributes only minimally to the year-to-year variations of water properties in the Gulf of Alaska, suggesting that these variations are mostly determined by local processes instead.

Jarosz, E., Wang, D., Wijesekera, H., Pegau, W. S., & Moum, J. N. (2017). Flow Variability within the Alaska Coastal Current in Winter. *Journal of Geophysical Research-Oceans,* 122(5), 3884-3906. https://doi.org/10.1002/2016jc012102

Coastal circulation off Kayak Island in the northern Gulf of Alaska was explored in wintertime (October 2012 to March 2013) by deploying nine moorings within the Alaska Coastal Current (ACC). Hydrographic, bottom-pressure, and velocity observations depicted well the winter variability of the ACC. Atmospheric observations showed a net loss of heat, 30 W m(-2) or more, from the ocean to the atmosphere and indicated that storms with downwelling-favorable winds over 10 m s(-1) frequently passed over the area. Due to vigorous mixing during storms, the waters were well-mixed or weakly stratified whereas bottom-pressure anomalies were mainly related to surface-elevation fluctuations and indicated that there was also a cross-shelf surface-elevation gradient. Current observations showed along-shelf nearly barotropic subtidal flow of 40 cm s(-1) or more throughout the water column. They also indicated that along-shelf flow was primarily driven by the cross-shelf pressure gradient resulting from the cross-shelf surface-elevation gradient and not by wind stress. Analyses suggested that flow dynamics within the ACC in winter were well-described by vertically averaged momentum equations and showed a dominance of the cross-shelf pressure gradient that was mainly balanced by the Coriolis term. Observations also showed that when winds relaxed, cold low-salinity waters moved offshore and stratification was reestablished. Consequently, near-shore waters were less dense, i.e., cooler and fresher than offshore waters resulting in the cross-shelf density gradient that may have contributed to the along-shelf flow by generating near-surface currents of approximate to 20 cm s(-1).

Liang, Y. C., Yu, J. Y., Saltzman, E. S., & Wang, F. (2017). Linking the Tropical Northern Hemisphere Pattern to the Pacific Warm Blob and Atlantic Cold Blob. *Journal of Climate,* 30(22), 9041-9057. https://doi.org/10.1175/jcli-d-17-0149.1

During 2013-15, prolonged near-surface warming in the northeastern Pacific was observed and has been referred to as the Pacific warm blob. Here, statistical analyses are conducted to show that the generation of the Pacific blob is closely related to the tropical Northern Hemisphere (TNH) pattern in the atmosphere. When the TNH pattern stays in its positive phase for extended periods of time, it generates prolonged blob events primarily through anomalies in surface heat fluxes and secondarily through anomalies in wind-induced ocean advection. Five prolonged (>= 24 months) blob events are identified

during the past six decades (1948-2015), and the TNH-blob relationship can be recognized in all of them. Although the Pacific decadal oscillation and El Nino can also induce an arc-shaped warming pattern near the Pacific blob region, they are not responsible for the generation of Pacific blob events. The essential feature of Pacific blob generation is the TNH-forced Gulf of Alaska warming pattern. This study also finds that the atmospheric circulation anomalies associated with the TNH pattern in the North Atlantic can induce SST variability akin to the so-called Atlantic cold blob, also through anomalies in surface heat fluxes and wind-induced ocean advection. As a result, the TNH pattern serves as an atmospheric conducting pattern that connects some of the Pacific warm blob and Atlantic cold blob events. This conducting mechanism has not previously been explored.

Pelland, N. A., Eriksen, C. C., & Cronin, M. F. (2016). Seaglider Surveys at Ocean Station Papa: Circulation and Water Mass Properties in a Meander of the North Pacific Current. *Journal of Geophysical Research-Oceans,* 121(9), 6816-6846. https://doi.org/10.1002/2016jc011920

A Seaglider autonomous underwater vehicle augmented the Ocean Station Papa (OSP; 50 degrees N, 145 degrees W) surface mooring, measuring spatial structure on scales relevant to the monthly evolution of the moored time series. During each of three missions from June 2008 to January 2010, a Seaglider made biweekly 50 km x 50 km surveys in a bowtie-shaped survey track. Horizontal temperature and salinity gradients measured by these surveys were an order of magnitude stronger than climatological values and sometimes of opposite sign. Geostrophically inferred circulation was corroborated by moored acoustic Doppler current profiler measurements and AVISO satellite altimetry estimates of surface currents, confirming that glider surveys accurately resolved monthly scale mesoscale spatial structure. In contrast to climatological North Pacific Current circulation, upper-ocean flow was modestly northward during the first half of the 18 month survey period, and weakly westward during its latter half, with Rossby number O(0.01). This change in circulation coincided with a shift from cool and fresh to warm, saline, oxygen-rich water in the upper-ocean halocline, and an increase in vertical fine structure there and in the lower pycnocline. The anomalous flow and abrupt water mass transition were due to the slow growth of an anticyclonic meander within the North Pacific Current with radius comparable to the scale of the survey pattern, originating to the southeast of OSP.

Wang, K. J., Thomson, R. E., Rabnovich, A. B., Fine, I. V., & Insua, T. L. (2020). The 2018 Alaska-Kodiak Tsunami Off the West Coast of North America: A Rare Mid-Plate Tsunamigenic Event. *Pure and Applied Geophysics,* 177(3), 1347-1378. https://doi.org/10.1007/s00024-020-02427-x

The major (M-w 7.9) earthquake that struck the Gulf of Alaska near Kodiak Island on 23 January 2018 was a rare, mid-plate strike-slip event that triggered a minor trans-Pacific tsunami. An analysis of the simultaneous measurements of tsunami waveforms at 21 open-ocean sites (including three independent arrays of stations) and 27 coastal tide gauges in the Gulf of Alaska and along the coast of North America has enabled us to examine properties of the 2018 tsunami, its transformation over the continental slope and shelf, and its amplification as the waves approached the coast. Results show that the tsunami wave variance decreased monotonically along the west coast from northern British Columbia to southern Oregon. Based on the variance structure, the mean amplification factor for Tofino on the west coast of Vancouver Island (a "beacon" site with a long time series), was A(RMS)(Tof) = 5.3, in good agreement with corresponding estimates for four major past events; 4.5 (2009 Samoa), 4.3 (2010

Chile), 6.3 (2011 Tohoku) and 5.2 (2012 Haida Gwaii). This variance-derived amplification for Tofino was greater than the amplification factor based on the amplitude ratio (A(Tof) = 3.2). Spectral analysis of the records showed that the tsunami had a relatively large high-frequency content (i.e., was "blueish"), with nearly 90% of the total energy in the open ocean at frequencies > 1.7 cph (periods < 35 min) and with an "integral frequency scale" of 4 cph (period 15 min). Wavelet analysis revealed strong dispersion of the propagating tsunami waves, in agreement with theoretical estimates. The abrupt jump in water depth of about 4 cm detected at DART 46409, located mid-plate about 85 km from the epicenter of the 2018 Kodiak earthquake, appears to have been due to an earthquake-induced seafloor subsidence.

Yelland, D., & Crawford, W. R. (2005). Currents in Haida Eddies. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 52(7-8), 875-892. https://doi.org/10.1016/j.dsr2.2005.02.010

Measurements by a variety of sensors provided details of flow in Haida Eddies, which are anticyclonic, mesoscale features that move slowly westward through the eastern Gulf of Alaska. These measurements provided the best comparison and analysis to date of mesoscale eddy Currents by various ship- and satellite-based sensors. The relative contribution of barotropic currents to the total eddy orbital motion Lit Ocean surface was found to be up to 16% based on comparison of total sea-surface height anornalies measured by satellite altimetry, and baroclinic elevation of the ocean surface detected by ship-based measurements of density through the eddies. Acoustic Doppler current meters oil a ship transiting two Haida Eddies found that the observed Currents were considerably different from the expected orbital motion, perhaps due to inertial currents or to previously undetected barotropic structure. Lagrangian drifters drogued near the ocean Surface in two eddies revealed that inertial currents in late spring and summer were similar in magnitude to eddy orbital motion and larger than eddy Currents following periods of strong winds. Drifter tracks also provided evidence that the eddy rotated as a solid body (constant vorticity) within 30-40kin of the eddy center, and that material could remain in these central waters for at least 2 months ill summer. For most of the 2-month period during which the drifters were tracked. they steadily moved away from the center of the eddy, implying a gradual uplift of the pycnocline within the eddy, core due to slow decay of the eddy, or to its uplift as it moved westward into denser ambient waters.

Section XIII: Northern Bering Sea

Biology

Glubokov, A. I., Novikova, S. V., & Afanasiev, P. K. (2018). Recent Data on Northern Rock Sole Lepidopsetta Polyxystra from the Northwestern Part of the Bering Sea. *Journal of Ichthyology,* 58(5), 761-764. https://doi.org/10.1134/s0032945218050077

The features of the biology and spatial distribution of northern rock sole Lepidopsetta polyxystra are described based on the analysis of samples from bottom trawlings in the northwestern part of the Bering Sea at depths of 57-440 m in June-August 1996-2001.

Kober, K. M., & Bernardi, G. (2013). Phylogenomics of Strongylocentrotid Sea Urchins. *BMC Evolutionary Biology,* 13. https://doi.org/10.1186/1471-2148-13-88

Background: Strongylocentrotid sea urchins have a long tradition as model organisms for studying many fundamental processes in biology including fertilization, embryology, development and genome regulation but the phylogenetic relationships of the group remain largely unresolved. Although the differing isolating mechanisms of vicariance and rapidly evolving gamete recognition proteins have been proposed, a stable and robust phylogeny is unavailable. Results: We used a phylogenomic approach with mitochondrial and nuclear genes taking advantage of the whole-genome sequencing of nine species in the group to establish a stable (i.e. concordance in tree topology among multiple lies of evidence) and robust (i.e. high nodal support) phylogenetic hypothesis for the family Strongylocentrotidae. We generated eight draft mitochondrial genome assemblies and obtained 13 complete mitochondrial genes for each species. Consistent with previous studies, mitochondrial sequences failed to provide a reliable phylogeny. In contrast, we obtained a very well-supported phylogeny from 2301 nuclear genes without evidence of positive Darwinian selection both from the majority of most-likely gene trees and the concatenated fourfold degenerate sites: ((P. depressus, (M. nudus, M. franciscanus), (H. pulcherrimus, (S. purpuratus, (S. fragilis, (S. pallidus, (S. droebachiensis, S. intermedius)). This phylogeny was consistent with a single invasion of deep-water environments followed by a holarctic expansion by Strongylocentrotus. Divergence times for each species estimated with reference to the divergence times between the two major clades of the group suggest a correspondence in the timing with the opening of the Bering Strait and the invasion of the holarctic regions. Conclusions: Nuclear genome data contains phylogenetic signal informative for understanding the evolutionary history of this group. However, mitochondrial genome data does not. Vicariance can explain major patterns observed in the phylogeny. Other isolating mechanisms are appropriate to explore in this system to help explain divergence patterns not well supported by vicariance, such as the effects of rapidly evolving gamete recognition proteins on isolating populations. Our findings of a stable and robust phylogeny, with the increase in mitochondrial and nuclear comparative genomic data, provide a system in which we can enhance our understanding of molecular evolution and adaptation in this group of sea urchins.

Chemistry

Lovvorn, J. R., Rocha, A. R., Danielson, S. L., Cooper, L. W., Grebmeier, J. M., & Hedstrom, K. S. (2020). Predicting Sediment Organic Carbon and Related Food Web Types from a Physical Oceanographic Model on a Subarctic Shelf. *Marine Ecology Progress Series,* 633, 37-54. https://doi.org/10.3354/meps13163

In changing environments, conservation planning for bottom-feeding marine predators requires estimating the present and future spatial patterns of benthic communities. In the northern Bering Sea, we used the Regional Ocean Modeling System (ROMS) to hindcast near-bottom flows that redistribute settled phytodetritus and organic sediments, which in turn strongly affect the dispersion of 3 food web types that differentially favor spectacled eiders Somateria fischeri, walruses Odobenus rosmarus, or gray whales Eschrichtius robustus. Using data collected between 1994 and 2010, we interpolated spatial patterns of sediment organic carbon from field samples and correlated them with water depths and modeled flow velocities, temperatures, and salinities. In the deeper (mean 63 m) southern study area with weak net flows, hindcast near-bottom currents had negligible effects on patterns of sediment longer-term organic carbon (LTOC); instead, regional depth gradients and local bathymetry were the best predictors (r(2) = 0.72-0.85 among 7 years). In that area, climatic variations in total primary production would affect the areal extent of different LTOC levels, but not the core locations of persistent patches defined by depth. In the shallower (mean 39 m) northern study area with much faster flows, seafloor depth had negligible effects, and patterns of LTOC depended mainly on currents (r(2) = 0.48-0.55 over 2 years) that are subject to climatic changes in winds. Based on ranges of LTOC for different food web types, substantial portions of both areas must be conserved to ensure annual availability of all 3 types. Regional ocean circulation models driven by downscaled climate models provide important opportunities for projecting spatial patterns of key benthic habitats in this region.

Geology

Turner, R. F., Martin, G. C., Risley, D. E., Steffy, D. A., Flett, T. O., & Lynch, M. B. (1986). *Geologic Report for the Norton Basin Planning Area, Bering Sea, Alaska.* Retrieved from https://www.worldcat.org/title/geologic-report-for-the-norton-basin-planning-area-bering-sea-alaska/oclc/14091793

No abstract available.

Zhou, W., Chen, G., Li, H., Luo, H., & Huang, S. L. (2007). Gis Application in Mineral Resource Analysis - a Case Study of Offshore Marine Placer Gold at Nome, Alaska. *Computers & Geosciences,* 33(6), 773-788. https://doi.org/10.1016/j.cageo.2006.11.001

Geographic information system (GIS) technology has been applied to analyze the offshore marine placer gold deposits at Nome, Alaska. Two geodatabases, namely Integrated Geodatabase (IG) and Regularized 2.5D Geodatabase (R2.5DG), were created to store and integrate digital data sets in heterogeneous formats. The IG served as a data warehouse and used to manage various geological data, such as borehole, bedrock geology, surficial geology, and geochemical data. The R2.5DG was generated based

on the IG and could be used for gold resource estimate at any given spatial domain. Information on placer gold deposits can be updated, queried, visualized, and analyzed by making use of these geodatabases. Ore body boundaries, gold distribution, and the resource estimation at various cutoff grades can be calculated in a timely manner. Based on the enhanced GIS architecture, a web-based GIS (http://uaf-db.uaf.edu/website/) was developed to facilitate remote users to access the offshore marine placer gold data. Users can integrate local data sources with remote data sources for query, visualization and analysis via a web browser. The GIS architecture developed in this project can be readily adapted to mineral resource management in other areas of the state.

Section XIX: Southeastern Gulf of Alaska

Biology

Andrews, A. H., Cailliet, G. M., Coale, K. H., Munk, K. M., Mahoney, M. M., & O'Connell, V. M. (2002). Radiometric Age Validation of the Yelloweye Rockfish (Sebastes ruberrimus) from Southeastern Alaska. *Marine and Freshwater Research,* 53(2), 139-146. https://doi.org/10.1071/MF01126

The yelloweye rockfish (Sebastes ruberrimus), a dominant component of an important deep-water rockfish fishery of the Gulf of Alaska, is thought to be long-lived with an estimated longevity exceeding 100 years. For the purpose of monitoring stocks, age is routinely estimated by counting growth zones in otolith cross-sections using the break-and-burn technique; however, such age estimates for this species have remained unvalidated. To evaluate these age data, age estimations from the break-and-burn technique were corroborated by comparing results from transverse sectioning of otoliths. The agreement between the techniques was excellent and each technique had a very low coefficient of variation (3.6% and 4.5%). Radiometric age validation of these estimates was performed on the otolith core material (first three years of growth) of pooled age groups having an average estimated age of 27.4–101.4 years. Agreement was variable and somewhat subjective, but radiometric data support ages estimated from otolith growth zone counts. The strongest support for age that exceeds 100 years comes from the observation that as age derived from growth zones approached and exceeded 100 years, the sample ratios measured (210Pb:226Ra) approached equilibrium. The radiometric results of our study validate the estimates derived from growth zones and the age estimating procedures, which confirms that the longevity of yelloweye rockfish exceeds 100 years.

Andrews, A. H., Cordes, E. E., Mahoney, M. M., Munk, K., Coale, K. H., Cailliet, G. M., & Heifetz, J. (2002). Age, Growth and Radiometric Age Validation of a Deep-Sea, Habitat-Forming Gorgonian (Primnoa resedaeformis) from the Gulf of Alaska. *Hydrobiologia,* 471(1/3), 101-110. https://doi.org/10.1023/A:1016501320206

Sustainable fisheries require (1) viable stock populations with appropriate harvest limits and (2) appropriate habitat for fish to survive, forage, seek refuge, grow and reproduce. Some deep-water habitats, such as those formed by deep-water stands of coral, may be vulnerable to fishing disturbance. The rate at which habitat can be restored is a critical aspect of fishery management. The purpose of this study was to characterize growth rates for a habitat-forming deep-sea coral. Two nearly complete colonies of red tree coral (Primnoa resedaeformis) collected from waters off southeast Alaska were used for an analysis of age and growth characteristics. CAT scans revealed that colonies consisted of multiple settlement events, where older basal structures provided for settlement of new colonies. The decay of Pb-210 over the length of the colony was used to validate age estimates from growth ring counts. Age estimates were over 100 yr for sections near the heavily calcified base. Based on validated growth ring counts, growth of red tree coral ranged from 1.60 to 2.32 cm per year in height and was approximately 0.36 mm per year in diameter. These growth rates suggest that the fishery habitat created by red tree coral is extremely vulnerable to bottom fishing activities and may take over 100 years to recover.

Andrews, A. H., Stone, R. P., Lundstrom, C. C., & DeVogelaere, A. P. (2009). Growth Rate and Age Determination of Bamboo Corals from the Northeastern Pacific Ocean Using Refined 210pb Dating. *Marine Ecology Progress Series,* 397, 173-185. https://doi.org/10.3354/meps08193

Bamboo corals from Davidson Seamount and from the Gulf of Alaska were aged using a refined 210Pb dating technique. The goal was to determine growth rates and age for several bamboo corals with higher precision. Radiometric results for 2 Davidson Seamount corals (Keratoisis sp.) converged on a radial growth rate of ~0.055 mm yr–1. One colony was aged at 98 ± 9 yr, with an average axial growth rate of ~0.7 cm yr–1. The age of a large colony was >145 yr with an estimated axial growth rate of 0.14 to 0.28 cm yr–1. Inconsistent rates may indicate nonlinear axial growth. A Keratoisis sp. specimen from the Gulf of Alaska was aged at 116 ± 29 yr from a radial growth rate of ~0.056 mm yr–1, which led to an average axial growth rate of ~1.0 cm yr–1. An Isidella tentaculum colony was aged at 53 ± 10 yr and grew most rapidly with a radial growth rate of ~0.10 mm yr–1 and an average axial growth rate of ~1.4 cm yr–1; however, the 210Pb decay pattern may have provided evidence for either a hiatus in radial growth or environmental changes in 210Pb. Our findings of slow growth and long life compared favorably with other bamboo coral studies and provided age estimates with greater precision. The high longevity of bamboo coral is an indication that recovery from disturbance or removal may take decades to a century. These age data provide a basis for a defensible position on the protection of bamboo coral and essential information for describing other life history characteristics.

Bracken, M. E. S., Bracken, B. E., & Rogers-Bennett, L. (2007). Species Diversity and Foundation Species: Potential Indicators of Fisheries Yields and Marine Ecosystem Functioning. *California Cooperative Oceanic Fisheries Investigations Reports,* 48, 82-91. Retrieved from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=60134&inline

Recent calls to incorporate ecosystem-based approaches, which consider multiple physical and biological aspects of a system instead of a single stock, into fisheries management have proven challenging to implement. Here, we suggest that managers can use the diversity of species in an area and the presence of foundation species as two indicators of marine ecosystem functioning. We used data from the 2006 sablefish (Anoplopoma fimbria) test fishery in the inside waters of southeastern Alaska to evaluate the relationship between the diversity of fish species present in an area and the abundance of both target and total fish caught. We found that areas where more fish species were present were characterized by higher catch levels of both sablefish and total fish, suggesting that diversity may be a reasonable indicator of fishery yields and productivity. Furthermore, because the incidence of deep-water coral was also logged in the surveys, we explored the relationship between coral, which provides habitat for groundfish, and catch levels. We found that abundances were highest where coral was present. Finally, we conducted meta-analyses of the importance of marine foundation species, such as corals, kelps, seagrasses, and oyster reefs, in promoting the diversity and abundance of associated taxa and found that diversity was 1.4-fold higher and abundances were 3.4-fold higher where these habitat-forming species were present. Together, these results suggest that biodiversity and the presence of foundation species can serve as useful indicators of a marine ecosystem's ability to provide the goods, services, and functions that we and other orgranisms rely, on. We therefore suggest that these indicators be incorporated into fisheries management strategies.

Clarke, A. D., Lewis, A., Telmer, K. H., & Shrimpton, J. M. (2007). Life History and Age at Maturity of an Anadromous Smelt, the Eulachon *Thaleichthys pacificus* (Richardson). *Journal of Fish Biology,* 71(5), 1479-1493. https://doi.org/10.1111/j.1095-8649.2007.01618.x

Trace element and fork length (L-F) frequency analyses of eulachon Thaleichthys pacificus otoliths were used to determine age at maturity and repeat spawning potential, two aspects of eulachon life history that are not known but are important for successful management of this species. The L-F-frequency analysis for ocean caught and spawning eulachon was used to estimate age at maturation. Two size classes of eulachon were caught in the ocean and spawning eulachon were consistently the largest fish indicating that spawners from mid-coast of British Columbia were 3 years old. Laser-ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS) was also used to reconstruct the Ba:Ca and Sr:Ca molar ratios deposited spatially into the otolith to estimate spawner age for five populations of eulachon. Age at maturation differed among populations examined. Based on the seasonal fluctuations in Ba: Ca molar ratios caused by seasonal upwelling of deep waters, it was determined that more southerly populations spawned at a younger age than the northern populations examined. Southern populations of eulachon, Columbia River, Washington, U. S. A., spawn after 2 years. Eulachon from the Fraser, Kemano and Skeena Rivers in British Columbia, Canada, generally mature after 3 years. Some Skeena River eulachon and most of the eulachon from the Copper River, Alaska, U. S. A., matured after 4 years. In contrast to the Ba: Ca molar ratios in the otolith, Sr: Ca molar ratios maintained a relatively. at pro. le over the life of the eulachon. The lack of a change in Sr: Ca ratios within the otolith, the single size class of spawners across all systems and the single age class within most populations strongly suggest that eulachon in the present study are semelparous.

Doherty, B., Johnson, S. D. N., & Cox, S. P. (2018). Using Autonomous Video to Estimate the Bottom Contact Area of Longline Trap Gear and Presence-Absence of Sensitive Benthic Habitat. *Canadian Journal of Fisheries and Aquatic Sciences,* 75(5), 797-812. https://doi.org/10.1139/cjfas-2016-0483

Bottom longline hook and trap fishing gear can potentially damage sensitive benthic areas (SBAs) in the ocean; however, the large-scale risks to these habitats are poorly understood because of the difficulties in mapping SBAs and in measuring the bottom-contact area of longline gear. In this paper, we describe a collaborative academic–industry–government approach to obtaining direct presence–absence data for SBAs and to measuring gear interactions with seafloor habitats via a novel deepwater trap camera and motion-sensing systems on commercial longline traps for sablefish (Anoplopoma fimbria) within SGaan Kinghlas – Bowie Seamount Marine Protected Area. We obtained direct presence–absence observations of cold-water corals (Alcyonacea, Antipatharia, Pennatulacea, Stylasteridae) and sponges (Hexactinellida, Demospongiae) at 92 locations over three commercial fishing trips. Video, accelerometer, and depth sensor data were used to estimate a mean bottom footprint of 53 m2 for a standard sablefish trap, which translates to 3200 m2 (95% CI = 2400–3900 m2) for a 60-trap commercial sablefish longline set. Our successful collaboration demonstrates how research partnerships with commercial fisheries have potential for massive improvements in the quantity and quality of data needed for conducting SBA risk assessments over large spatial and temporal scales.

Fedorowski, J., Stevens, C. H., & Katvala, E. (2014). New Late Carboniferous Heritschioidinae (Rugosa) from the Kuiu Island Area and Brooks Range, Alaska. *Geologica Acta,* 12(1), 29-U123. https://doi.org/10.1344/105.000002074

Three new species of the genus Heritschioides, i.e., H. alaskensis sp. nov., H. kuiuensis sp. nov., and H. splendidus sp. nov., and Kekuphyllum sandoense gen. et sp. nov. from the northeastern Kuiu Island area and nearby islets, part of Alexander terrane in southeastern Alaska, and Heritschioides separatus sp. nov. from the Brooks Range, Alaska, are described and illustrated. The three new fasciculate colonial coral species from the Kuiu Island area, collected from the Moscovian Saginaw Bay Formation, are phylogenetically related to those of probable BashIcirian age in the Brooks Range in northern Alaska as shown by the presence of morphologically similar species of Heritschioides. These corals from both areas also are related to one species in the Quesnel terrane in western Canada. Kekuphyllum sandoense from the Saginaw Bay Formation of the Kuiu Island area is the only cerioid-aphroid species within the Subfamily Heritschioidinae described so far. The complete early ontogeny of a protocorallite is for the first time described here on a basis of H. kuiuensis sp. nov. and compared to the hystero-ontogeny in order to show similarities and differences in those processes.

Hallmann, N., Burchell, M., Schone, B. R., Irvine, G. V., & Maxwell, D. (2009). High-Resolution Sclerochronological Analysis of the Bivalve Mollusk *Saxidomus gigantea* from Alaska and British Columbia: Techniques for Revealing Environmental Archives and Archaeological Seasonality. *Journal of Archaeological Science,* 36(10), 2353-2364. https://doi.org/10.1016/j.jas.2009.06.018

The butter clam, Saxidomus gigantea, is one of the most commonly recovered bivalves from archaeological shell middens on the Pacific Coast of North America. This study presents the results of the sclerochronology of modern specimens of S. gigantea, collected monthly from Pender Island (British Columbia), and additional modern specimens from the Dundas Islands (BC) and Mink and Little Takli Islands (Alaska). The methods presented can be used as a template to interpret local environmental conditions and increase the precision of seasonality estimates in shellfish using sclerochronology and oxygen isotope analysis. This method can also identify, with a high degree of accuracy, the date of shell collection to the nearest fortnightly cycle, the time of day the shell was collected and the approximate tidal elevation (i.e., approx. water depth and distance from the shoreline) from which the shell was collected. Life-history traits of S. gigantea were analyzed to understand the timing of growth line formation, the duration of the growing season, the growth rate, and the reliability of annual increments. We also examine the influence of the tidal regime and freshwater mixing in estuarine locations and how these variables can affect both incremental structures and oxygen isotope values. The results of the sclerochronological analysis show that there is a latitudinal trend in shell growth that needs to be considered when using shells for seasonality studies. Oxygen isotope analysis reveals clear annual cycles with the most positive values corresponding to the annual winter growth lines, and the most negative values corresponding to high temperatures during the summer. Intra-annual increment widths demonstrate clear seasonal oscillations with broadest increments in summer and very narrow increments or no growth during the winter months. This study provides new insights into the biology, geochemistry and seasonal growth of S. gigantea, which are crucial for paleoclimate reconstructions and interpreting seasonality patterns of past human collection.

Kerr, L. A., Andrews, A. H., Frantz, B. R., Coale, K. H., Brown, T. A., & Cailliet, G. M. (2004). Radiocarbon in Otoliths of Yelloweye Rockfish (Sebastes ruberrimus): A Reference Time Series for the Coastal Waters of Southeast Alaska. *Canadian Journal of Fisheries and Aquatic Sciences,* 61(3), 443-451. https://doi.org/10.1139/f04-009

Atmospheric testing of thermonuclear devices during the 1950s and 1960s created a global radiocarbon ((14)C) signal that has provided a useful tracer and chronological marker in oceanic systems and organisms. The bomb-generated (14)C signal retained in fish otoliths can be used as a time-specific recorder of the (14)C present in ambient seawater, making it a useful tool in age validation of fishes. The goal of this study was to determine (14)C in otoliths of the age-validated yelloweye rockfish (Sebastes ruberrimus) to establish a reference time series for the coastal waters of southeast Alaska. Radiocarbon values from the first year's growth of 43 yelloweye rockfish otoliths plotted against estimated birth year produced a (14)C time series (1940-1990) for these waters. The initial rise of (14)C occurred in 1958 and (14)C levels rose to peak values (60-70e) between 1966 and 1971, with a subsequent declining trend through the end of the record in 1990 (-3.2e). In addition, the (14)C data confirmed the longevity of the yelloweye rockfish to a minimum of 44 years and strongly support higher age estimates. This (14)C time series will be useful for the interpretation of (14)C accreted in biological samples from these waters.

Krieger, K. J., & Wing, B. L. (2002). Megafauna Associations with Deepwater Corals (Primnoa spp.) in the Gulf of Alaska. *Hydrobiologia,* 471, 83-90. https://doi.org/10.1023/a:1016597119297

Few in situ observations have been made of deepwater corals and, therefore, little is known about their biology or ecological significance. Deepwater corals (Primnoa spp.) were observed from a manned submersible at 11 sites in the Gulf of Alaska from 1989 to 1997 at depths of 161-365 m. We identified 10 megafaunal groups that associate with Primnoa to feed on the coral, use the coral branches for suspension feeding, or for protection. Predators on Primnoa polyps included sea stars, nudibranchs, and snails. Sea stars were the main predators, consuming 45% and 34% of the polyps at two sites. Suspension-feeders included crinoids, basket stars, anemones, and sponges. Most suspension-feeders observed at depths >300 m were associated with Primnoa. Protection seekers included rockfish, crab, and shrimp. Six rockfish species were either beneath, among, or above Primnoa. Shrimp were among the polyps, and a pair of mating king crabs were beneath Primnoa. These observations indicate Primnoa are important components of the deepwater ecosystem and removal of these slow-growing corals could cause long-term changes in associated megafauna.

Kriz, J., Blodgett, R. B., & Rohr, D. M. (2011). Silurian Bivalvia from Chichagof Island Southeast Alaska (Alexander Terrane). *Bulletin of Geosciences,* 86(2), 241-257. https://doi.org/10.3140/bull.geosci.1277

The new Silurian Bivalvia Goniophora thula-Mytilarca boucoti Community from a new locality east of the Hoonah Airport on Chichagof Island, Southeast Alaska, U. S. A. is composed of 9 species [Colpomya aff. hugini Liljedahl, 1994 and Colpomya aff. audae Liljedahl, 1994 (Colpomyidae); Modiolopsis aff. modiolaris Conrad, 1838 (Modiolopsidae); Mytilarca boucoti sp. nov. (Ambonychiidae); ?Schizodus sp. A and ?Schizodus sp. B (Schizodidae); Sanguinolites sp. (Sanguinolitidae); Modiomorpha sp. and Goniophora thula sp. nov. (Modiomorphinae)]. In this paper two new species are described. The Goniophora thula-Mytilarca boucoti Community most probably occupied a gently inclined upper slope

environment lying seaward of a cyanobacterial reef front which marked the outer edge of a late Silurian carbonate platform (represented by the Kennel Creek Limestone). The fauna of this locality consists of a rich benthos, especially rich in brachiopods, but secondarily dominated by bivalves and gastropods. Cephalopods are rare, favositid tabulate corals are also present, but form only a very minor component. The new community is most closely related to the homologous and analogous late Wenlock Bivalvia community described from Gotland, Sweden, Baltica. Similar biotic ties are with the shallow water early Ludlow Janicula potens Community from the Prague Basin, Bohemia, Perunica. Cosmopolitanism is characteristic for the Silurian Bivalvia genera, which were dispersed in most regions of the world due to their relatively long pelagic larval life and relatively small distances between the basins, islands and continents in the Silurian. For the distribution of Bivalvia during the Silurian were more limiting physical factors like temperature, salinity, substrate, food, oxygen content, light, and depth. The fauna described here is from the Alexander terrane, an accreted terrane which appears to represent a rifted block of the eastern Siberian palaeocontinent. The latter interpretation is based on faunal affinities, notably brachiopods, but suggested by other groups such as gastropods and sponges, as well as on the basis of similarities in sedimentary succession.

Leon, F., Galvan-Tirado, C., Velasco, L. S., Silva-Segundo, C. A., Hernandez-Guzman, R., Barriga-Sosa, I. D., . . . Cruz-Hernandez, P. (2018). Role of Oceanography in Shaping the Genetic Structure in the North Pacific Hake *Merluccius productus*. *Plos One,* 13(3), 26. https://doi.org/10.1371/journal.pone.0194646

Determining the relative influence of biotic and abiotic factors on genetic connectivity among populations remains a major challenge in evolutionary biology and in the management and conservation of species. North Pacific hake (Merluccius productus) inhabits upwelling regions in the California Current ecosystem from the Gulf of California to the Gulf of Alaska. In this study, we examined mitochondrial DNA (mtDNA) and microsatellite variation to estimate levels of genetic differentiation of M. productus in relation to the role of oceanographic features as potential barriers to gene flow. Samples were obtained from nine sites spanning a large part of the geographic range of the species, from Puget Sound, Washington to Costa Rica. The microsatellite results revealed three genetically discrete populations: one spanning the eastern Pacific coast, and two apparently resident populations circumscribed to the Puget Sound and the northern Gulf of California (FST = 0.032, p = 0.036). Cytochrome b sequence data indicated that isolation between the Puget Sound and northern Gulf of California populations from the coastal Pacific were recent phenomena (18.5 kyr for Puget Sound and 40 kyr for the northern Gulf of California). Oceanographic data obtained from the Gulf of California support the hypothesis that permanent fronts within the region, and strong gradients at the entrance to the Gulf of California act as barriers to gene flow. A seascape genetics approach found significant genetic environment associations, where the daytime sea surface temperature and chlorophyll concentrations were the best predictive variables for the observed genetic differentiation. Considering the potential causes of genetic isolation among the three populations, e.g. spawning areas in different latitudes associated with upwelling processes, oceanographic barriers, asymmetric migration and specialized diet, that no competing interests exist. oceanographic barriers appear to be a likely mechanism restricting gene flow.

Masuda, M. M., & Stone, R. P. (2015). Bayesian Logistic Mixed-Effects Modelling of Transect Data: Relating Red Tree Coral Presence to Habitat Characteristics. *ICES Journal of Marine Science,* 72(9), 2674-2683. https://doi.org/10.1093/icesjms/fsv163

The collection of continuous data on transects is a common practice in habitat and fishery stock assessments; however, the application of standard regression models that assume independence to serially correlated data is problematic. We show that generalized linear mixed models (GLMMs), i.e. generalized linear models for longitudinal data, that are normally used for studies performed over time can also be applied to other types of clustered or serially correlated data. We apply a specific GLMM for longitudinal data, a hierarchical Bayesian logistic mixed-effects model (BLMM), to a marine ecology dataset obtained from submersible video recordings of the seabed on transects at two sites in the Gulf of Alaska. The BLMM was effective in relating the presence of red tree corals (Primnoa pacifica; i.e. binary data) to habitat characteristics: the presence of red tree corals is highly associated with bedrock as the primary substrate (estimated odds ratio 9-19), high to very high seabed roughness (estimated odds ratio 3-5), and medium to high slope (estimated odds ratio 2-3). The covariate depth was less important at the sites. We also demonstrate and compare two methods of model checking: full and mixed posterior predictive assessments, the latter of which provided a more realistic assessment, and we calculate the variance partition coefficient for reporting the variation explained by multiple levels of the hierarchical model.

Morrison, C. L., Springmann, M. J., Shroades, K. M., & Stone, R. P. (2015). Development of Twelve Microsatellite Loci in the Red Tree Corals *Primnoa resedaeformis* and *Primnoa pacifica*. *Conservation Genetics Resources,* 7(3), 763-765. https://doi.org/10.1007/s12686-015-0455-1

A suite of tetra-, penta-, and hexa-nucleotide microsatellite loci were developed from Roche 454 pyrosequencing data for the cold-water octocorals Primnoa resedaeformis and P. pacifica. Twelve of 98 primer sets tested consistently amplified in 30 P. resedaeformis samples from Baltimore Canyon (western North Atlantic Ocean) and in 24 P. pacifica samples (Shutter Ridge, eastern Gulf of Alaska). The loci displayed moderate levels of allelic diversity (average 7.5 alleles/locus) and heterozygosity (average 47 %). Levels of genetic diversity were sufficient to produce unique multi-locus genotypes and to distinguish species. These common species are long-lived (hundreds of years) and provide essential fish habitat (P. pacifica), yet populations are provided little protection from human activities. These loci will be used to determine regional patterns of population connectivity to inform effective marine spatial planning and ecosystem-based fisheries management.

Porter, S. S., Eckert, G. L., Byron, C. J., & Fisher, J. L. (2008). Comparison of Light Traps and Plankton Tows for Sampling Brachyuran Crab Larvae in an Alaskan Fjord. *Journal of Crustacean Biology,* 28(1), 175-179. https://doi.org/10.1651/06-2818r.1

We compared the effectiveness of light traps and plankton tows for sampling brachyuran crab larvae in Bartlett Cove, Glacier Bay, Alaska, U.S.A. during three nights each in July and August 2001 and June, August, and September 2002. Proportions of species and stages were used to compare larvae caught by light traps and plankton tows. Absolute numbers of larvae are difficult to compare because of the difference in sampling volume and duration of each method. Both methods captured early and late-stage larvae of four brachyuran families, Cancridae, Grapsidae, Pinnotheridae, and Majidae. However,

light traps collected many late-stage (megalopae) cancrid larvae, which were rarely collected by plankton tows, suggesting that late-stage larvae may be undersampled by plankton tows. In contrast, plankton tows collected many early stage (zoeae) pinnotherid larvae, which may be undersampled by light traps. These results follow the same pattern as that found for tropical fish larvae, that light traps are a useful sampling device for settlement-size larvae. Light traps provide a simple method to collect high resolution temporal data on late-stage larval abundance, and their use has improved our ability to discern recruitment dynamics for decapod crustaceans.

Rodgveller, C. J., Tribuzio, C. A., Malecha, P. W., & Lunsford, C. R. (2017). Feasibility of Using Pop-up Satellite Archival Tags (PSATs) to Monitor Vertical Movement of a Sebastes: A Case Study. *Fisheries Research,* 187, 96-102. https://doi.org/10.1016/j.fishres.2016.11.012

Pop-up satellite archival tags (PSATs) were deployed on eight blackspotted rockfish (Sebastes melanostictus) (37-54 cm fork length) caught in southeast Alaska at depths from 148 to 198 m. Six of these fish were tagged and released immediately after capture in a commercially available inverted, weighted crab ring, descended quickly to what was assumed to be the seafloor, and remained at that depth until the PSATs released early (after 12-14 days). The remaining two fish were held in a laboratory after capture, one for 8 months and one for 46 months, and were then released at the surface nearby the capture site. One of these two tags released after 12 days while the tag deployed on a 37 cm fish was retained for 190 days. Both fish moved to deeper depths initially and then moved back to more shallow depths, indicating that rockfish may require time to acclimate to increased pressure if the swim bladder is not currently ruptured. For the tag that was retained for 190 days, we identified six phases of vertical movement behavior. During the longest phase (122 days) the fish made rapid descents, sometimes in less than 15 min, which were deeper during the day and during high-tide, but more frequent at night. During some of the shorter phases (lasting from 8 to 28 days) the fish was more sedentary or was deeper at night. Our results show that it is possible to tag a deepwater rockfish with a PSAT.

Starr, R. M., O'Connell, V., & Ralston, S. (2004). Movements of Lingcod (Ophiodon elongatus) in Southeast Alaska: Potential for Increased Conservation and Yield from Marine Reserves. *Canadian Journal of Fisheries and Aquatic Sciences,* 61(7), 1083-1094. https://doi.org/10.1139/f04-054

Residence time and movement rates of lingcod (Ophiodon elongatus) were recorded in an area closed to fishing in southeast Alaska to evaluate the potential effects of reserves on mortality, egg production, and fishery yield. In 1999, 43 lingcod were tagged with sonic transmitters, and an array of receivers moored in the reserve recorded signals transmitted from tagged fish for 14 months. Most of the tagged fish frequently left the reserve but were only absent for short time periods. Tagged fish showed a high degree of site fidelity. Models generated from the tag data provided a way to predict the effects of marine reserves on yield and eggs per recruit for a cohort of female lingcod. Model results indicated that for lingcod stocks with low abundance, marine reserves could improve egg production while having a small effect on fishery yield. For more abundant stocks, if a portion of the stock is protected in reserves, fishing rates could be increased outside reserves without reducing egg production relative to egg production levels in the absence of reserves.

Stone, R. P., Malecha, P. W., & Masuda, M. M. (2017). A Five-Year, in Situ Growth Study on Shallow-Water Populations of the Gorgonian Octocoral *Calcigorgia spiculifera* in the Gulf of Alaska. *Plos One,* 12(1). https://doi.org/10.1371/journal.pone.0169470

Gorgonian octocorals are the most abundant corals in Alaska where they provide important structural habitat for managed species of demersal fish and invertebrates. Fifty-nine gorgonian species have been reported from Alaska waters but little is known about their life history characteristics to help us gauge their ability to recover from seafloor disturbance. Colonies of the holaxonian Calcigorgia spiculifera were tagged beginning in 1999 at three sites in Chatham Strait, Southeast Alaska, using scuba and their growth measured annually for up to 5 years. Colonies were video recorded, and computer image analysis tools provided calibration of video images for measuring the length of several branches. Growth data indicate that C. spiculifera grows much slower (6.0 mm yr(-1)) than other gorgonians in Alaska for which there are data and that intraspecific growth is highly variable. We fit a Bayesian linear mixed-effects model that showed that average colony growth was significantly reduced with warmer temperature and presence of necrosis. The model further indicated that growth may slow among larger (older) colonies. Based on these results and previous studies, we propose that gorgonian growth rates are taxonomically constrained at the Suborder level and that holaxonians grow the slowest followed by scleraxonians and calcaxonians (2-3 times as fast). Findings of this study indicate that it would take approximately 60 years for C. spiculifera to grow to its maximum size and depending on the location and size of the parental standing stock, at least one and possibly 10 additional years for recruitment to occur. Our results further indicate that colonies that are injured, perhaps chronically in areas of frequent disturbance, grow at slower rates and if the current trend of ocean warming continues then we can expect these corals to grow more slowly, and the habitats they form will require more time to recover from disturbance.

Stone, R. P., Masuda, M. M., & Karinen, J. F. (2015). Assessing the Ecological Importance of Red Tree Coral Thickets in the Eastern Gulf of Alaska. *ICES Journal of Marine Science,* 72(3), 900-915. https://doi.org/10.1093/icesjms/fsu190

Red tree corals (Primnoa pacifica), the largest structure-forming gorgonians in the North Pacific Ocean, form dense thickets in some areas. These thickets are a dominant benthic habitat feature in the Gulf of Alaska (GOA), yet little is known about the ecosystems they support. In 2005, we used a submersible to study the ecology of thickets inside or near five small areas of the eastern GOA later designated in 2006 as habitat areas of particular concern (HAPCs)aEuro center dot areas closed to all bottom contact fishing. We show that red tree corals are keystone species in habitats where they form thickets (mean density 0.52 corals m(-2))-the densest and largest thickets documented anywhere. Measured sponge densities (2.51 sponges m(-2)) were also among the highest documented anywhere. The corals and sponges in the study areas provide essential fish habitat for some fish species, and we show with logistic regression models modified with a scaled binomial variance that bedrock, while important habitat for some fish, is even more important when paired with corals and sponges. Red tree corals were not equally distributed with regard to habitat characteristics, and we show that their presence was correlated with bedrock substrate, moderate to high seabed roughness, and slope > 10A degrees. Most corals and sponges are vulnerable to disturbance from longlining, the principal bottom contact fishing in this region, but the larger corals and sponges are the most vulnerable. We observed evidence of infrequent recruitment events and a strong pulse of predation, apparently from fishing gear-induced

trauma, that could exacerbate slow recovery of red tree corals from disturbance. Some red tree coral thickets are provided protection within designated HAPCs and some are not. Modifications to longline gear and an expanded network of HAPCs could help preserve these keystone species and the ecosystems they support.

Waller, R. G., Stone, R. P., Johnstone, J., & Mondragon, J. (2014). Sexual Reproduction and Seasonality of the Alaskan Red Tree Coral, *Primnoa pacifica*. *Plos One,* 9(4). https://doi.org/10.1371/journal.pone.0090893

The red tree coral Primnoa pacifica is an important habitat forming octocoral in North Pacific waters. Given the prominence of this species in shelf and upper slope areas of the Gulf of Alaska where fishing disturbance can be high, it may be able to sustain healthy populations through adaptive reproductive processes. This study was designed to test this hypothesis, examining reproductive mode, seasonality and fecundity in both undamaged and simulated damaged colonies over the course of 16 months using a deepwater-emerged population in Tracy Arm Fjord. Females within the population developed asynchronously, though males showed trends of synchronicity, with production of immature spermatocysts heightened in December/January and maturation of gametes in the fall months. Periodicity of individuals varied from a single year reproductive event to some individuals taking more than the 16 months sampled to produce viable gametes. Multiple stages of gametes occurred in polyps of the same colony during most sampling periods. Mean oocyte size ranged from 50 to 200 mu m in any season, and maximum oocyte size (802 mu m) suggests a lecithotrophic larva. No brooding larvae were found during this study, though unfertilized oocytes were found adhered to the outside of polyps, where they are presumably fertilized. This species demonstrated size-dependent reproduction, with gametes first forming in colonies over 42-cm length, and steady oocyte sizes being achieved after reaching 80-cm in length. The average fecundity was 86 (+/- 12) total oocytes per polyp, and 17 (+/- 12) potential per polyp fecundity. Sub-lethal injury by removing 21-40% of colony tissue had no significant reproductive response in males or females over the course of this study, except for a corresponding loss in overall colony fecundity. The reproductive patterns and long gamete generation times observed in this study indicate that recruitment events are likely to be highly sporadic in this species increasing its vulnerability to anthropogenic disturbances.

Waller, R. G., Stone, R. P., Ricea, L. N., Johnstone, J., Rossin, A. M., Hartill, E., . . . Morrison, C. L. (2019). Phenotypic Plasticity or a Reproductive Dead End? *Primnoa pacifica* (Cnidaria: Alcyonacea) in the Southeastern Alaska Region. *Frontiers in Marine Science,* 6. https://doi.org/10.3389/fmars.2019.00709

Red tree corals (Primnoa pacifica) are abundant in the eastern Gulf of Alaska, from the glacial fjords of Southeast Alaska where they emerge to as shallow as 6 m, to the continental shelf edge and seamounts where they are more commonly found at depths greater than 150 - 500 m. This keystone species forms large thickets, creating habitat for many associated species, including economically valuable fishes and crabs, and so are important benthic suspension feeders in this region. Though the reproductive periodicity of this species was reported in 2014 from a shallow fjord (Tracy Arm), this study examined reproductive ecologies from 8 sites - two within Glacier Bay National Park and Preserve, three on the continental shelf edge, one within Endicott Arm (Holkham Bay) and two time points from the Tracy Arm

(Holkham Bay) study. Male reproductive traits were similar at all sites but there were distinct differences in oogenesis. Though per polyp fecundity mostly showed no significant difference between sites, there was a non-significant trend of increasing number of oocytes with depth. In addition, the average oocyte size from Tracy Arm (the shallowest site) was 105 mm, whereas from Shutter Ridge (one of the deepest sites) the average size was 309 mm. Moreover, the maximum oocyte size at Endicott Arm was 221 mm and at Tracy Arm was 802 mm (both shallow sites), whereas at Dixon Entrance (a deep site) it was 2120 mm, a difference not usually observed within a single species. We propose two theories to explain the observed differences, (a) this species shows great phenotypic plasticity in reproductive ecology, adjusting to different environmental variables based on energetic need and potentially demonstrating micro-evolution; or (b) the fjord sites are at a reproductive dead end, with the stress of shallow-water conditions effectively preventing gametogenesis reaching full potential and likely limiting successful reproductive events from occurring, at least on a regular basis.

Chemistry

Baumberger, T., Embley, R. W., Merle, S. G., Lilley, M. D., Raineault, N. A., & Lupton, J. E. (2018). Mantle-Derived Helium and Multiple Methane Sources in Gas Bubbles of Cold Seeps Along the Cascadia Continental Margin. *Geochemistry Geophysics Geosystems,* 19(11), 4476-4486. https://doi.org/10.1029/2018gc007859

During E/V Nautilus NA072 expedition, multibeam sonar surveys located over 800 individual bubble streams rising from the Cascadia Margin between the Strait of Juan de Fuca and Cape Mendocino at depths between 104 and 2,073m. Gas bubbles were collected directly at the seafloor using gastight sampling bottles. These bubbles were consistently composed of over 99% methane with traces of carbon dioxide, oxygen, nitrogen, noble gases, and more rarely higher hydrocarbons. A common previous view was that a biogenic source was responsible for seeps from within the gas hydrate stability zone (upper limit near 500-m isobath) and a thermogenic source was responsible for seeps from the upper slope and the shelf. Higher hydrocarbons in deep seeps with a biogenic methane signature, as well as the lack of higher hydrocarbons in some shallower seeps with a thermogenic methane signature, show that the origin of the gas cannot simply be attributed to seep location on the margin. Instead, mixing and oxidation processes play an integral role. He-3/He-4 ratios at Coquille SW point to a contribution of 30% mantle helium, whereas all the other investigated sites are characterized by a crustal helium signature. Hence, the Coquille SW seeps are directly or indirectly connected to the mantle or to very young oceanic crust. The detection of mantle helium in these seeps can thus be used as a tracer for deep-reaching fracture systems and their changing pathways.

Geology

Barrie, J. V., Conway, K. W., & Harris, P. T. (2013). The Queen Charlotte Fault, British Columbia: Seafloor Anatomy of a Transform Fault and Its Influence on Sediment Processes. *Geo-Marine Letters,* 33(4), 311-318. https://doi.org/10.1007/s00367-013-0333-3

The Queen Charlotte Fault Zone (QCFZ) off western Canada is the northern equivalent to the San Andreas Fault Zone, the Pacific-North American plate boundary. Geomorphologic expression and surface processes associated with the QCFZ system have been revealed in unprecedented detail by recent

seabed mapping surveys. Convergence of the Pacific and North American plates along northern British Columbia is well known, but how the QCFZ accommodates this convergence is still a subject of controversy. The multibeam sonar bathymetry data reveal, for the first time, evidence of a fault valley with small depressions on the upper slope, offshore central Haida Gwaii (Queen Charlotte Islands). The depressions form where strike-slip right-step offsets have realigned the fault due to oblique convergence. Core stratigraphy and radiocarbon dating of sediments within the fault valley and small depressions suggest that these features are recent in origin. In addition, the development of the fault valley and dislocation of submarine canyons control sediment migration from the continental shelf through to the lower slope. This interpretation of the geomorphic expression of major plate tectonic processes along the QCFZ can now be tested with new surveys subsequent to the October 2012 magnitude 7.7 earthquake.

Brothers, D. S., Andrews, B. D., Walton, M. A. L., Greene, H. G., Barrie, J. V., Miller, N. C., . . . Conrad, J. E. (2019). Slope Failure and Mass Transport Processes Along the Queen Charlotte Fault, Southeastern Alaska. *Geological Society, London, Special Publications,* 477(1), 69-83. https://doi.org/10.1144/sp477.30

The Queen Charlotte Fault defines the Pacific–North America transform plate boundary in western Canada and southeastern Alaska for c. 900 km. The entire length of the fault is submerged along a continental margin dominated by Quaternary glacial processes, yet the geomorphology along the margin has never been systematically examined due to the absence of high-resolution seafloor mapping data. Hence the geological processes that influence the distribution, character and timing of mass transport events and their associated hazards remain poorly understood. Here we develop a classification of the first-order shape of the continental shelf, slope and rise to examine potential relationships between form and process dominance. We found that the margin can be split into six geomorphic groups that vary smoothly from north to south between two basic end-members. The northernmost group (west of Chichagof Island, Alaska) is characterized by concave-upwards slope profiles, gentle slope gradients (<6°) and relatively low along-strike variance, all features characteristic of sediment-dominated siliciclastic margins. Dendritic submarine canyon/channel networks and retrogressive failure complexes along relatively gentle slope gradients are observed throughout the region, suggesting that high rates of Quaternary sediment delivery and accumulation played a fundamental part in mass transport processes. Individual failures range in area from 0.02 to 70 km2 and display scarp heights between 10 and 250 m. Transpression along the Queen Charlotte Fault increases southwards and the slope physiography is thus progressively more influenced by regional-scale tectonic deformation. The southernmost group (west of Haida Gwaii, British Columbia) defines the tectonically dominated end-member: the continental slope is characterized by steep gradients (>20°) along the flanks of broad, margin-parallel ridges and valleys. Mass transport features in the tectonically dominated areas are mostly observed along steep escarpments and the larger slides (up to 10 km2) appear to be failures of consolidated material along the flanks of tectonic features. Overall, these observations highlight the role of first-order margin physiography on the distribution and type of submarine landslides expected to occur in particular morphological settings. The sediment-dominated end-member allows for the accumulation of under-consolidated Quaternary sediments and shows larger, more frequent slides; the rugged physiography of the tectonically dominated end-member leads to sediment bypass and the collapse of uplifted tectonic features. The maximum and average dimensions of slides are an order of magnitude smaller than those of slides observed along other (passive) glaciated margins. We propose that the general patterns observed in slide distribution are caused by the interplay between

tectonic activity (long- and short-term) and sediment delivery. The recurrence (<100 years) of M > 7 earthquakes along the Queen Charlotte Fault may generate small, but frequent, failures of under-consolidated Quaternary sediments within the sediment-dominated regions. By contrast, the tectonically dominated regions are characterized by the bypass of Quaternary sediments to the continental rise and the less frequent collapse of steep, uplifted and consolidated sediments.

Brothers, D. S., Miller, N. C., Barrie, J. V., Haeussler, P. J., Greene, H. G., Andrews, B. D., . . . Dartnell, P. (2020). Plate Boundary Localization, Slip-Rates and Rupture Segmentation of the Queen Charlotte Fault Based on Submarine Tectonic Geomorphology. *Earth and Planetary Science Letters,* 530. https://doi.org/10.1016/j.epsl.2019.115882

Linking fault behavior over many earthquake cycles to individual earthquake behavior is a primary goal in tectonic geomorphology, particularly across an entire plate boundary. Here, we examine the 1150-km-long, right-lateral Queen Charlotte-Fairweather fault system using comprehensive multibeam bathymetry data acquired along the Queen Charlotte Fault (QCF) offshore southeastern Alaska and western British Columbia. Fine-scale analysis of tectonic geomorphology allowed us to identify and reconstruct 184 strike-slip piercing points over a 630 km stretch of the QCF. Age constraints from glacial recession and offshore sedimentation patterns yield a consistent slip-rate of similar to 50-57 mm/yr since similar to 17-12 ka, the fastest rate for a continent-ocean strike-slip fault on Earth. These slip-rates equal or exceed estimates of Pacific-North America (PA-NA) relative motion from global plate reconstructions, indicating that PA-NA motion is highly localized. The QCF cuts the seafloor along a narrow and unusually straight trace for its entire length and multiple fault traces are observed only at local step-overs. The geometry and behavior of the QCF over many earthquake cycles is simple and typical of mature faults with relatively homogeneous stress fields. Since the QCF is the primary PA-NA plate boundary, we used the trace of the QCF to define the small circle path for relative plate motion and computed the associated Euler pole. Predicted along-strike obliquity variations based on the new pole agree with observed tectonic geomorphology and suggest that previous global plate reconstructions overestimated the degree of oblique convergence along the QCF. We also find that subtle, long-wavelength (75-150 km) bends and discrete step-overs appear to define the endpoints of M>7 earthquakes, suggesting that obliquity and resultant fault geometry may control rupture segmentation and asperity development. Lastly, the agreement between predicted obliquity and tectonic geomorphology along the entire length of QCF compelled a reevaluation of regional tectonic models. In the north, the eastern Yakatat Terrane appears to be translating northwest with the Pacific plate, and slip transferred from the QCF to the Fairweather Fault results in similar to 20 mm/yr of convergence along the southern St. Elias mountains. In the south, we predict a reduced rate of convergence along the QCF west of Haida Gwaii (similar to 5-6 mm/yr of shortening, on average) relative to previous studies. Our results support a model for transpression and strike-slip partitioning along the edge of a hot and weak Pacific Plate, leading to crustal thickening and growth of the Queen Charlotte Terrace to the west of Haida Gwaii.

Carrara, P. E., Ager, T. A., & Baichtal, J. F. (2007). Possible Refugia in the Alexander Archipelago of Southeastern Alaska During the Late Wisconsin Glaciation. *Canadian Journal of Earth Sciences,* 44(2), 229-244. https://doi.org/10.1139/E06-081

The interpretation of the extent of late Wisconsin glaciation in southeastern Alaska has varied between geologists and biologists. Maps and reports of the region prepared by geologists commonly indicated that late Wisconsin ice extended as a large uniform front west to the edge of the continental shelf. However, the distribution of plants and animals in the region has led many biologists to suggest that there may have been ice-free areas that served as refugia during the late Wisconsin. Based on analyses of aerial photographs, topographic maps, and bathymetric charts, in conjunction with a review of previous literature and reconnaissance fieldwork throughout the region, this study presents data supporting a limited ice extent in the Alexander Archipelago during the late Wisconsin and identifies possible ice-free areas that may have served as refugia. These areas include (1) the Fairweather Ground, (2) the Herbert Graves Island area, (3) the western coast of southern Baranof Island and adjacent continental shelf, (4) Coronation Island and the adjacent continental shelf, (5) the Warren Island area, (6) the continental shelf from west of Heceta Island to Forrester Island in the south, (7) parts of the west coast of southern Dall Island, and (8) lowland areas in southern Prince of Wales Island. The identification of these possible refugia has bearing on the recolonization of the Alexander Archipelago, as they could have served as centers of biotic dispersal upon regional deglaciation and as stepping stones for early humans with a maritime tradition entering the western hemisphere from Asia.

Caruthers, A. H., & Stanley, G. D. (2008). Systematic Analysis of Upper Triassic Silicified Scleractinian Corals from Wrangellia and the Alexander Terrane, Alaska and British Columbia. *Journal of Paleontology,* 82(3), 470-491. https://doi.org/10.1666/06-115.1

Acid processing allowed systematic identification of 458 Upper Triassic silicified scleractinian corals (20 genera, 47 species) from the Alexander terrane (southeast Alaska) and Wrangellia (Wrangell Mountains, southern Alaska and Vancouver Island, Canada). Coral faunas, here presented. show taxonomic affinity with coeval collections from other Cordilleran terranes, specifically the Wallowa terrane (northeastern Ore-on and Idaho) and Peru (South America) as well as the distant Tethys region. Genera from the Alexander terrane include: Kompsasteria Roniewicz, Gablonzeria Cuif, Cuifia Melnikova, Paracuifia Melnikova, Distichophyllia Cuif, Retiophyllia Cuif, Kuhnastraea Cuif, Margarosmilia Volz. Distichomeandra Cuif, Astraeomorpha Reuss, Pamiroseris Melnikova, Crassistella Roniewicz, Stylophyllum Frech, and Meandrostylis Frech. Genera from Wrangellia include: Gablonzeria Cuif. Distichophyllia Cuif, Retiophyllia Cuif, Kuhnastraea Cuif, Margarosmilia Volz, Distichomeandra Cuif. Astraeomorpha Reuss, Parastraeomorpha Roniewicz, Chondrocoenia Roniewicz, Pamiroseris Melnikova, Crassistella Roniewicz. Ampakabastraea? Alloiteau, Recticostastraea Stanley and Whalen, Meandrostylis Frech, Anthostylis Roniewicz, and the new genus Campesteria n. gen. New species include: Gablonzeria grandiosa n. sp., Paracuifia smithi n. sp., Paracuifia jennieae n. sp., P. anomala n. sp., Retiophyllia dendriformis n. sp., R. obtusa D. sp., and Campesteria prolixia n. sp.

Courtney, M., Duvoy, P., Jump, S., Kasper, J., Stafford, K., Castellote, M., & Seitz, A. C. (2019). *Annual Report Yakutat Wave Energy Converter Impact Assessment.* Retrieved from [No URL available.]

Multiple trips to Yakutat were completed between September 2018-January 2019 including vessel based trawl and hydrographic surveys as well as mooring deployments and turnarounds and mapping of Cannon Beach. Much of the data processing is in the earliest stages so results presented here are considered preliminary.

Fedorowski, J., & Stevens, C. H. (2014). Late Carboniferous Colonial Rugosa (Anthozoa) from Alaska. *Geologica Acta,* 12(3), 239-267. https://doi.org/10.1344/GeologicaActa2014.12.3.6

Late Carboniferous colonial corals from the Moscovian Saginaw Bay Formation and the underlying Bashkirian crinoidal limestone exposed on northeastern Kuiu Island and a nearby islet, part of the Alexander terrane in southeastern Alaska, are described and illustrated for the first time, and are supplemented by revision, redescription and reillustration of most Atokan specimens from Brooks Range, northern Alaska, first described by Armstrong (1972). New taxa from the Kuiu Island area include the new species Paraheritschioides katvalae and the new genus and species Arctistrotion variabilis, as well as the new Subfamily Arctistrotioninae. The corals Corwenia jagoensis and Lithostrotionella wahooensis of Armstrong (1972) also are redefined and redescribed. Paraheritschioides jagoensis is based on the holotype of 'C'. jagoensis. P. compositus sp. nov. is based on a "paratype" of 'C.' jagoensis. In addition to a redefinition and redescription of 'L.' wahooensis as Arctistrotion wahooense, one "paratype" of that species is described as A. simplex sp. nov. The phylogeny and suspected relationships of some fasciculate Carboniferous Rugosa also are discussed. Based on relationships and similarities within the Late Carboniferous colonial Rugosa from the Brooks Range, Kuiu Island and the eastern Klamath terrane, we conclude that all three areas were geographically close enough at that time so that larvae were occasionally dispersed by oceanic currents. Distances between these areas, however, may have been so great and/or isolation so long that individual speciation occurred in all of the various locations. That hypothetical situation is reflected by a common generic, but not a specific, content of the particular faunas.

Greene, H. G., Barrie, J. V., Brothers, D. S., Conrad, J. E., Conway, K., East, A. E., . . . Rohr, K. M. M. (2019). Slope Failure and Mass Transport Processes Along the Queen Charlotte Fault Zone, Western British Columbia. *Geological Society, London, Special Publications,* 477(1), 85-106. https://doi.org/10.1144/sp477.31

Multibeam echosounder (MBES) images, 3.5 kHz seismic-reflection profiles and piston cores obtained along the southern Queen Charlotte Fault Zone are used to map and date mass-wasting events at this transform margin – a seismically active boundary that separates the Pacific Plate from the North American Plate. Whereas the upper continental slope adjacent to and east (upslope) of the fault zone offshore of the Haida Gwaii is heavily gullied, few large-sized submarine landslides in this area are observed in the MBES images. However, smaller submarine seafloor slides exist locally in areas where fluid flow appears to be occurring and large seafloor slides have recently been detected at the base of the steep continental slope just above its contact with the abyssal plain on the Queen Charlotte Terrace. In addition, along the subtle slope re-entrant area offshore of the Dixon Entrance shelf bathymetric data suggest that extensive mass wasting has occurred in the vicinity of an active mud volcano venting gas. We surmise that the relative lack of submarine slides along the upper slope in close proximity to the Queen Charlotte Fault Zone may be the result of seismic strengthening (compaction and cohesion) of a sediment-starved shelf and slope through multiple seismic events.

Greene, H. G., O'Connell, V. M., & Brylinsky, C. K. (2011). Tectonic and Glacial Related Seafloor Geomorphology as Possible Demersal Shelf Rockfish Habitat Surrogates-Examples Along the Alaskan Convergent Transform Plate Boundary. *Continental Shelf Research,* 31(2), S39-S53. https://doi.org/10.1016/j.csr.2010.11.004

Seafloor geology plays a major role in habitat formation and can be used to remotely identify key habitats for some commercially important fish species. We have used a combination of side-scan sonar mosaics, multibeam bathymetry, and backscatter data, and in situ observations and video from the submersible Delta to investigate marine benthic habitats in the Eastern Gulf of Alaska. The intent of this paper is to review the results of previous marine benthic habitat mapping efforts completed by us along the transform plate boundary of Alaska and to present new information that show how volcanic, plutonic, and glacial submarine geomorphology can be used to identify potentially important discrete habitat areas. Demersal shelf rockfish, a seven-species management complex of nearshore rockfish, including yellow-eye rockfish (Sebastes ruberrimus), are found in rugged and highly rugose geomorphologic features. Eroded volcanic edifices, lava fields, and a pit crater, as well as a small shutterridge, deformed and differentially eroded sedimentary bedrock, and highly fractured and faulted plutonic rock outcrops are features that attract adult rockfish. Volcanic edifices that lie along the leaky (magma-conducting) Fairweather transform fault system intercept ocean currents, in turn producing upward eddies that bring nutrients to species residing on the features. We show that geologic processes such as fault deformation, volcanism, and glaciation are critical to the development of Essential Fish Habitats (EFH) for demersal shelf rockfish. Our work is the first attempt to determine a common geologic link between desperate commercial fishing areas in SE Alaska, USA, and to suggest how tectonic and glacial processes, including sea level rise and transgression, can be used to identify seafloor geologic characteristics as surrogates for marine groundfish habitats.

Swartz, J. M., Gulick, S. P. S., & Goff, J. A. (2015). Gulf of Alaska Continental Slope Morphology: Evidence for Recent Trough Mouth Fan Formation. *Geochemistry Geophysics Geosystems,* 16(1), 165-177. https://doi.org/10.1002/2014gc005594

Glaciated continental shelves are host to numerous morphologic features that help understand past glacier dynamics. Southeastern Alaska is home to the St. Elias mountains, an active orogen that also hosts temperate marine glaciers. During glacial periods ice streams advance across the continental shelf, carving shelf-crossing troughs that reach the shelf edge. We use high-resolution multibeam data to develop the relationship between the Yakutat and Alsek Sea Valleys and the resulting continental slope morphology. The shelf and slope geomorphology can be divided into statistical groupings that relate to the relative balance of erosion and deposition. Our analysis indicates that only the Yakutat system has been able to build an incipient trough-mouth fan. The extreme sediment supply from this region was able to overwhelm the steep initial topography of the transform margin while further to the east sediment slope-bypass dominates. This analysis provides an extreme end member to existing studies of temperate glaciation along continental margins. The unique interplay between rapid uplift due to ongoing collision and the massive erosion caused by temperate glaciers provides for sedimentary flux far above most other systems.

Taylor, C. D., Premo, W. R., Meier, A. L., & Taggart, J. E. (2008). The Metallogeny of Late Triassic Rifting of the Alexander Terrane in Southeastern Alaska and Northwestern British Columbia. *Economic Geology,* 103(1), 89-115. https://doi.org/10.2113/gsecongeo.103.1.89

A belt of unusual volcanogenic massive sulfide (VMS) occurrences is located along the eastern margin of the Alexander terrane throughout southeastern Alaska and northwestern British Columbia and exhibits a range of characteristics consistent with a variety of syngenetic to epigenetic deposit types. Deposits within this belt include Greens Creek and Windy Craggy, the economically most significant VMS deposit in Alaska and the largest in North America, respectively. The occurrences are hosted by a discontinuously exposed, 800-km-long belt of rocks that consist of a 200- to 800-m-thick sequence of conglomerate, limestone, marine elastic sedimentary rocks, and tuff intercalated with and overlain by a distinctive unit of mafic pyroclastic rocks and pillowed flows. Faunal data bracket the age of the host rocks between Anisian (Middle Triassic) and late Norian (late Late Triassic). This metallogenic belt is herein referred to as the Alexander Triassic metallogenic belt. The VMS occurrences show systematic differences in degree of structural control, chemistry, and stratigraphic setting along the Alexander Triassic metallogenic belt that suggest important spatial or temporal changes in the tectonic environment of formation. At the southern end of the belt, felsic volcanic rocks overlain by shallow-water limestones characterize the lower part of the sequence. In the southern and middle portion of the belt, a distinctive pebble conglomerate marks the base of the section and is indicative of high-energy deposition in a near slope or- basin margin setting. At the northern end of the belt the conglomerates, limestones, and felsic volcanic rocks are absent and the belt is composed of deep-water sedimentary and mafic volcanic rocks. This northward change in depositional environment and lithofacies is accompanied by a northward transition from epithermal-like structurally controlled, discontinuous, vein- and pod-shaped, Pb-Zn-Ag-Ba-(Cu) occurrences with relatively simple mineralogy, to sulfosalt-enriched VMS occurrences exhibiting characteristics of vein, diagenetic replacement, and exhalative styles of mineralization, and finally to Cu-Zn-(Co-Au) occurrences with larger and more clearly stratiform orebody morphologies. Occurrences in the middle of the belt are transitional in nature between structurally controlled types of mineralization that formed in a shallow-water, near-arc setting, to those having a more stratiform appearance, formed in a deeper water, rift-basin setting. The geologic setting in the south is consistent with shallow subaqueous emplacement on the flanks of the Alexander terrane. Northward, the setting changes to an increasingly deeper back- or- intra-arc rift basin. Igneous activity in the Alexander Triassic metallogenic belt is characterized by a bimodal suite of volcanic rocks and a previously unrecognized association with mafic-ultramafic hypabyssal intrusions. Immobile trace and rare earth element (REE) geochemical data indicate that felsic rocks in the southern portion of the belt are typical calc-alkaline rhyolites, which give way in the middle of the belt to peralkaline rhyolites. Rhyolites are largely absent in the northern part of the belt. Throughout the belt, the capping basaltic rocks have transitional geochemical signatures. Radiogenic isotope data for these rocks are also transitional (basalts and gabbros: epsilon(Nd) = 4-9 and Sr-87/Sr-86 initial at 215 Ma = 0.70377-0.7074). Together these data are interpreted to reflect variable assimilation of mature island-arc crust by more primitive melts having the characteristics of either mid-ocean ridge (MORB) or intraplate (within-plate) basalts (WPB). The ore and host-rock geochemistry and the sulfosalt-rich mineralogy of the deposits are strikingly similar to recent descriptions of active sea-floor hydrothermal (white smoker) systems in back arcs of the southwest Pacific Ocean. These data, in concert with existing faunal ages, record the formation of a belt of VMS deposits and occurrences in a propagating intra- to back-arc rift tectonic setting during the Late Triassic. A modern analogue having similar tectonic and metallogenic features is the southward projection of the Lau basin, from the active sea-floor hydrothermal vents of the Valu Fa Ridge to the Taupo volcanic zone of the North Island, New Zealand.

Management

Malecha, P., & Heifetz, J. (2017). Long-Term Effects of Bottom Trawling on Large Sponges in the Gulf of Alaska. *Continental Shelf Research,* 150, 18-26. https://doi.org/10.1016/j.csr.2017.09.003

Manipulative studies that characterize short-term effects of bottom trawls on seafloor habitats are numerous, but studies that examine long-term effects are rare. The long-term (13 years) effects of a single bottom trawl on large (>20 cm) erect sponges were investigated by revisiting the site of prior experimental trawling studies. In prior studies, large sponges were assessed immediately after trawling and 1 yr post-trawling. Thirteen years post trawling, the average density of large sponges was 31.7% lower (range 1.5-53.0%) and the incidence of sponge damage (torn, necrotic, missing tissue, prone) was 58.8% higher within strip transects in trawled versus untrawled reference areas. For all sponge species combined, the mean density of large sponges was 3.19 individuals 100 m(-2) in trawled areas and 4.67 individuals 100 m(-2) in reference areas. The most abundant sponge species in both trawled and reference areas was Rhabdocalyptus dawsoni. Mean density of this species differed greatly between trawled (1.57 individuals 100 m(-2)) and reference areas (2.91 individuals 100 m(-2)). Thirteen years after trawling, the mean percentage of damaged sponges on strip transects was 15.3% in trawled areas and 6.3% in reference areas. The rate of damage in trawled areas was less than that observed both immediately after trawling and 1 year later. The persistence of damage (lower sponge densities and higher rates of injury in trawled areas) and the potential resultant changes to benthic communities where deepwater habitat-forming biota, such as large erect sponges, are present provide rationale for cautious management of the long term effects of bottom trawling.

Marine Culture Heritage

Dixon, E. J., & Monteleone, K. (2011). *Gateway to the Americas.* Maxwell Museum of Anthropology, University of New Mexico, for the Alaskan State Historic Preservation Office. Retrieved from [No URL available]

Discovery and dating of Ice Age archeological sites south of North America's Pleistocene continental glaciers is revolutionizing traditional interpretations of North American archeology. Continental glaciers lowered global sea level exposing the Bering Land Bridge and blocked the entry of humans migrating from Asia to the Americas during the last Ice Age. However, archeological discoveries indicate that humans had colonized areas south of the ice sheets prior to the end of the last Ice Age (c 11,000 years ago). These data question the predominant theory that the Bering Land Bridge and southward migration through central North America was the original route of human entry to the Americas. An alternative hypothesis suggests that between 16,000 and 12,000 years ago humans using watercraft may have first entered the Americas by colonizing refugia and deglaciated areas of the continental shelf of the Northwest (NW) Coast of North America exposed by lower sea level. This idea challenges traditional thought regarding the origins of Native Americans, the nature of their original adaptation, and when and how they first colonized the Americas. Native American oral histories, recent discovery of artifacts on the ocean floor, and refined paleoenvironmental and geological data, make it possible to identify specific locales were ancient submerged sites may be located in SE Alaska. By analyzing these data it is possible to identify likely underwater sites and sample them using marine archeological techniques. Field archaeological permit 2010-02 was requested to identify and explore underwater locales on the

continental shelf of Southeast (SE) Alaska for evidence that could document early human occupation and test the coastal migration hypothesis.

Physics

Ladd, C., & Cheng, W. (2016). Gap Winds and Their Effects on Regional Oceanography Part I: Cross Sound, Alaska. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 132, 41-53. https://doi.org/10.1016/j.dsr2.2015.08.006

Gap-wind events flowing from Cross Sound in the eastern Gulf of Alaska (GOA) were examined using QuikSCAT wind data. The average duration of an event is 3.6 days with the longest event recorded in the QuikSCAT dataset being 12 days. Daily offshore directed winds with speeds > 10 m s(-1) are more common during the winter months (October-March), averaging 20.0 days per year, and less common during the summer (April - September), averaging 2.8 days per year. Interannual variability in the frequency of gap-wind events is correlated with El Nino. During gap-wind events, the spatial scales of high off-shore directed winds (> 10 m s(-1)) reach almost 200 km off-shore and 225 km along the shelf break, suggesting that the winds directly influence both the shelf (20-65 km wide) and the off-shore waters. A model experiment suggests that a gap-wind event can result in eddy formation and changes in circulation and water properties. Increased entrainment of water from below the mixed layer due to the gap-wind event implies that mixed-layer nitrate concentrations could increase on the order of 5-10.mu mole/l, potentially enhancing primary production in the region. An accompanying paper discusses part II of our study (Ladd et al., 2016) focusing on gap-wind events in the western GOA around Kodiak Island.

Weingartner, T., Eisner, L., Eckert, G. L., & Danielson, S. (2009). Southeast Alaska: Oceanographic Habitats and Linkages. *Journal of Biogeography,* 36(3), 387-400. https://doi.org/10.1111/j.1365-2699.2008.01994.x

We provide an overview of the physical oceanographic and geological processes that affect marine biological habitats and production in the marine waters throughout the archipelago and continental shelf of Southeast Alaska. Given the paucity of regional data, our overview summarizes work done in adjacent regions of the Gulf of Alaska shelf and basin, and draws on research carried out in similar settings elsewhere. The geological setting, which critically influences the regional meteorology and oceanography, includes a narrow continental shelf, deep channels that permeate the archipelago, fjords, glaciers and a rugged, mountainous coast. The large-scale meteorology is influenced primarily by seasonal variations in the intensity and position of the Aleutian Low. Winds, freshwater runoff, tides and cross-shelf exchange control the regional oceanography. The large-scale flow field advects mass, heat, salt, nutrients and planktonic organisms northward from British Columbia (and even further south) to the northern Gulf of Alaska along the slope, shelf, and within the channels of Southeast Alaska. The deep channels permeating the island archipelago and narrow continental shelf facilitate communication between basin and interior waters. Water properties and flow fields are subject to large annual variations in response to similarly large variations in winds and coastal freshwater discharge. The complex geological setting leads to large spatial heterogeneity in the physical processes controlling the local circulation fields and mixing, thereby creating numerous and diverse marine biological habitats. These various circulation and mixing processes modify substantially Southeast Alaska water masses and

thus influence marine ecosystem processes downstream over the northern and western Gulf of Alaska shelf.

Section XX: General

Biology

Burnham, R. (2017). Whale Geography: Acoustics, Biogeography and Whales. *Progress in Physical Geography,* 41(5), 676-685. https://doi.org/10.1177/0309133317734103

Typically, organism-based biogeographic studies consider distribution and abundance over time on various scales. However, to be comprehensive, factors of environment and habitat, energetics, morphology, and population dynamics should also be included. In addition, these studies should consider not only the spatial extent that an individual or species occupies or can roam within, but also the space over which an animal can extract and interpret information, a less well-defined element of niche space which largely shapes its movements or distribution. Understanding the processes that inform patterns of species distribution, both intrinsic and external to the animal, is key to understanding a species' ecology. Here, we consider the biogeography of whales, given these ideas, with a particular focus on the acoustical components of their biology and landscape. Cetaceans use of sound to communicate, navigate and forage, and so interpret the soundscape, is a central consideration. It has important implications in a changing ambient environment and will increasingly influence species' survival.

Chu, J. W. F., Nephin, J., Georgian, S., Knudby, A., Rooper, C., & Gale, K. S. P. (2019). Modelling the Environmental Niche Space and Distributions of Cold-Water Corals and Sponges in the Canadian Northeast Pacific Ocean. *Deep Sea Research Part I: Oceanographic Research Papers,* 151. https://doi.org/10.1016/j.dsr.2019.06.009

Cold-water coral and sponge (CWCS) communities are important indicators of vulnerable marine ecosystems (VMEs) and are used to delineate areas for marine conservation and fisheries management. Although the northeast Pacific region of Canada (NEPC) is notable for having unique CWCS assemblages and is the location of >80% of Canadian seamounts, the extent of potential CWCS-defined VMEs in this region is unknown. Here, we used a diverse set of environmental data layers (n=30) representing a range of bathymetric derivatives, physicochemical variables, and water column properties to assess the primary factors influencing the niche separation and potential distributions of six habitat-forming groups of CWCS in the NEPC (sponge classes: Hexactinellida, Demospongiae; coral orders: Alcyonacea, Scleractinia, Antipatharia, Pennatulacea). The primary environmental gradients that influence niche separation among CWCS are driven by total alkalinity, dissolved inorganic carbon, and dissolved oxygen. Significant niche separation among groups indicates CWCS to be primarily specialists occurring in rare habitat conditions in the NEPC. Species distribution models (SDMs) developed for each CWCS group shared severely low dissolved oxygen levels ([O2] < 0.5 ml L−1) as a top predictor for habitat suitability in the NEPC. Niche separation is further emphasized by differences in the model-predicted areas of suitable habitat among CWCS groups. Although niches varied among taxa, the general areas of high habitat suitability for multiple CWCS groups in the NEPC occurred within the 500–1400 m bottom depth range which is strongly associated with the extensive oxygen minimum zone (OMZ) characterizing this region. As a result, the largest continuous area of potential CWCS habitat occurred along the continental slope with smaller, isolated patches also occurring at several offshore seamounts that have summits

that extend into OMZ depths. Our results provide insight into the factors that influence the distributions of some of the most important habitat-forming taxa in the deep ocean and create an empirical foundation for supporting cold-water coral and sponge conservation in the NEPC.

Cox, S. L., Embling, C. B., Hosegood, P. J., Votier, S. C., & Ingram, S. N. (2018). Oceanographic Drivers of Marine Mammal and Seabird Habitat-Use across Shelf-Seas: A Guide to Key Features and Recommendations for Future Research and Conservation Management. *Estuarine Coastal and Shelf Science,* 212, 294-310. https://doi.org/10.1016/j.ecss.2018.06.022

Mid-latitude (similar to 30-60 degrees) seasonally stratifying shelf-seas support a high abundance and diversity of marine predators such as marine mammals and seabirds. However, anthropogenic activities and climate change impacts are driving changes in the distributions and population dynamics of these animals, with negative consequences for ecosystem functioning. Across mid-latitude shelf-seas marine mammals and seabirds are known to forage across a number of oceanographic habitats that structure the spatio-temporal distributions of prey fields. Knowledge of these and the bio-physical mechanisms driving such associations are needed to improve marine management and policy. Here, we provide a concise and easily accessible guide for both researchers and managers of marine systems on the predominant oceanographic habitats that are favoured for foraging by marine mammals and seabirds across mid-latitude shelf-seas. We (1) identify and describe key discrete physical features present across the continental shelf, working inshore from the shelf-edge to the shore line, (2) provide an overview of findings relating to associations between these habitats and marine mammals and seabirds, (3) identify areas for future research and (4) discuss the relevance of such information to conservation management. We show that oceanographic features preferentially foraged at by marine mammals and seabirds include shelf edge fronts, upwelling and tidal-mixing fronts, offshore banks and internal waves, regions of stratification, and topographically complex coastal areas subject to strong tidal flow. Whilst associations were variable across taxa and through space and time, in the majority of cases interactions between bathymetry and tidal currents appear to play a dominant role, alongside patterns in seasonal stratification and shelf-edge upwelling. We suggest that the ecological significance of these bio-physical structures stems from a capacity to alter the densities, distributions (both horizontally and vertically) and/or behaviours of prey in a persistent and/or predictable manner that increases accessibility for predators, and likely enhances foraging efficiency. Future conservation management should aim to preserve and protect these habitats. This will require adaptive and holistic strategies that are specifically tailored to the characteristics of an oceanographic feature, and where necessary, evolve through space and time in response to spatio-temporal variability. Improved monitoring of animal movements and biophysical conditions across shelf-seas would aid in this. Areas for future research include multi-disciplinary/ trophic studies of the mechanisms linking bio-physical processes, prey and marine mammals and seabirds (which may elucidate the importance of lesser studied features such as bottom fronts and Langmuir circulation cells), alongside a better understanding of how predators perceive their environment and develop foraging strategies during immature/juvenile stages. Estimates of the importance of oceanographic habitat features at a population level should also be obtained. Such information is vital to ensuring the future health of these complex ecosystems, and can be used to assess how anthropogenic activities and future environmental changes will impact the functioning and spatio-temporal dynamics of these bio-physical features and their use by marine predators.

Finucci, B., Stevens, D. W., Jones, E. G., & Dunn, M. R. (2017). Some Observations on the Biology of Two Rarely Seen Deep-Sea Chimaerids, *Chimaera carophila* and *Hydrolagus homonycteris*. *Journal of Fish Biology,* 90(5), 2020-2040. https://doi.org/10.1111/jfb.13284

Chimaera carophila (n = 45) and Hydrolagus homonycteris (n = 11), two deep-sea chimaerids rarely caught in the waters off New Zealand, were collected from research trawl catches and commercial fishery catches around New Zealand at depths between 400 and 1300 m, between 2014 and 2016. Additional preserved specimens of both species (n = 58) from museum collections were analysed for size, sex and maturity. External assessment of male claspers and a combination of internal assessments of female gonad mass and oviducal gland width, were used to determine maturity. For both species, length at first maturity was 0·70–0·82 of their maximum observed chimaera length (L C), with females maturing at a larger size. Length at maturity for C. carophila (L C range: 28·7–103·9 cm) was estimated at 72·5 cm L C for males (n = 163) and 82·5 L C for females (n = 58). In H. homonycteris , length at maturity (length range: 78·6–99·8 cm L C) was estimated at 79·1 cm L C for males (n = 51) and 80·1 cm L C for females (n = 17). Ovarian fecundity was up to 31 for C. carophila and sperm storage was confirmed in the oviducal gland of this species. Both species preyed on benthic invertebrates. Some C. carophila and H. homonycteris inhabit depths beyond most current fisheries, but both species appear to be relatively rare and have reproductive parameters characteristic of low productivity, which may make these species vulnerable to population decline if mortality was to increase in the future.

Guazzo, R. A., Helble, T. A., D'Spain, G. L., Weller, D. W., Wiggins, S. M., & Hildebrand, J. A. (2017). Migratory Behavior of Eastern North Pacific Gray Whales Tracked Using a Hydrophone Array. *Plos One,* 12(10). https://doi.org/10.1371/journal.pone.0185585

Eastern North Pacific gray whales make one of the longest annual migrations of any mammal, traveling from their summer feeding areas in the Bering and Chukchi Seas to their wintering areas in the lagoons of Baja California, Mexico. Although a significant body of knowledge on gray whale biology and behavior exists, little is known about their vocal behavior while migrating. In this study, we used a sparse hydrophone array deployed offshore of central California to investigate how gray whales behave and use sound while migrating. We detected, localized, and tracked whales for one full migration season, a first for gray whales. We verified and localized 10,644 gray whale M3 calls and grouped them into 280 tracks. Results confirm that gray whales are acoustically active while migrating and their swimming and acoustic behavior changes on daily and seasonal time scales. The seasonal timing of the calls verifies the gray whale migration timing determined using other methods such as counts conducted by visual observers. The total number of calls and the percentage of calls that were part of a track changed significantly over both seasonal and daily time scales. An average calling rate of 5.7 calls/whale/day was observed, which is significantly greater than previously reported migration calling rates. We measured a mean speed of 1.6 m/s and quantified heading, direction, and water depth where tracks were located. Mean speed and water depth remained constant between night and day, but these quantities had greater variation at night. Gray whales produce M3 calls with a root mean square source level of 156.9 dB re 1 mu Pa at 1 m. Quantities describing call characteristics were variable and dependent on site-specific propagation characteristics.

Hiddink, J. G., Jennings, S., Sciberras, M., Bolam, S. G., Cambiè, G., McConnaughey, R. A., . . . Trenkel, V. (2018). Assessing Bottom Trawling Impacts Based on the Longevity of Benthic Invertebrates. *Journal of Applied Ecology,* 56(5), 1075-1084. https://doi.org/10.1111/1365-2664.13278

1. Bottom trawling is the most widespread human activity directly affecting seabed habitats. Assessment and effective management of the effects of bottom trawling at the scale of fisheries requires an understanding of differences in sensitivity of biota to trawling. Responses to disturbance are expected to depend on the intrinsic rate of increase in populations (r), which is expected to be linearly related to the reciprocal of longevity.

2. We examine the relationship between the longevity of benthic invertebrates and their response to bottom trawling; both in terms of the immediate mortality following a trawl pass and their subsequent rates of recovery. We collate all available data from experimental and comparative trawling studies, and test how longevity influences these aspects of sensitivity.

3. The shortest lived organisms (<1 year) increased in abundance shortly after experimental trawling but showed no response to trawling in long-term comparative studies. Conversely, the abundance of biota with a life span >1 year decreased by ~9% immediately following a trawl pass. The effect of bottom trawling in comparative studies increased with longevity, with a 2–3× larger effect on biota living >10 years than on biota living 1–3 years. We attribute this difference to the slower recovery rates of the long-lived biota.

4. The observed relationship between the intrinsic rate of population increase (r , our metric of recovery rate) and the reciprocal of longevity matches theoretical expectation and predicts that the sensitivity of habitats to bottom trawling is higher in habitats with higher proportions of long-lived organisms.

5. Synthesis and applications . Where the longevity of a species or the longevity distribution of a community is known or can be inferred, our estimates of depletion and intrinsic rate of increase can be combined with high-resolution maps of trawling intensity to assess trawling impacts at the scale of the fishery or other defined unit of assessment. Our estimates of r may also be used to estimate recovery times following other forms of seabed disturbance.

Hiddink, J. G., Jennings, S., Sciberras, M., Szostek, C. L., Hughes, K. M., Ellis, N., . . . Kaiser, M. J. (2017). Global Analysis of Depletion and Recovery of Seabed Biota after Bottom Trawling Disturbance. *PNAS,* 114(31), 8301-8306. https://doi.org/10.1073/pnas.1618858114

Bottom trawling is the most widespread human activity affecting seabed habitats. Here, we collate all available data for experimental and comparative studies of trawling impacts on whole communities of seabed macroinvertebrates on sedimentary habitats and develop widely applicable methods to estimate depletion and recovery rates of biota after trawling. Depletion of biota and trawl penetration into the seabed are highly correlated. Otter trawls caused the least depletion, removing 6% of biota per pass and penetrating the seabed on average down to 2.4 cm, whereas hydraulic dredges caused the most depletion, removing 41% of biota and penetrating the seabed on average 16.1 cm. Median recovery times posttrawling (from 50 to 95% of unimpacted biomass) ranged between 1.9 and 6.4 y. By accounting for the effects of penetration depth, environmental variation, and uncertainty, the models explained much of the variability of depletion and recovery estimates from single studies. Coupled with large-scale, high-resolution maps of trawling frequency and habitat, our estimates of depletion and recovery rates enable the assessment of trawling impacts on unprecedented spatial scales.

Hurst, T. P., Fernandez, E. R., & Mathis, J. T. (2013). Effects of Ocean Acidification on Hatch Size and Larval Growth of Walleye Pollock (Theragra calcogramma). *ICES Journal of Marine Science,* 70(4), 812-822. https://doi.org/10.1093/icesjms/fst053

Rising atmospheric concentrations of CO2 are predicted to decrease the pH of high-latitude oceans by 0.3–0.5 units by 2100. Because of their limited capacity for ion exchange, embryos and larvae of marine fishes are predicted to be more sensitive to elevated CO2 than juveniles and adults. Eggs and larvae of walleye pollock (Theragra chalcogramma) were incubated across a broad range of CO2 levels (280–2100 µatm) to evaluate sensitivity in this critical resource species. Slightly elevated CO2 levels (~450 µatm) resulted in earlier hatching times, but differences among egg batches were greater than those observed across CO2 treatments. Egg batches differed significantly in size-at-hatch metrics, but we observed no consistent effect of CO2 level. In three independent experiments, walleye pollock were reared at ambient and elevated CO2 levels through the early larval stage (to ~30 days post-hatch). Across trials, there were only minor effects of CO2 level on size and growth rate, but fish in the ambient treatments tended to be slightly smaller than fish reared at elevated CO2 levels. These results suggest that growth potential of early life stages of walleye pollock is resilient with respect to the direct physiological effects of ocean acidification.

Hurst, T. P., Fernandez, E. R., Mathis, J. T., Miller, J. A., Stinson, C. M., & Ahgeak, E. F. (2012). Resiliency of Juvenile Walleye Pollock to Projected Levels of Ocean Acidification. *Aquatic Biology,* 17(3), 247-259. https://doi.org/10.3354/ab00483

As atmospheric concentrations of CO2 rise, the pH of high-latitude oceans is predicted to decrease by 0.3 to 0.5 units by 2100. Several biological consequences of ocean acidification across this pH range have already been documented in invertebrates and tropical marine fishes. However, little work has been done examining potential responses of the temperate and boreal marine fish species that support major fisheries. In 2 experiments, we examined the growth responses of juvenile walleye pollock Theragra chalcogramma at ambient and 3 elevated CO2 levels. In a short-term experiment with yearlings, CO2 treatment had no significant effect on growth or condition after 6 wk of rearing. Elevated CO2 levels (>450 µatm) increased the rate of otolith deposition, but did not affect otolith elemental composition. In a second experiment, growth in length of sub-yearlings over 12 wk at 8°C was 7.2% faster in the 2 higher CO2 treatments (>1200 µatm) than in the lower CO2 treatments (<900 µatm). Growth of sub-yearlings measured during 11 subsequent weeks of rearing at 2.5°C did not differ among CO2 treatments. There was no effect of CO2 treatment on condition factor following either phase of the experiment. Sub-yearling consumption rates were not directly affected by CO2 treatment, confirming that growth at elevated CO2 levels is not maintained through compensatory feeding. While not exhaustive of potential interactive environmental factors, these experiments demonstrate a general resiliency of growth energetics in juvenile walleye pollock to the direct effects of CO2 changes predicted for the Gulf of Alaska and Bering Sea in the next century.

Kahn, A. S., Vehring, L. J., Brown, R. R., & Leys, S. P. (2016). Dynamic Change, Recruitment and Resilience in Reef-Forming Glass Sponges. *Journal of the Marine Biological Association of the United Kingdom,* 96(2), 429-436. https://doi.org/10.1017/s0025315415000466

Glass sponge reefs on the continental shelf of western Canada and south-east Alaska are considered stable deep-sea habitats that do not change significantly over time. Research cruises using a remotely operated vehicle equipped with accurate GPS positioning have allowed us to observe the same sponges at two reefs in the Strait of Georgia, British Columbia to document recruitment, growth and response to damage over time. Spermatocysts and putative embryos found in winter suggest annual, asynchronous reproduction. Juvenile sponges (2-10 cm in osculum diameter) in densities up to 1 m(-2) were more concentrated near live sponges and sponge skeletons than away (Spearman rank correlations, P < 0.0001 for live cover and for skeletons), suggesting that recruitment occurs in particular regions using sponge skeletons as substrate. Most sponges showed no change in shape or size over 2-3 years, but some had died while others showed growth of 1-9 cm year(-1). Deposition rates of reef-cementing sediments were 97 mm year(-1) at Galiano Reef and 137 mm year(-1) at Fraser Reef, but sediments eroded so that there was no net gain or loss over time. Sponges recovered within 1 year from small-scale damage that mimicked bites by fish or nudibranchs; however sponges did not recover from crushing of a large area (1.5 x 2 m(2)) even 3 years later. These observations and experiments show that while recruitment and growth of sponge reefs is more dynamic than previously thought, the reefs are not resilient in the face of larger-scale disturbances such as might be inflicted by trawling.

Loher, T. (2011). Analysis of Match-Mismatch between Commercial Fishing Periods and Spawning Ecology of Pacific Halibut (Hippoglossus stenolepis), Based on Winter Surveys and Behavioural Data from Electronic Archival Tags. *ICES Journal of Marine Science,* 68(10), 2240-2251. https://doi.org/10.1093/icesjms/fsr152

The fishery for halibut (Hippoglossus stenolepis) in the eastern Pacific is closed during the boreal winter, roughly corresponding to the seasonal spawning of the species. Opening and closing dates for each season are stipulated annually based on economics and biology. Historical surveys and data from electronic tags are analysed to assess the extent to which recent closures have encompassed the annual spawning cycle of the species, as defined by migration to offshore spawning sites, active spawning, and return to feeding areas. These were assessed by calculating mean maximum daily depth profiles for fish exhibiting seasonal migration, calculating the date-specific proportions of the tagged population either migrating to or resident on their feeding or spawning grounds, and examining the temporal distribution of spent and running fish in historical surveys along with evidence of spawning contained in high-resolution tag data. The data indicate that fishery closures over the past 20 years have been consistently too short to protect the entirety of a migration period that begins as early as September and is not substantially completed until May. Additionally, some recent season openings have encroached on the active spawning season. Failure to fully protect spawning migrations may allow seasonal interception fisheries, and the selective removal of early and late spawners could cause changes in stock demographics, restrict effective spawning, and influence long-term stock productivity, especially in the face of environmental variability.

Malyutin, A. N. (2015). Deep-Sea (Cold-Water) Coral Communities of the North Pacific and Problems of Their Conservation. *Russian Journal of Marine Biology,* 41(1), 1-9. https://doi.org/10.1134/s1063074015010058

This review paper is devoted to the deep-sea (cold-water) coral communities of the North Pacific. The composition of these communities differs from that of the deep-sea coral communities of the Atlantic Ocean and the South Pacific. In the former case, the community structure is mainly determined by octocorals (soft and horn corals, sea pens) and stylasterids; in the latter case, the dominant coral group is hard (true) corals (order Scleractinia). The distribution of corals in the North Pacific is described. The main threats to deep-sea coral communities, primarily bottom trawling and oil and gas exploration and extraction, are discussed. The locations of deep-sea coral communities in the Kuril Islands region were found for the first time. The most interesting and endangered sites are proposed for the creation of marine protected areas, viz., the southern and middle .

Mostofa, K. M. G., Liu, C. Q., Zhai, W. D., Minella, M., Vione, D., Gao, K. S., . . . Sakugawa, H. (2016). Reviews and Syntheses: Ocean Acidification and Its Potential Impacts on Marine Ecosystems. *Biogeosciences,* 13(6), 1767-1786. https://doi.org/10.5194/bg-13-1767-2016

Ocean acidification, a complex phenomenon that lowers seawater pH, is the net outcome of several contributions. They include the dissolution of increasing atmospheric CO2 that adds up with dissolved inorganic carbon (dissolved CO2, H2CO3, HCO3-, and CO32-) generated upon mineralization of primary producers (PP) and dissolved organic matter (DOM). The aquatic processes leading to inorganic carbon are substantially affected by increased DOM and nutrients via terrestrial runoff, acidic rainfall, increased PP and algal blooms, nitrification, denitrification, sulfate reduction, global warming (GW), and by atmospheric CO2 itself through enhanced photosynthesis. They are consecutively associated with enhanced ocean acidification, hypoxia in acidified deeper seawater, pathogens, algal toxins, oxidative stress by reactive oxygen species, and thermal stress caused by longer stratification periods as an effect of GW. We discuss the mechanistic insights into the aforementioned processes and pH changes, with particular focus on processes taking place with different timescales (including the diurnal one) in surface and subsurface seawater. This review also discusses these collective influences to assess their potential detrimental effects to marine organisms, and of ecosystem processes and services. Our review of the effects operating in synergy with ocean acidification will provide a broad insight into the potential impact of acidification itself on biological processes. The foreseen danger to marine organisms by acidification is in fact expected to be amplified by several concurrent and interacting phenomena.

Sciberras, M., Hiddink, J. G., Jennings, S., Szostek, C. L., Hughes, K. M., Kneafsey, B., . . . Kaiser, M. J. (2018). Response of Benthic Fauna to Experimental Bottom Fishing: A Global Meta-Analysis. *Fish and Fisheries,* 19(4), 698-715. https://doi.org/10.1111/faf.12283

Bottom-contact fishing gears are globally the most widespread anthropogenic sources of direct disturbance to the seabed and associated biota. Managing these fishing disturbances requires quantification of gear impacts on biota and the rate of recovery following disturbance. We undertook a systematic review and meta-analysis of 122 experiments on the effects-of-bottom fishing to quantify the removal of benthos in the path of the fishing gear and to estimate rates of recovery following disturbance. A gear pass reduced benthic invertebrate abundance by 26% and species richness by 19%.

The effect was strongly gear-specific, with gears that penetrate deeper into the sediment having a significantly larger impact than those that penetrate less. Sediment composition (% mud and presence of biogenic habitat) and the history of fishing disturbance prior to an experimental fishing event were also important predictors of depletion, with communities in areas that were not previously fished, predominantly muddy or biogenic habitats being more strongly affected by fishing. Sessile and low mobility biota with longer life-spans such as sponges, soft corals and bivalves took much longer to recover after fishing (>3 year) than mobile biota with shorter life-spans such as polychaetes and malacostracans (<1 year). This meta-analysis provides insights into the dynamics of recovery. Our estimates of depletion along with estimates of recovery rates and large-scale, high-resolution maps of fishing frequency and habitat will support more rigorous assessment of the environmental impacts of bottom-contact gears, thus supporting better informed choices in trade-offs between environmental impacts and fish production.

Soja, C. M., Mitchell, M., Newton, A. J., Vendetti, J., Visaggi, C., Antoshkina, A. I., & White, B. (2003). Paleolecology of Sponge-? Hydroid Associations in Silurian Microbial Reefs. *Palaios,* 18(3), 225-235. https://doi.org/10.1669/0883-1351(2003)018<0225:Poshai>2.0.Co;2

Microbial boundstones from Alaska and Russia yield new insights into the paleoecology of Silurian biotas that inhabited stromatolite reefs. These high-energy reefs were built along the Uralian Seaway in the Late Silurian by a diverse suite of microorganisms in association with accessory metazoans, predominantly sphinctozoan sponges. Within the stromatolite framework, three species of small, solitary, sphinctozoans (aphrosalpingids) encrusted a variety of hard substrates, mostly skeletal remains but also microbial laminae and cavity surfaces. Fossils encrusted by the sponges include the problematic hydroid Fistulella, possible stromatoporoids (recrystallized), crinoids, the possible cyanobacterium Ludlovia, corals, and unidentifiable shelly debris. In addition to the ubiquitous microbial laminae, the sponges, Fistulella, and ?stromatoporoids were less commonly encrusted by Ludlovia, Renalcis, or crinoids. Well-developed attachment surfaces, including enlarged holdfasts, allowed the sponges to achieve stability on the seafloor after larvae settled randomly on available hard surfaces. A greater incidence of sponge encrustations on Fistulella than on other organisms indicates that some of the sponges may have enjoyed a commensalistic relationship while attached as juveniles to a living substrate. The sponges' orientation on Fistulella in the sediment suggests that the relationship between the two taxa may have become parasitic, whereby the weight of the sponges caused Fistulella to collapse into the muddy substrate. Recognition of the intimate growth relationships shared by Silurian sphinctozoans, Fistulella, and other organisms expands the fossil record of encrusting sponges, identifies a novel sponge-?hydroid association, and reveals organismal responses to competition for space in mid-Paleozoic microbial reefs.

Stone, R. P., & Cairns, S. D. (2017). *Deep-Sea Coral Taxa in the Alaska Region: Depth and Geographical Distribution.* Retrieved from https://repository.si.edu/handle/10088/34994

In summary, we have confirmed the presence of 137 unique coral taxa in Alaskan waters. Octocorals were the most speciose (89 taxa total), followed by hydrocorals (24 taxa), antipatharians (12 taxa) and scleractinians (12 taxa). The Aleutian Islands region has the most taxa (n=96), followed by the Gulf of Alaska Seamount Province (n=42), the eastern Gulf of Alaska (n=39), the western Gulf of Alaska (n=24),

and the Bering Sea (n=18 taxa). Only a single coral species is known from the Arctic Region. Black corals (Order Antipatharia) were found over a depth range of 401-4685 m throughout the Alaska Region, scleractinians (Order Scleractinia) were found over a depth range of 17-6328 m, octocorals (Orders Alcyonacea and Pennatulacea) were found over a depth range of 3-4784 m, and hydrocorals (Order Anthoathecata) had the narrowest depth range of 10-2124 m in the region.

Wahltinez, S. J., Newton, A. L., Harms, C. A., Lahner, L. L., & Stacy, N. I. (2020). Coelomic Fluid Evaluation in *Pisaster ochraceus* Affected by Sea Star Wasting Syndrome: Evidence of Osmodysregulation, Calcium Homeostasis Derangement, and Coelomocyte Responses. *Frontiers in Veterinary Science,* 7. https://doi.org/10.3389/fvets.2020.00131

Sea Star Wasting Syndrome (SSWS) is one of the largest marine wildlife die-offs ever recorded, killing millions of sea stars from more than 20 Asteroid species from Alaska to Mexico from 2013 to 2015 from yet undetermined cause(s). Coelomic fluid surrounds the sea star's organs, playing critical roles in numerous systemic processes, including nutrient transportation and immune functions. Coelomocytes, which are cellular components of coelomic fluid and considered functionally equivalent to vertebrate leukocytes, are responsible for innate cell-mediated immunity. The objectives of this study were to (1) evaluate changes in coelomic fluid chemistry, coelomocyte counts, and cytology from ochre sea stars (Pisaster ochraceus) (n = 55) with clinical signs consistent with SSWS at varying intensity (SSWS score 1: n = 4, score 2: n = 2, score 3: n = 3, score 4: n = 18, score 5: n = 26) in comparison to coelomic fluid from clinically normal sea stars (n = 26) and to (2) correlate SSWS score with cellular and biochemical analytes. SSWS-affected sea stars had wider ranges of all electrolytes, except calcium; statistically significantly higher chloride, osmolality, and total protein; lower calcium; and higher coelomocyte counts when compared to clinically normal sea stars maintained under identical environmental conditions. Free and/or phagocytized bacteria were noted in 29% (16 of 55) coelomic fluid samples from SSWS-affected sea stars but were absent in clinically normal sea stars. SSWS score correlated significantly with increasing chloride concentration, osmolality, and coelomocyte counts. These chemistry and cytological findings in coelomic fluid of SSWS-affected sea stars provide insight into the pathophysiology of SSWS as these results suggest osmo- and calcium dysregulation, coelomocyte responses, and presumptive opportunistic bacterial infection in SSWS-affected sea stars. This information provides potential future research applications for the development of treatment strategies for sea stars in managed care and for understanding the complexity of various biochemical and cellular pathophysiological mechanisms involved in sea star wasting.

Yamamoto, T., Yamada, T., Fujimoto, H., & Hamasaki, K. (2015). Effects of Salinity on Snow Crab (Chionoecetes opilio) Larval Survival and Development under Laboratory Conditions. *Journal of Shellfish Research,* 34(2), 499-504. https://doi.org/10.2983/035.034.0234

To better understand the factors influencing larval dispersal and settlement of the snow crab Chionoecetes opilio in its natural habitats, we tested the effects of salinities ranging from 18 to 38 and 20-38 on the survival and developmental duration of snow crab larvae in the zoeal and megalopal stages, respectively. Survivals to second-stage zoeae and to megalopae were highest at salinities of 20-38 and 26-38, respectively. There were no significant differences in survival among megalopae reared at salinities between 24 and 38, although survival tended to be higher at salinities range 28-36. The mean

periods from hatching to the second zoeal and megalopal stages, and from the megalopal to first crab stage, were shortest at salinities of 30, 30, and 32, respectively, and progressively increased at salinities above and below these values.

Yamamoto, T., Yamada, T., Fujimoto, H., & Hamasaki, K. (2015). The Moulting Cycle and Changes in Body Density in Larvae of the Snow Crab Chionoecetes opilio (Brachyura: Majoidea) under Laboratory Conditions. *Invertebrate Reproduction & Development,* 59(3), 176-187. https://doi.org/10.1080/07924259.2015.1059904

The moulting cycle and the time course of changes in body density from hatching to the end of the megalopal stage in snow crab (Chionoecetes opilio) larvae were investigated in laboratory-reared specimens. Morphological changes in the epidermis and cuticle were photographically documented to characterize the moult-cycle stages: A-B (postmoult), C (intermoult), D (premoult) and E (ecdysis). Moult-stage characteristics were based on a microscopical examination of integumental modifications, particularly of the telson. During stages A-C, the larval cuticle changed from a spongy structure to become conspicuously thicker and more solid in appearance. In stage D, the epidermis retracted from the cuticle and new setae and appendages were formed. The body densities of larval snow crabs were lowest just after moulting; they increased greatly during stage C, and then gradually increased to reach a plateau at 1.0897-1.0931gcm(-3) during stage D. Over the whole larval period, they have a density greater than that of seawater. These observations will assist in understanding of larval distribution and transport in snow crabs in their natural habitat, and provide a useful tool to determine the developmental stages of larvae sampled from the plankton and from larval cultures.

Chemistry

Cramer, B. D., Munnecke, A., Schofield, D. I., Haase, K. M., & Haase-Schramm, A. (2011). A Revised Sr-87/Sr-86 Curve for the Silurian: Implications for Global Ocean Chemistry and the Silurian Timescale. *Journal of Geology,* 119(4), 335-349. https://doi.org/10.1086/660117

Recent recalibration of the Silurian timescale and improved global chronostratigraphic correlation of Silurian strata significantly altered the Silurian Sr-87/Sr-86 curve and the temporal extent of available data. Whereas previous Silurian Sr-87/Sr-86 composites showed a generally monotonic increase throughout the Silurian, revisions to the Silurian timescale now require a major increase in the rate of change in Sr-87/Sr-86 at or near the onset of the Gorstian Age of the Ludlow Epoch. Similarly, improved chronostratigraphic correlations between Silurian outcrops on Anticosti Island, Canada, and Gotland, Sweden, indicate that the middle part of the Telychian Age, which is roughly 10%-15% of the total duration of the Silurian period, is undersampled and underrepresented in Silurian Sr-87/Sr-86 composites. A revised Silurian Sr-87/Sr-86 curve based on 241 new and published analyses confirms the significant increase in the rate of change of Sr-87/Sr-86 toward more radiogenic values near the base of the Ludlow Series. On the basis of these data, we propose that the rapid trend toward more radiogenic Sr-87/Sr-86 values is indicative of increased weathering of old sialic crust exposed during the Silurian uplift of portions of Baltica, Laurentia, and Avalonia. Importantly, however, the actual rate of change of Sr-87/Sr-86 will remain equivocal until the durations of Silurian epochs and ages are better constrained.

Stemmler, I., & Lammel, G. (2012). Long-Term Trends of Continental-Scale Pcb Patterns Studied Using a Global Atmosphere-Ocean General Circulation Model. *Environmental Science and Pollution Research,* 19(6), 1971-1980. https://doi.org/10.1007/s11356-012-0943-8

Continental-scale distribution and inter-continental transport of four polychlorinated biphenyl (PCB) congeners (28, 101, 153, 180) from 1950 to 2010 were studied using the global multicompartment chemistry transport model MPI-MCTM. Following identical primary emissions for all PCB congeners into air, most of the burden is stored in terrestrial (soil and vegetation) compartments. Thereby, PCB-28, PCB-101 and PCB-153 show a shift of the soil burden maxima from source to remote regions. This shift is downwind with regard to the westerlies for Eurasia and upwind for North America and more prominent for the lighter PCBs than for PCB-153 or PCB-180. In meridional direction, all congeners' distributions underwent a northward migration in Eurasia and North America since the 1950s. Inter-continental transport from Eurasian sources accounts largely for contamination of Alaska and British Columbia and determines the migration of the PCB distribution in soil in North America. Trans-Pacific transport occurs mainly in the gas phase in boreal winter (December-January-February) at 3-4 km altitude and is on a multi-year time scale strongly linked to the atmospheric pressure systems over the Pacific. Inter-continental transport of the lighter, more volatile PCBs is more efficient than for the heavier PCBs.

Geology

Brayard, A., Escarguel, G., Bucher, H., & Bruhwiler, T. (2009). Smithian and Spathian (Early Triassic) Ammonoid Assemblages from Terranes: Paleoceanographic and Paleogeographic Implications. *Journal of Asian Earth Sciences,* 36(6), 420-433. https://doi.org/10.1016/j.jseaes.2008.05.004

Early Triassic paleobiogeography is characterised by the stable supercontinental assembly of Pangea. However, at that time, several terranes such as the South Kitakami Massif (SK), South Primorye (SP) and Chulitna (respectively, and presently located in Japan, eastern Russia and Alaska) straddled the vast oceans surrounding Pangea. By means of quantitative biogeographical methods including Cluster Analysis, Non-metric Multidimensional Scaling and Bootstrapped Spanning Network applied to Smithian and Spathian (Early Triassic) ammonoid assemblages: we analyze similarity relationships between faunas and suggest paleopositions for the above-cited terranes. Taxonomic similarities between faunas indicate that primary drivers of the ammonoid distribution were Sea Surface Temperature and currents. Possible connections due to current-controlled faunal exchanges between both sides of the Panthalassa are shown and terranes such as SK, SP and Chulitna played an important role as stepping stones in the dispersal of ammonoids. SK and SP terranes show strong subequatorial affinities during the Smithian, thus suggesting a location close to South China. At the same time. the Chulitna terrane shows strong affinities with equatorial faunas of the eastern Panthalassa. This paleoceanographic pattern was markedly altered during the Spathian, possibly indicating significant modifications of oceanic circulation at that time, as illustrated by the development of a marked intertropical faunal belt across Tethys and Panthalassa.

Letham, B., Martindale, A., Macdonald, R., Guiry, E., Jones, J., & Ames, K. M. (2016). Postglacial Relative Sea-Level History of the Prince Rupert Area, British Columbia, Canada. *Quaternary Science Reviews,* 153, 156-191. https://doi.org/10.1016/j.quascirev.2016.10.004

This paper presents a history of relative sea level (RSL) change for the last 15,000 years in the Prince Rupert region on the northern coast of British Columbia, Canada. One hundred twenty-three radiocarbon ages of organic material from isolation basin cores, sediment sequence exposures, and archaeological sites having a recognized relation to past sea levels constrain postglacial RSL. The large number of new measurements relating to past sea-level provides a well constrained RSL curve that differs in significant ways from previously published results. After deglaciation following the Last Glacial Maximum, the region experienced an isostatically-induced rapid RSL drop from as much 50 m asl to as low as -6.3 m asl in as little as a few centuries between 14,500 BP and 13,500 BP. After a lowstand below current sea level for about 2000 years during the terminal Pleistocene, RSL rose again to a highstand at least 6 m asl after the end of the Younger Dryas. RSL slowly dropped through the Holocene to close to its current position by 2000-1500 BP, with some potential fluctuations between 3500 and 1500 BP. This study highlights variation in RSL histories across relatively short distances, which must be accounted for by local RSL reconstructions such as this one. This RSL curve aided in the identification of an 8000-9000 year old archaeological site on a 10-12 m asl terrace, which is currently the earliest dated archaeological site in the area, and it provides guidance for searching for even older archaeological remains. We highlight the utility and potential of this refined RSL history for developing surveys for other archaeological sites associated with paleoshorelines.

Sigloch, K., & Mihalynuk, M. G. (2017). Mantle and Geological Evidence for a Late Jurassic-Cretaceous Suture Spanning North America. *Geological Society of America Bulletin,* 129(11-12), 1489-1520. https://doi.org/10.1130/b31529.1

Crustal blocks accreted to North America form two major belts that are separated by a tract of collapsed Jurassic-Cretaceous basins extending from Alaska to Mexico. Evidence of oceanic lithosphere that once underlay these basins is rare at Earth's surface. Most of the lithosphere was subducted, which accounts for the general difficulty of reconstructing oceanic regions from surface evidence. However, this seafloor was not destroyed; it remains in the mantle beneath North America and is visible to seismic tomography, revealing configurations of arc-trench positions back to the breakup of Pangea. The double uncertainty of where trenches ran and how subducting lithosphere deformed while sinking in the mantle is surmountable, owing to the presence of a special-case slab geometry. Wall-like, linear slab belts exceeding 10,000 km in length appear to trace out intra-oceanic subduction zones that were stationary over tens of millions of years, and beneath which lithosphere sank almost vertically. This hypothesis sets up an absolute lower-mantle reference frame. Combined with a complete Atlantic spreading record that positions paleo-North America in this reference frame, the slab geometries permit detailed predictions of where and when ocean basins at the leading edge of westward-drifting North America were subducted, how intra-oceanic subduction zones were overridden, and how their associated arcs and basement terranes were sutured to the continent. An unconventional paleogeography is predicted in which mid-to late Mesozoic arcs grew in a long-lived archipelago located 2000-4000 km west of Pangean North America (while also consistent with the conventional view of a continental arc in early Mesozoic times). The Farallon Ocean subducted beneath the outboard (western) edge of the archipelago, whereas North America converged on the archipelago by westward subduction of an intervening, major ocean, the Mezcalera-Angayucham Ocean. The most conspicuous geologic

prediction is that of an oceanic suture that must run along the entire western margin of North America. It formed diachronously between ca. 155 Ma and ca. 50 Ma, analogous to diachro-nous suturing of southwest Pacific arcs to the northward-migrating Australian continent today. We proceed to demonstrate that this suture prediction fits the spatio-temporal evidence for the collapse of at least 11 Middle Jurassic to Late Cretaceous basins wedged between the Intermontane and Insular-Guerrero superterranes, about half of which are known to contain mantle rocks. These relatively late suturing ages run counter to the Middle Jurassic or older timing required and asserted by the prevailing, Andean-analogue model for the North American Cordillera. We show that the arguments against late suturing are controvertible, and we present multiple lines of direct evidence for late suturing, consistent with geophysical observations. We refer to our close integration of surface and subsurface evidence from geology and geophysics as "tomotectonic analysis." This type of analysis provides a stringent test for currently accepted tectonic models and offers a blueprint for similar, continental-scale investigations in other accretionary orogens.

Wang, J. D., Sheng, Y. W., Hinkel, K. M., & Lyons, E. A. (2012). Drained Thaw Lake Basin Recovery on the Western Arctic Coastal Plain of Alaska Using High-Resolution Digital Elevation Models and Remote Sensing Imagery. *Remote Sensing of Environment,* 119, 325-336. https://doi.org/10.1016/j.rse.2011.10.027

The landscape on the Arctic Coastal Plain (ACP) of Alaska is dominated by thousands of thaw (thermokarst) lakes and associated drained thaw lake basins (DTLBs). Knowledge of the DTLBs benefits our understanding of thaw lake dynamics, carbon cycles, and paleo-climatic change on the ACP since the end of the Late Glacial. This study initializes the application of high-resolution digital elevation models (DEMs) into a systematic reconstruction of DTLBs on the western ACP and adjacent northern Arctic Foothills. The method combines a machine-based detection algorithm automating the delineation of basin paleoshorelines on IfSAR DEM data and a posterior quality control with the aid of high-resolution aerial photograph and Landsat-5 TM imagery. A total of similar to 3590 km(2) of thaw lakes and similar to 10130 km(2) of DTLBs were mapped, with an overall accuracy of 99.2% and a Kappa coefficient of 0.988. The delineated DUB extents are conservative, as validated from eleven field-sampled paleoshorelines. A variety of topologic patterns such as merging, nesting, and overtopping are presented in the reconstructed DTLBs. Basin paleoshoreline levels are subject to average uncertainties of 0.4-0.7 m. The combined area of thaw lakes and DTLBs accounts for 57.1% of the western ACP and 23.2% of the northern Arctic Foothills in the study site. Regional analysis of several spatial and topographic characteristics demonstrates a distinct heterogeneity among the younger Outer Coastal Plain (YOCP), Outer Coastal Plain (OCP), Inner Coastal Plain (ICP), and the Arctic Foothills. Generally, the areal density of DTLBs decreases progressively on higher and older surfaces. The ICP has a lake-DTLB area ratio (0.37) greater than that in the other regions. DUB bathymetry presents a positive correlation with surface elevation: basin maximum depths range from similar to 2.0 m on the YOCP to similar to 8.0 m on the Arctic Foothills. Given the reconstructed DTLBs, a total of 31.9 (+/- 4.9) gigatons of net water drainage were estimated for the entire study area.

Management

Capotondi, A., Jacox, M., Bowler, C., Kavanaugh, M., Lehodey, P., Barrie, D., . . . Pesant, S. (2019). Observational Needs Supporting Marine Ecosystems Modeling and Forecasting: From the Global Ocean to Regional and Coastal Systems. *Frontiers in Marine Science,* 6. https://doi.org/10.3389/fmars.2019.00623

Many coastal areas host rich marine ecosystems and are also centers of economic activities, including fishing, shipping and recreation. Due to the socioeconomic and ecological importance of these areas, predicting relevant indicators of the ecosystem state on sub-seasonal to interannual timescales is gaining increasing attention. Depending on the application, forecasts may be sought for variables and indicators spanning physics (e.g., sea level, temperature, currents), chemistry (e.g., nutrients, oxygen, pH), and biology (from viruses to top predators). Many components of the marine ecosystem are known to be influenced by leading modes of climate variability, which provide a physical basis for predictability. However, prediction capabilities remain limited by the lack of a clear understanding of the physical and biological processes involved, as well as by insufficient observations for forecast initialization and verification. The situation is further complicated by the influence of climate change on ocean conditions along coastal areas, including sea level rise, increased stratification, and shoaling of oxygen minimum zones. Observations are thus vital to all aspects of marine forecasting: statistical and/or dynamical model development, forecast initialization, and forecast validation, each of which has different observational requirements, which may be also specific to the study region. Here, we use examples from United States (U.S.) coastal applications to identify and describe the key requirements for an observational network that is needed to facilitate improved process understanding, as well as for sustaining operational ecosystem forecasting. We also describe new holistic observational approaches, e.g., approaches based on acoustics, inspired by Tara Oceans or by landscape ecology, which have the potential to support and expand ecosystem modeling and forecasting activities by bridging global and local observations.

Cozzetto, K., Chief, K., Dittmer, K., Brubaker, M., Gough, R., Souza, K., . . . Chavan, P. (2013). Climate Change Impacts on the Water Resources of American Indians and Alaska Natives in the US. *Climatic Change,* 120(3), 569-584. https://doi.org/10.1007/s10584-013-0852-y

This paper provides an overview of climate change impacts on tribal water resources and the subsequent cascading effects on the livelihoods and cultures of American Indians and Alaska Natives living on tribal lands in the U.S. A hazards and vulnerability framework for understanding these impacts is first presented followed by context on the framework components, including climate, hydrologic, and ecosystem changes (i.e. hazards) and tribe-specific vulnerability factors (socioeconomic, political, infrastructural, environmental, spiritual and cultural), which when combined with hazards lead to impacts. Next regional summaries of impacts around the U.S. are discussed. Although each tribal community experiences unique sets of impacts because of their individual history, culture, and geographic setting, many of the observed impacts are common among different groups and can be categorized as impacts on-1) water supply and management (including water sources and infrastructure), 2) aquatic species important for culture and subsistence, 3) ranching and agriculture particularly from climate extremes (e.g., droughts, floods), 4) tribal sovereignty and rights associated with water resources, fishing, hunting, and gathering, and 5) soil quality (e.g., from coastal and riverine

erosion prompting tribal relocation or from drought-related land degradation). The paper finishes by highlighting potentially relevant research questions based on the five impact categories.

Ekstrom, J. A., Suatoni, L., Cooley, S. R., Pendleton, L. H., Waldbusser, G. G., Cinner, J. E., . . . Portela, R. (2015). Vulnerability and Adaptation of Us Shellfisheries to Ocean Acidification. *Nature Climate Change,* 5(3), 207-214. https://doi.org/10.1038/nclimate2508

Ocean acidification is a global, long-term problem whose ultimate solution requires carbon dioxide reduction at a scope and scale that will take decades to accomplish successfully. Until that is achieved, feasible and locally relevant adaptation and mitigation measures are needed. To help to prioritize societal responses to ocean acidification, we present a spatially explicit, multidisciplinary vulnerability analysis of coastal human communities in the United States. We focus our analysis on shelled mollusc harvests, which are likely to be harmed by ocean acidification. Our results highlight US regions most vulnerable to ocean acidification (and why), important knowledge and information gaps, and opportunities to adapt through local actions. The research illustrates the benefits of integrating natural and social sciences to identify actions and other opportunities while policy, stakeholders and scientists are still in relatively early stages of developing research plans and responses to ocean acidification.

Frisch, L. C., Mathis, J. T., Kettle, N. P., & Trainor, S. F. (2015). Gauging Perceptions of Ocean Acidification in Alaska. *Marine Policy,* 53, 101-110. https://doi.org/10.1016/j.marpol.2014.11.022

While ocean acidification (OA) poses a significant threat to ocean-related ecosystems and communities reliant on marine fisheries, aquaculture, and coral reef systems, limited public understanding and awareness can prevent coastal regions from being able to adequately assess the need for OA adaptation or mitigation. This study assessed public understanding of OA and how social and demographic factors influence the public's concern for OA. The analysis was based on 311 questionnaires from full-time Alaska residents. The results showed that most Alaskans self-reported to have a basic awareness of OA, and subsequently were able to recognize that CO2 emissions related to human activity are the dominant driver of changing ocean conditions. However, there was a low recognition of how natural variability in the marine environment affects OA, and most respondents were not very confident in their understanding of OA-related science. Moreover, even though many communities in Alaska are reliant on commercial and subsistence fishing activities, the respondents had a low awareness of fisheries-related OA risk. Given the ongoing debate associated with climate change research, evaluating CO2 mitigation efforts through the perspective of OA could give individuals an unbiased way to assess the pros and cons of more intensive efforts to curb CO2 emissions. Furthermore, using OA communication to enhance the understanding of how natural variability influences OA around the state and the potential economic implications for Alaska fisheries would help residents and stakeholders make informed decisions when considering fisheries management plans, food security, and job diversity as OA intensifies. Solidifying the understanding that any reduction in pH and intensification of OA can have implications for marine species that are irreversible on human timescales will reinforce not only that OA is an immediate concern, but also the importance of taking action now.

Hiddink, J. G., Kaiser, M. J., Sciberras, M., McConnaughey, R. A., Mazor, T., Hilborn, R., . . . Pinto, R. (2020). Selection of Indicators for Assessing and Managing the Impacts of Bottom Trawling on Seabed Habitats. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.13617

1. Bottom trawl fisheries are the most widespread source of anthropogenic physical disturbance to seabed habitats. Development of fisheries-, conservation- and ecosystem-based management strategies requires the selection of indicators of the impact of bottom trawling on the state of benthic biota. Many indicators have been proposed, but no rigorous test of a range of candidate indicators against nine commonly agreed criteria (concreteness, theoretical basis, public awareness, cost, measurement, historical data, sensitivity, responsiveness, specificity) has been performed.

2. Here, we collated data from 41 studies that compared the benthic biota in trawled areas with those in control locations (that were either not trawled or trawled infrequently), examining seven potential indicators (numbers and biomass for individual taxa and whole communities, evenness, Shannon–Wiener diversity and species richness) to assess their performance against the set of nine criteria.

3. The effects of trawling were stronger on whole-community numbers and biomass than for individual taxa. Species richness was also negatively affected by trawling but other measures of diversity were not. Community numbers and biomass met all criteria, taxa numbers and biomass and species richness satisfied most criteria, but evenness and Shannon–Wiener diversity did not respond to trawling and only met few criteria, and hence are not suitable state indicators of the effect of bottom trawling.

4. Synthesis and applications . An evaluation of each candidate indicator against a commonly agreed suite of desirable properties coupled with the outputs of our meta-analysis showed that whole-community numbers of individuals and biomass are the most suitable indicators of bottom trawling impacts as they performed well on all criteria. Strengths of these indicators are that they respond strongly to trawling, relate directly to ecosystem functioning and are straightforward to measure. Evenness and Shannon–Wiener diversity are not responsive to trawling and unsuitable for the monitoring and assessment of bottom trawl impacts.

Hourigan, T. F. (2015). A Strategic Approach to Address Fisheries Impacts on Deep-Sea Coral Ecosystems. In *Interrelationships between Corals and Fisheries.* S. A. Bortone (Ed.), (pp. 127-145) Retrieved from https://www.routledge.com/Interrelationships-Between-Corals-and-Fisheries/Bortone/p/book/9780367378547

No abstract available.

Mathis, J. T., Cooley, S. R., Lucey, N., Colt, S., Ekstrom, J., Hurst, T., . . . Feely, R. A. (2015). Ocean Acidification Risk Assessment for Alaska's Fishery Sector. *Progress in Oceanography,* 136, 71-91. https://doi.org/10.1016/j.pocean.2014.07.001

The highly productive fisheries of Alaska are located in seas projected to experience strong global change, including rapid transitions in temperature and ocean acidification-driven changes in pH and other chemical parameters. Many of the marine organisms that are most intensely affected by ocean acidification (OA) contribute substantially to the state's commercial fisheries and traditional subsistence way of life. Prior studies of OA's potential impacts on human communities have focused only on possible

direct economic losses from specific scenarios of human dependence on commercial harvests and damages to marine species. However, other economic and social impacts, such as changes in food security or livelihoods, are also likely to result from climate change. This study evaluates patterns of dependence on marine resources within Alaska that could be negatively impacted by OA and current community characteristics to assess the potential risk to the fishery sector from OA. Here, we used a risk assessment framework based on one developed by the Intergovernmental Panel on Climate Change to analyze earth-system global ocean model hindcasts and projections of ocean chemistry, fisheries harvest data, and demographic information. The fisheries examined were: shellfish, salmon and other finfish. The final index incorporates all of these data to compare overall risk among Alaska's federally designated census areas. The analysis showed that regions in southeast and southwest Alaska that are highly reliant on fishery harvests and have relatively lower incomes and employment alternatives likely face the highest risk from OA. Although this study is an intermediate step toward our full understanding, the results presented here show that OA merits consideration in policy planning, as it may represent another challenge to Alaskan communities, some of which are already under acute socio-economic strains.

Matta, M. E., Tribuzio, C. A., Ebert, D. A., Goldman, K. J., & Gburski, C. M. (2017). Age and Growth of Elasmobranchs and Applications to Fisheries Management and Conservation in the Northeast Pacific Ocean. In *Northeast Pacific Shark Biology, Research and Conservation, Pt A.* S. E. Larson & D. Lowry (Eds.), (Vol. 77, pp. 179-220) https://doi.org/10.1016/bs.amb.2017.06.002

In addition to being an academic endeavour, the practical purpose of conducting age and growth studies on fishes is to provide biological data to stock assessment scientists and fisheries managers so they may better understand population demographics and manage exploitation rates. Age and size data are used to build growth models, which are a critical component of stock assessments. Though age determination of elasmobranchs in the northeast Pacific Ocean (NEP) began in the 1930s, the field has evolved substantially in recent years, allowing scientists to incorporate age data into assessments for more species than ever before. Owing to the highly diverse biology of this group of fishes, each species has its own set of challenges with regard to age determination. Age determination methods typically rely on semicalcified hard structures that form regular growth patterns; however, the structure selected and preparation method used is often species specific. New staining techniques have improved the ability to assess age and improve ageing precision for some species, and advances in microchemical methods have allowed for independent means of estimating age and validating age determination accuracy. Here we describe current age determination methods for NEP elasmobranchs. While the library of available techniques is increasing, there are still some NEP species for which reliable ageing methods have yet to be defined; we discuss these challenges and potential avenues of future research. Finally, we conclude by describing how age estimates are used in growth models and subsequently in stock assessments of selected NEP elasmobranchs.

McConnaughey, R. A., Hiddink, J. G., Jennings, S., Pitcher, C. R., Kaiser, M. J., Suuronen, P., . . . Hilborn, R. (2019). Choosing Best Practices for Managing Impacts of Trawl Fishing on Seabed Habitats and Biota. *Fish and Fisheries,* 21(2), 319-337. https://doi.org/10.1111/faf.12431

Bottom trawling accounts for almost one quarter of global fish landings but may also have significant and unwanted impacts on seabed habitats and biota. Management measures and voluntary industry actions can reduce these impacts, helping to meet sustainability objectives for fisheries, conservation and environmental management. These include changes in gear design and operation of trawls, spatial controls, impact quotas and effort controls. We review nine different measures and actions and use published studies and a simple conceptual model to evaluate and compare their performance. The risks and benefits of these management measures depend on the extent to which the fishery is already achieving management objectives for target stocks and the characteristics of the management system that is already in place. We offer guidance on identifying best practices for trawl-fisheries management and show that best practices and their likelihood of reducing trawling impacts depend on local, national and regional management objectives and priorities, societal values and resources for implementation. There is no universal best practice, and multiple management measures and industry actions are required to meet sustainability objectives and improve trade-offs between food production and environmental protection.

Miyamoto, M., & Kiyota, M. (2017). Application of Association Analysis for Identifing Indicator Taxa of Vulnerable Marine Ecosystems in the Emperor Seamounts Area, North Pacific Ocean. *Ecological Indicators,* 78, 301-310. https://doi.org/10.1016/j.ecolind.2017.03.028

Reflecting the growing interest in ecosystem-based fishery management, deep sea bottom fisheries are being called upon to minimize adverse impacts on vulnerable marine ecosystems (VMEs), communities of marine organisms susceptible to anthropogenic disturbance. Many fishery management organizations have introduced indicator-based management measures for VME conservation, such as encounter protocols, in which VME indicator species and bycatch weight thresholds are assigned. If the bycatch amount of the indicator species in a fishing operation exceeds the predetermined threshold, the fishing vessel halts the fishing operation and moves a certain distance away from the encounter point. However, the representativeness of VME indicator taxa has not been evaluated quantitatively. In this study, we analyzed the co-occurrence of benthic animals collected by scientific bottom tow-net surveys in the Emperor Seamounts area, North Pacific Ocean, to characterize benthic communities in the area and to examine the ability of six candidate indicator taxa (gorgonians, Alcyonacea excluding gorgonians, Antipatharia, Scleractinia, Stylasterina, and Porifera) to represent the local benthic communities. Cluster analysis revealed four clusters of benthic communities, each of which includes both sessile and mobile benthos: (1) gorgonians-Scleractinia community with many mobile benthic taxa and Pisces; (2) Porifera-Stylasterina community with Polychaeta and Bivalvia; (3) Antipatharia-Alcyonacea (excluding gorgonians) community with Cephalopoda; and (4) Zoanthidea-Pennatulacea community with Crinoidae and Holothuroidea. The first cluster included the largest number of taxa and showed strong tendencies of co-occurrence, possibly reflecting the habitat-providing function of gorgonians and Scleractinia as well as the common environmental preferences of filter feeders, which constitute major components of the cluster. We used association analysis to identify VME indicator species in the study area. Association analysis reveals relationships between items in the form of association rules, where the occurrence of an "antecedent" {A} implies the co-occurrence of a "consequent" {B}; {A} and {B} contain items, in this case, taxa. Association analysis applied to the co-occurrence data extracted many effective association

rules that include gorgonians or Scleractinia as the consequent and many benthic taxa as antecedents. These results demonstrate that gorgonians and Scleractinia are effective VME indicators in the study area because they co-occur with many other benthic animals and represent VME characteristics such as functional significance as habitat and structural complexity as well as fragility and slow recovery from physical damage.

Moffitt, E. A., Punt, A. E., Holsman, K., Aydin, K. Y., Ianelli, J. N., & Ortiz, I. (2016). Moving Towards Ecosystem-Based Fisheries Management: Options for Parameterizing Multi-Species Biological Reference Points. *Deep-Sea Research Part II-Topical Studies in Oceanography,* 134, 350-359. https://doi.org/10.1016/j.dsr2.2015.08.002

Multi-species models can improve our understanding of the effects of fishing so that it is possible to make informed and transparent decisions regarding fishery impacts. Broad application of multi-species assessment models to support ecosystem-based fisheries management (EBFM) requires the development and testing of multi-species biological reference points (MBRPs) for use in harvest-control rules. We outline and contrast several possible MBRPs that range from those that can be readily used in current frameworks to those belonging to a broader EBFM context. We demonstrate each of the possible MBRPs using a simple two species model, motivated by walleye pollock (Gadus chalcogrammus) and Pacific cod (Gadus macrocephalus) in the eastern Bering Sea, to illustrate differences among methods. The MBRPs we outline each differ in how they approach the multiple, potentially conflicting management objectives and trade-offs of EBFM. These options for MBRPs allow multi-species models to be readily adapted for EBFM across a diversity of management mandates and approaches.

Sakakibara, C. (2009). 'No Whale, No Music': Inupiaq Drumming and Global Warming. *Polar Record,* 45(235), 289-303. https://doi.org/10.1017/s0032247408008164

This article explores how climate change has recently influenced the Inupiaq Cultural identity as the people of the whales. Their traditional whaling cycle reveals strong indivisibility of music, emotions, and place based human identity. To illustrate such integrity of the Inupiat and their culturally critical bowhead whale (Balaena mysticetus), a search was made for specific ways in which climate change influences Inupiaq spiritual and physical ties with the whale in relation to traditional music making. Traditionally, the Inupiat say that it is the whale who brings them music, thus no whale harvest means no music production. However, when the environment is less predictable, the homeland eroded, place based songs gone, and human-whale integrity threatened, how specifically are these changes manifested in the Inupiat-whale relationship? Providing detailed descriptions of 2005-2006 nalukataq (midsummer whale feasts), this article examines how contemporary Inupiat respond to environmental changes in the emotional and cultural dimensions through their music making.

Marine Culture Heritage

Tornfelt, E. E., & Burwell, M. (1992). *Shipwrecks of the Alaska Shelf and Shore.* Minerals Management Service. Retrieved from https://www.worldcat.org/title/shipwrecks-of-the-alaskan-shelf-and-shore/oclc/25742605

OCS Report MMS 92-0002 is a comprehensive list of shipwrecks that have occurred in Alaska from earliest Russian times (1741) to the pre-World War II era compiled from an extensive literature search. The shipwreck list is segregated by MMS, Alaska OCS Region lease-sale planning area. This report builds on the scholarship of previous shipwreck researchers and maritime historians but adds a new dimension: a thorough cross-checking for accuracy and consistency of individual wreck accounts against all the sources of record. The report summarizes the historic context of Alaskan shipwrecks and provides a general discussion of shipwreck causes and locations. Section VI of the report presents a series of six tables containing the basic data of a ship loss: OCS planning area location, vessel name, vessel type, date of wreck, location of wreck (not in latitude/longitude), cause of wreck, and other pertinent information important for vessel identification. Report data will assist the historic archaeologist and those involved in cultural resource management.

Physics

Marin-Moreno, H., Sahoo, S. K., & Best, A. I. (2017). Theoretical Modeling Insights into Elastic Wave Attenuation Mechanisms in Marine Sediments with Pore-Filling Methane Hydrate. *Journal of Geophysical Research-Solid Earth,* 122(3), 1835-1847. https://doi.org/10.1002/2016jb013577

The majority of presently exploitable marine methane hydrate reservoirs are likely to host hydrate in disseminated form in coarse grain sediments. For hydrate concentrations below 25-40%, disseminated or pore-filling hydrate does not increase elastic frame moduli, thus making impotent traditional seismic velocity-based methods. Here, we present a theoretical model to calculate frequency-dependent P and S wave velocity and attenuation of an effective porous medium composed of solid mineral grains, methane hydrate, methane gas, and water. The model considers elastic wave energy losses caused by local viscous flow both (i) between fluid inclusions in hydrate and pores and (ii) between different aspect ratio pores (created when hydrate grows); the inertial motion of the frame with respect to the pore fluid (Biot's type fluid flow); and gas bubble damping. The sole presence of pore-filling hydrate in the sediment reduces the available porosity and intrinsic permeability of the sediment affecting Biot's type attenuation at high frequencies. Our model shows that attenuation maxima due to fluid inclusions in hydrate are possible over the entire frequency range of interest to exploration seismology (1-10(6)Hz), depending on the aspect ratio of the inclusions, whereas maxima due to different aspect ratio pores occur only at sonic to ultrasound frequencies (10(4)-10(6)Hz). This frequency response imposes further constraints on possible hydrate saturations able to reproduce broadband elastic measurements of velocity and attenuation. Our results provide a physical basis for detecting the presence and amount of pore-filling hydrate in seafloor sediments using conventional seismic surveys.

Seymour, R. J. (2011). Evidence for Changes to the Northeast Pacific Wave Climate. *Journal of Coastal Research,* 27(1), 194-201, 198. https://doi.org/10.2112/JCOASTRES-D-09-00149.1

A large database of deep water wave buoy measurements over a 24-year period is created for four regions comprising the West Coast of the United States. The regional monthly mean significant wave height (MMSWH) is selected as the defining wave climate parameter and averaging multiple data sources within a region is found to significantly reduce data gaps. Two 12-year periods are compared, showing significant temporal variability but high correlation between regions, allowing the further collapse of the data to a northern and a southern region. Correlations between MMSWH records with three global-scale climate indices are investigated and only the North Pacific Index (NPI), a measure of atmospheric pressure in the Gulf of Alaska, shows strong correlation. The Multivariate ENSO Index (MEI) is less correlated and the Pacific Decadal Index (PDO), which is a measure of ocean surface temperature, provides no significant correlation. A method for displaying multiple correlations is developed that shows the mean of all MMSWH records that occur at unique temporal combinations of two climate indices. The graphics depicting the mean wave height as a function of NPI and MEI for the two 12-year periods are shown to be very instructive in establishing why the two periods are so different. On the contrary, the same procedure with PDO substituted for MEI produces uniform distributions with little interpretive value. Century-scale variation in the climate indices is investigated, and significant linear trends are found for NPI and MEI, both consistent with causing increases in mean wave energy in these regions. Causal relationships for the observed correlations are discussed, and conclusions are reached indicating that global warming is a likely contributor to observed increases in wave intensity in the North Pacific.