Aquaculture Interactions with Endangered Species

Bibliography

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Background & Scope

This bibliography focuses on aquaculture interactions with ESA-listed species and protected resource species, with an emphasis on research conducted from 2005 forward. The references herein attempt to understand the potential risks that aquaculture may pose to protected resource species including whales, sea turtles, dolphins, porpoises, pinnipeds (e.g., seals and sea lions), and other marine species that are listed as endangered under ESA (e.g., Atlantic salmon, Atlantic sturgeon). This includes any reported interaction including physical, behavioral, or other, from both domestic and international aquaculture operations. It is organized alphabetically by author.

Section I: Aquaculture

This section highlights all research found that mentioned aquaculture and marine mammal interactions and policies surrounding their environmental impact.

Section II: Fisheries

This section highlights the impact of fisheries on ESA species, especially the oceanic whitetip shark, either as bycatch or entanglement.

Section III: Mixed

This section highlights a mix of both aquaculture and fisheries impacts.

Sources Reviewed

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

Section I: Aquaculture

A. Finfish Aquaculture

Alston, D. E., Cabarcas, A., Capella, J., Benetti, D. D., Keene-Meltzoff, S., Bonilla, J., & Cortés, R. (2005). *Environmental and Social Impact of Sustainable Offshore Cage Culture Production in Puerto Rican Waters.* Final Report to the National Oceanic and Atmospheric Administration, Contract NA16RG1611. Retrieved from http://archive.gulfcouncil.org/Beta/GMFMCWeb/Aquaculture/Final%20Report%20UPRM%20Sea%20Grant.pdf

This project was the first large-scale environmental evaluation of open-ocean submerged cages in the Caribbean to assess the technological feasibility and possible environmental effects involved in adapting cutting-edge technology to culture Lutjanus analis (mutton snapper) and Rachycentron canadum (cobia) in submerged open-ocean cages in Puerto Rico. The study provides "base-line" information that will be useful as the open-ocean aquaculture industry expands. The information obtained from this project provides a basis for Puerto Rican authorities and the private aquaculture industry to evaluate the feasibility of this operation. This project used the "shotgun" approach to select the most important water and sediment quality variables and their effects on the local environment. The study determined if the cages served as fish aggregation devices (FADs), the concentrations of nutrients in the water and sediment; effects on the benthic community, and the rate of biofouling growth. Currents were monitored at the control site located 375 m from the cage site. Results indicated no evidence of anaerobic sediments beneath the cages, inorganic nitrogen near the cages was similar to background levels, macroinvertebrates populations and sediment were only affected directly beneath the cages just before harvest when feeding rates were highest. Many wild fish (40 species) were attracted to the cages. As more cages are installed, especially if stocking rates are increased, focus should be made on the sediment, especially just before harvest; possible effects on distant coral reefs, and to determine the positive or negative interactions by having wild fish attracted to the cages. Because biofouling grows rapidly (and needs to be cleaned biweekly), it should be evaluated to remove nutrients from the water column to ameliorate effects on the environment. Knowledgeable residents near the project had a positive attitude concerning the open-aquaculture project; however, 55% of the members of the general community of Culebra did not have general or specific knowledge about the open-ocean aquaculture project and did not have specific information about the advantages or disadvantages in relation to the impact on economy, fishing, fishermen, or community life. It is important to increase their knowledge by developing an informative program. The extension phase of this research indicated no significant differences to the body of the research.

Bonizzoni, S., Furey, N. B., Pirotta, E., Valavanis, V. D., Würsig, B., & Bearzi, G. (2014). Fish Farming and Its Appeal to Common Bottlenose Dolphins: Modelling Habitat Use in a Mediterranean Embayment. *AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS, 24*(5), 696-711 https://doi.org/10.1002/aqc.2401

1. Common bottlenose dolphins Tursiops truncatus interact with fish farms in the Mediterranean Sea. These interactions were investigated in a Greek bay by incorporating multiple geographic, bathymetric, oceanographic, and anthropogenic variables.
2. Generalized additive models (GAMs) and generalized estimation equations (GEEs) were used to describe dolphin presence. Visual surveys were conducted over 2909 km under favourable viewing

conditions that included 54 dolphin group follows for 457 km. Sea surface temperature (SST) and chlorophyll-a (Chl-a) data were obtained from remote sensing imagery, and distances to sources of human influences including fish farms, a ferronickel plant, and a slag disposal area were calculated within a geographic information system (GIS).
3. Bottlenose dolphins were encountered mainly in the south-eastern portion of the study area, and occurrence was not clearly related to SST and Chl-a, nor the ferro-nickel plant or nearby slag disposal area.
4. Dolphin occurrence generally increased within 20 km offish farms, with four farms and dolphins displaying a positive relationship, seven no clear relationship, and two a negative one.
5. While it is likely that uneaten food and other detritus attract dolphin prey, individual farms (or clusters of farms) clearly had a different appeal. The proximity of the ferro-nickel plant and slag disposal area to 'attractive' fish farms could compromise dolphin health, but physiological data are unavailable.
6. The modelling of multiple variables allowed for a description of dolphin habitat use and attraction to some fish farms. More such data analysed in similar manner would be instructive for other areas where marine mammals and fish farms co-occur.

Canada. Department of Fisheries and Oceans. (2011). *Regulating and Monitoring British Columbia's Marine Finfish Aquaculture Facilities.* F. a. O. Canada.Ottawa, ON. Retrieved from http://publications.gc.ca/site/eng/9.834882/publication.html

In British Columbia, the aquaculture industry is primarily regulated and managed by Fisheries and Oceans Canada (DFO). DFO began licensing aquaculture facilities in B.C. in December 2010. Between 2010 and 2014, DFO licensed up to 123 marine finfish aquaculture facilities ("fish farms") with a total combined peak production of over 280,000 metric tonnes of fish. Generally, about half of these facilities have fish on site at any given time. A list of all current licence holders for marine finfish aquaculture is available on the DFO website: http://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/index-eng.html.

Chenoweth, E. M., Straley, J. M., McPhee, M. V., Atkinson, S., & Reifenstuhl, S. (2017). Humpback Whales Feed on Hatchery-Released Juvenile Salmon. *R Soc Open Sci, 4*(7), 170180 https://doi.org/10.1098/rsos.170180

Humpback whales are remarkable for the behavioural plasticity of their feeding tactics and the diversity of their diets. Within the last decade at hatchery release sites in Southeast Alaska, humpback whales have begun exploiting juvenile salmon, a previously undocumented prey. The anthropogenic source of these salmon and their important contribution to local fisheries makes the emergence of humpback whale predation a concern for the Southeast Alaska economy. Here, we describe the frequency of observing humpback whales, examine the role of temporal and spatial variables affecting the probability of sighting humpback whales and describe prey capture behaviours at five hatchery release sites. We coordinated twice-daily 15 min observations during the spring release seasons 2010-2015. Using logistic regression, we determined that the probability of occurrence of humpback whales increased after releases began and decreased after releases concluded. The probability of whale occurrence varied among release sites but did not increase significantly over the 6 year study period. Whales were reported to be feeding on juvenile chum, Chinook and coho salmon, with photographic and video records of whales feeding on coho salmon. The ability to adapt to new prey sources may be key to sustaining their population in a changing ocean.

Clement, D. (2013). Effects on Marine Mammals. Chapter 4. In *Literature Review of Ecological Effects of Aquaculture.*: Ministry for Primary Industries. Retrieved from https://www.mpi.govt.nz/dmsdocument/3752-literature-review-of-ecological-effects-of-aquaculture-chapter-4-effects-on-marine-mammals

Interactions between marine mammals and aquaculture result from an overlap between the spatial location of the aquaculture facilities and the habitats and/or migration routes of the marine mammal species. Such interactions have been relatively minor issues with New Zealand farms to date given the small scale of the current finfish aquaculture industry here. However, overseas experience with these issues (e.g., Kemper & Gibbs 2001; Kemper et al. 2003; Heinrich & Hammond 2006) suggests the potential for adverse effects still exists with continued growth in both marine mammal populations and larger scale, offshore finfish farm developments. Several overseas studies (Würsig & Gailey 2002; Kemper et al. 2003; Wright 2008) have characterised the possible interactions, which include: • competition for space (habitat modification or exclusion); • potential for entanglement; • underwater noise disturbance; • attraction to artificial lighting; • possible flow-on effects due to alterations in trophic pathways.

Crecco, C. (2013). *A Policy Analysis of Open Ocean Aquaculture in the Hawaiian Islands Humpback Whale National Marine Sanctuary.* (Masters), University of Miami, Open Access Theses. Retrieved from https://scholarlyrepository.miami.edu/oa_theses/420

An exponentially growing world population has put human innovation and ingenuity to the test. Over the past few decades, our ability to develop technology for the purpose of adjusting to an increasing demand for natural resources has shown our capacity for growth and adaptation. However, how much growth can be sustained to solve problems related to food security? Aquaculture has become a viable option to combat food scarcity issues. Aquaculture that takes place offshore is a relatively new field of study that warrants further investigation. As research continues to evaluate environmental effects from offshore aquaculture, it must be tied with social considerations that come with food production and security. It is also important to note that aquaculture developments should be scrutinized on a case-by-case basis because projects vary considerably in terms of inputs, business plans, management, and can range from intensive to extensive systems. This study addresses some of the major legal frameworks offshore aquaculture practitioners must comply with if such developments were to occur within marine protected waters, specifically those of the Hawaiian Islands Humpback Whale National Marine Sanctuary. The main goal of the sanctuary is to promote the conservation of the humpback whales. Uncertainty regarding effects on certain marine mammals has yet to be fully investigated. Thus, further studies are needed to assess the compatibility of offshore aquaculture with biological conservation. This policy analysis is also accompanied with a spatial analysis to better understand relevant statutes and agency jurisdictions.

DeCew, J., Celikkol, B., Baldwin, K., Chambers, M., Irish, J., Swift, M. R., & Tsukrov, I. (2012). Assessment of a Mooring System for Offshore Aquaculture. *World Aquaculture, 43*(3), 32-36 Retrieved from https://www.was.org/Magazine/Contents.aspx?Id=43

A submerged grid mooring was deployed for seven years at an exposed site off the northeast coast of the United States. During that time, a series of engineering and biological studies were conducted, advancing the state-of-the-art and science of offshore aquaculture. The mooring grid required minimal maintenance over the deployment duration. The submerged platform survived numerous storms and other extreme environmental conditions. The pretension mooring arrangement and depth below the surface minimized wear betwe components from relati motion. In addition, no marine mammal entanglements were observed during the mooring deployment, although minke and fin whales were seen nearby.

Department of Fisheries Western Australia. (2017). *Mid West Aquaculture Development Zone Marine Fauna Interaction Management Plan.* Retrieved from http://www.fish.wa.gov.au/Documents/Aquaculture/mid_west_aqua_dev_zone_marine_fauna_interaction_plan.pdf

The Marine Fauna Interaction Management Plan (MFIMP) is designed to achieve the Environmental Protection Authority's Objective for Marine Fauna: "To maintain the diversity, geographic distribution and viability of fauna at the species and population levels" and the proposal specific objective that the MWADZ will have no adverse impact on the viability and persistence of the Abrolhos Islands populations of Australian sea lions or threatened sea birds. More specifically the MFIMP provides a practical set of management and mitigation measures to address potential impacts to marine fauna. This MFIMP is based on a combination of best available data for marine fauna species found in the Houtman Abrolhos Islands and best practice aquaculture measures used in other jurisdictions.

Diaz Lopez, B. (2017). Temporal Variability in Predator Presence around a Fin Fish Farm in the Northwestern Mediterranean Sea. *Marine Ecology-an Evolutionary Perspective, 38*(1) https://doi.org/10.1111/maec.12378

Recently, aquaculture has generated worldwide interest as a result of the overexploitation of wild stocks combined with a growing international demand for fish and seafood products. Wild fish attracted to the marine fish farms, together with the presence of the farmed fish, are powerful attractants to predators that normally feed on similar or identical fish stocks in nature. This 9-year study describes for the first time in Mediterranean waters the temporal variability of mammalian and avian predators in a coastal fin fish farm. In all, 99months (1062days during 36 consecutive seasons) were spent in the field. By examining the results of this study, it is clear that species as seagulls, shags, bottlenose dolphins and grey herons (considered to cause economic loss in aquaculture owing to direct predation) interact regularly with the fish farm. Although bottlenose dolphins and grey herons were not the most important of all predator species, predatory interactions with the fish farm occurred with what seems to be increasing regularity. Another result observed is the possible bottlenose dolphins' attraction caused by the harvesting operations in the fish farm. The fish farm offers an alternative food source for predators; hunting at fish farms usually requires less effort on the part of the predator, and becomes a more attractive option than hunting wild fish over wide ranges. During the period of this study, individually identified dolphins feeding were regularly observed feeding on discarded fish from fish farm workers during harvesting operations, supporting the possibility that some individuals are habituated to this food supply. Based on the evidence presented in this paper, it is recommended that strategies for the management of both the aquaculture industry and marine mammal populations should take the results of this study into consideration.

Díaz López, B. (2006). Bottlenose Dolphin (Tursiops Truncatus) Predation on a Marine Fin Fish Farm: Some Underwater Observations. *Aquatic Mammals, 32*(3), 305 https://doi.org/10.1578/AM.32.3.2006.305

This paper reports on the results of underwater observations of bottlenose dolphin feeding behaviour in a marine fin fish farm on the Sardinian coast in Italy from 2000 to 2005. During the study period, 178 underwater encounters were noted during 79 sightings of bottlenose dolphins at a fish farm. Total time spent underwater in the presence of dolphins was 284 min, with a mean encounter duration of 1.6 ± 1.3 min. Bottlenose dolphins were primarily observed hunting both schooling and solitary prey around the fish farm cages, using seven cooperative and individual feeding strategies throughout the water column. The underwater observations suggest that the use of different feeding strategies is consistent with the hypothesis that bottlenose dolphins apply common decision rules in relation to prey availability, resulting in the use of different foraging techniques. The observed frequency of the feeding strategies employed by dolphins preying directly on farmed fish could be worrisome for aquaculture.

Díaz López, B. (2012). Bottlenose Dolphins and Aquaculture: Interaction and Site Fidelity on the North-Eastern Coast of Sardinia (Italy). *Marine Biology, 159*(10), 2161-2172 https://doi.org/10.1007/s00227-012-2002-x

Owing to the worldwide growth of aquaculture over the last years, new habitats have been created through the supplement of nutrients. This addition of nutrients affects the whole marine food web, resulting in predator species such as bottlenose dolphins becoming attracted to these areas. During this 5-year-long study that was carried out along the north-eastern coast of Sardinia (Italy), bottlenose dolphin's history of exposure to aquaculture perturbations and their effects was documented. The interaction with a fish farm was assessed by studying the site fidelity, group dynamics, and seasonal and yearly occurrence. In all, 1,838 hours were spent in the field. Behavioural observations showed that the predominant activity (89 % of the time) in the fish farm was foraging (predation and depredation). The occurrence of bottlenose dolphins appeared to be related with the seasons and with the fish farm harvesting operations. Thus, the peak dolphin occurrence in the fish farm area throughout Fall coincides with the period in which they spend most of their time foraging. A relatively small community remained resident interacting with the fish farm over a long period of time. Hence, these individuals gained intimate knowledge on how to capitalize on the fish farm industry. This heterogeneity in site fidelity and residence patterns is highly relevant when coastal management initiatives are considered.

Díaz López, B., & Bernal Shirai, J. A. (2007). Bottlenose Dolphin (Tursiops Truncatus) Presence and Incidental Capture in a Marine Fish Farm on the North-Eastern Coast of Sardinia (Italy). *Journal of the Marine Biological Association of the United Kingdom, 87*(1), 113-117 https://doi.org/10.1017/s0025315407054215

On the north-eastern coast of Sardinia, from November 2004 to January 2006, the first attempt in the Mediterranean basin to obtain information on encounter rate, group size and incidental capture of bottlenose dolphins in a marine fish farm was assessed, combining direct observations from fish farm boats with photoidentification studies. During 15 months of research, 79 d (65.3% of the total monitored days) were spent in direct observation of 146 groups of bottlenose dolphins around the fish

farm cages. There was a peak in bottlenose dolphin presence during winter. Photographs were taken in the fish farm area during 79 encounters on 61 different days (totalling 34 marked individuals). The regular occurrence of some dolphins suggests individual preferences for the fish farm area. The incidental bottlenose dolphin capture observed in large, loose predator nets (1 dolphin per month) is cause for concern, as it is questionable whether or not the bottlenose dolphins in the area can sustain incidental capture of this magnitude. The information gained from this study shows the necessity for further regulations to be established, both in the use of predator nets and management of marine fish farms.

Díaz López, B., Bunke, M., & Bernal Shirai, J. A. (2008). Marine Aquaculture Off Sardinia Island (Italy): Ecosystem Effects Evaluated through a Trophic Mass-Balance Model. *Ecological Modelling, 212*(3-4), 292-303 https://doi.org/10.1016/j.ecolmodel.2007.10.028

Marine aquaculture is an important growing worldwide industry. An ecosystem approach to study the effects of aquaculture on the Aranci Bay (Sardinia, Italy) was implemented by using a trophic mass-balance model in order to estimate the potential effects of finfish aquaculture and, therefore, to identify the species playing a key-role in ecosystem. Additionally, this study was used to evaluate the conflict between top predators and aquaculture. Mass-balance models were built using Ecopath software to characterize and compare the present state of the ecosystem versus a reconstructed past model representing the bay before the start of aquaculture activities. This modelling approach to the study of the fish farm activities in Aranci Bay has shown its appropriateness to describe the modifications induced, at an ecosystem level, by the nutrient loading into the area. Increased nutrient loading into the fish farm area may result in greater biological activity and may induce a strong coupling between the pelagic and benthic subsystems. Based on the results, the possible effect of top predators in the fish farm activities is not substantial. Furthermore, the use of mass-balance models can provide important additional information, complementary to the normal environmental assessment impact studies, before starting fish farm activities in an area.

Díaz López, B., MARINI, L., & POLO, F. (2005). The Impact of a Fish Farm on a Bottlenose Dolphin Population in the Mediterranean Sea. *Thalassas, 21*(2), 65-70 Retrieved from http://thalassas.webs.uvigo.es/thalassas_marco%20principal.htm

The increasing presence of aquaculture in coastal waters calls for a better understanding of its environmental effects. Despite a number of studies focusing on the impact of aquaculture on marine mammals, the interaction between common bottlenose dolphins (Tursiops truncatus) with fish farms has been the subject of few investigations (Watson-Capps and Mann, 2005). In this paper we report the results of our research on the interaction between bottlenose dolphins with a fish farm on the Sardinian coast (Italy) from 1991 to 2004. We divided the study area latitudinally into two sections: southern (Gulf of Olbia) and northern (Gulf of Congianus). In the southern section in November 1995 the plant of a small fish farm was completely increased and transformed. Data were pooled into two periods (1991 to 1994 and 1999 to 2004). All years but 2003 were sampled. During the first and second research periods the same land-based searches were conducted under fair to excellent weather conditions. A total of 255 sightings were carried out in over 1320 hours of research of dolphins: in the first period 52 sightings were recorded in 517 hours of research, in the second period 203 sightings were realized in 803 hours of research. The presence of bottlenose dolphins changed dramatically between the two research periods. Observations of dolphins indicate that are mainly present in the southern area during the second period.

The preference for the southern section seemed to be consistent after the transformation of the fish farm, since 1995.

Ernst, W., Jackman, P., Doe, K., Page, F., Julien, G., Mackay, K., & Sutherland, T. (2001). Dispersion and Toxicity to Non-Target Aquatic Organisms of Pesticides Used to Treat Sea Lice on Salmon in Net Pen Enclosures. *Marine Pollution Bulletin, 42*(6), 432-443 https://doi.org/10.1016/s0025-326x(00)00177-6

Pesticides are used extensively in the finfish aquaculture industry to control sea lice infestations on farmed salmon. The most prevalent method of use is to enclose a net pen withan impervious tarpaulin and mix a pesticide solution within that enclosure. After treatment for short periods (1 h) the pesticide solution is released to the environment. Concerns have been raised that there is a potential risk to non-target aquatic organisms from those releases. The fate of dispersing pesticide solutions was measured after six simulated treatments in the Lower Bay of Fundy, New Brunswick. Three simulated treatments were done with azamethiphos and three with cypermethrin. Rhodamine dye was added to all pesticide solutions in order to facilitate tracking of the dispersing plume through real-time measurements of dye concentrations by a fow-through fluorometer coupled witha differential global positioning system (DGPS). Water samples were obtained from within the plumes at various times after release and analysed for pesticide content and toxicity to a benthic amphipod Eohaustorius estuaris. Dye concentrations were detectable for time periods after release which varied from 2 to 5.5 h. Distances travelled by the dye patches ranged from 900 to 3000 m and the dye concentrations at the final sampling period were generally 1/200±1/3000 the pre-release concentrations and cypermethrin concentrations were generally 1/1000±1/2000 the pre-release concentrations. Cypermethrin concentrations in water samples were closely correlated withdye concentrations, indicating that dye analyses were an accurate surrogate for cypermethrin concentrations. Most samples taken after the releases of azamethiphos were not toxic to test organisms in 48 h exposures and none were beyond 20 min post-release. By contrast, almost all samples taken after the release of cypermethrin, even up to 5-h post-release, were toxic. Data indicate the potential to cause toxic effects over areas of hectares from a single release of cypermethrin.

Fairgrieve, W. T., & Nash, C. E. (2005). Ecological Risk Assessment of Marine Fish Aquaculture. Retrieved from https://www.fra.affrc.go.jp/bulletin/bull/bull29/14.pdf

No abstract

Fisheries and Oceans Canada (DFO). (2019). Marine Mammal Interactions at British Columbia Marine Finfish Aquaculture Sites. Retrieved from http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/mar-mam/index-eng.html 10/25/2019

Marine mammal predator control is governed by the Marine Mammal Regulations under the Fisheries Act. In British Columbia, Fisheries and Oceans Canada's licence conditions allow the lethal control of harbour seals and California sea lions that pose an imminent danger to human life or the aquaculture facility, should reasonable deterrent efforts fail. Records of marine mammal mortalities are maintained and results reported publicly. Additional licences can be obtained for control of other species.

Fisheries and Oceans Canada works with industry to improve marine mammal deterrent and control measures. At present, the most common system includes anti-predator netting that surrounds the facility structure on all sides and from below. Fisheries and Oceans Canada biologists conduct site audits and inspections to ensure that licence holders are complying with their licence conditions and implementing elements of their predator management plans. Aquaculture facilities must report marine mammal fatalities to Fisheries and Oceans Canada.

Ford, J. S., & Myers, R. A. (2008). A Global Assessment of Salmon Aquaculture Impacts on Wild Salmonids. *PLoS Biol, 6*(2), e33 https://doi.org/10.1371/journal.pbio.0060033

Since the late 1980s, wild salmon catch and abundance have declined dramatically in the North Atlantic and in much of the northeastern Pacific south of Alaska. In these areas, there has been a concomitant increase in the production of farmed salmon. Previous studies have shown negative impacts on wild salmonids, but these results have been difficult to translate into predictions of change in wild population survival and abundance. We compared marine survival of salmonids in areas with salmon farming to adjacent areas without farms in Scotland, Ireland, Atlantic Canada, and Pacific Canada to estimate changes in marine survival concurrent with the growth of salmon aquaculture. Through a meta-analysis of existing data, we show a reduction in survival or abundance of Atlantic salmon; sea trout; and pink, chum, and coho salmon in association with increased production of farmed salmon. In many cases, these reductions in survival or abundance are greater than 50%. Meta-analytic estimates of the mean effect are significant and negative, suggesting that salmon farming has reduced survival of wild salmon and trout in many populations and countries.

Forrest, B., Keeley, N., Gillespie, P., Hopkins, G., Knight, B., & Govier, D. (2007). *Review of the Ecological Effects of Marine Finfish Aquaculture: Final Report.* Prepared for Ministry of Fisheries Cawthron Report No. 1285. Nelson, New Zealand. Retrieved from https://www.cawthron.org.nz/media_new/publications/pdf/2014_07/CR1285-Review_of_the_ecological_effects_of_marine_finfish_aquaculture_Final_report.pdf

The marine finfish aquaculture industry in New Zealand is small by comparison with many other countries, and based primarily around sea-cage farming of King salmon (Oncorhynchus tshawytscha) at sites in the Marlborough Sounds, Akaroa Harbour, and Big Glory Bay (Stewart Island). There has been recent interest in expansion of the finfish industry to new areas and new species such as yellowtail kingfish and groper, among others. A trial kingfish farm is already established in the Marlborough Sounds. This report reviews existing information on the ecological effects of finfish farming, providing background knowledge that will assist with resource management decisions in relation to future development. However, this review is not intended to be an assessment of environmental effects that could be used directly in relation to a resource consent application; any assessment for such purposes would need to consider a range of site-specific issues.

The ecological effects of finfish farms have been intensively studied world-wide, primarily in relation to the development of the salmon farming industry. Finfish held in aquaculture are fed artificial diets in the form of food pellets, and early work highlighted significant effects on the seabed beneath farm structures, which arose from the deposition of waste (i.e., uneaten) feed and faecal material from the farmed stock. There is now a considerable amount of scientific literature on the seabed effects of salmon farms from both New Zealand and overseas. More recently a range of other potential effects

and interactions have also been recognised, most of which are represented in the following diagram. Below we provide a summary of our findings for each of these issues, along with management and mitigation approaches.

Gaitan-Espitia, J. D., Gomez, D., Hobday, A. J., Daley, R., Lamilla, J., & Cardenas, L. (2017). Spatial Overlap of Shark Nursery Areas and the Salmon Farming Industry Influences the Trophic Ecology of Squalus Acanthias on the Southern Coast of Chile. *Ecology and Evolution, 7*(11), 3773-3783 https://doi.org/10.1002/ece3.2957

Potential interactions between marine predators and humans arise in the southern coast of Chile where predator feeding and reproduction sites overlap with fisheries and aquaculture. Here, we assess the potential effects of intensive salmon aquaculture on food habits, growth, and reproduction of a common predator, the spiny dogfishidentified as Squalus acanthias via genetic barcoding. A total of 102 (89 females and 13 males) individuals were collected during winter and summer of 2013-2014 from the Chiloe Sea where salmon aquaculture activities are concentrated. The low frequency of males in our study suggests spatial segregation of sex, while immature and mature females spatially overlapped in both seasons. Female spiny dogfish showed a functional specialist behavior as indicated by the small number of prey items and the relative high importance of the austral hake and salmon pellets in the diet. Immature sharks fed more on pellets and anchovies than the larger hake-preferring mature females. Our results also indicate that spiny dogfish switch prey (anchovy to hake) to take advantage of seasonal changes in prey availability. Despite differences in the trophic patterns of S. acanthias due to the spatial association with intensive salmon farming, in this region, there appears to be no difference in fecundity or size at maturity compared to other populations. Although no demographic effects were detected, we suggest that a range of additional factors should be considered before concluding that intensive aquaculture does not have any impact on these marine predators.

Galaz, T., & De Maddalena, A. (2004). On a Great White Shark, Carcharodon Carcharias(Linnaeus, 1758), Trapped in a Tuna Cage Off Libya, Mediterranean Sea. *Annales. Series historia naturalis, 14*(2), 159-164 Retrieved from https://zdjp.si/en/annales-series-historia-naturalis-14-2004-2/

On June 12, 2002, a towing boat on its way from Libya to Spain stopped at 33 50 N, 13 50 E, 55 miles off Tripoli, for a check of its 50-m diameter tuna cage containing 60 tons of blue-fin tuna. Here, an estimated 5-m female long white shark suddenly tore the net and entered the cage, where the tuna farm staff then observed it for 2.5 hours. Photographic and filmed evidence was collected. The towing boat continured its journey, and two days later the shark left the cage. Other cases of sharks trapped in tuna cages in the Mediterranean include two blue sharks in a cage between Italy and Spain in 2001, and a shortfin mako in a cage between the Baleares Island and Murcia, Spain, in 2002. The vulnerable status of white sharks in the Mediterranean necessitaties monitoring of the interactions between white sharks and the tuna farm industry, in order that an appropriate action is taken during the attempts to release sharks trapped in tuna cages.

Glover, K. A., Sorvik, A. G., Karlsbakk, E., Zhang, Z., & Skaala, O. (2013). Molecular Genetic Analysis of Stomach Contents Reveals Wild Atlantic Cod Feeding on Piscine Reovirus (Prv) Infected Atlantic Salmon Originating from a Commercial Fish Farm. *PLoS One, 8*(4) https://doi.org/10.1371/journal.pone.0060924

In March 2012, fishermen operating in a fjord in Northern Norway reported catching Atlantic cod, a native fish forming an economically important marine fishery in this region, with unusual prey in their stomachs. It was speculated that these could be Atlantic salmon, which is not typical prey for cod at this time of the year in the coastal zone. These observations were therefore reported to the Norwegian Directorate of Fisheries as a suspected interaction between a local fish farm and this commercial fishery. Statistical analyses of genetic data from 17 microsatellite markers genotyped on 36 partially-degraded prey, samples of salmon from a local fish farm, and samples from the nearest wild population permitted the following conclusions: 1. The prey were Atlantic salmon, 2. These salmon did not originate from the local wild population, and 3. The local farm was the most probable source of these prey. Additional tests demonstrated that 21 of the 36 prey were infected with piscine reovirus. While the potential link between piscine reovirus and the disease heart and skeletal muscle inflammation is still under scientific debate, this disease had caused mortality of large numbers of salmon in the farm in the month prior to the fishermen's observations. These analyses provide new insights into interactions between domesticated and wild fish.

Goldburg, R., & Naylor, R. (2005). Future Seascapes, Fishing, and Fish Farming. *Frontiers in Ecology and the Environment, 3*(1), 21-28 Retrieved from https://www.jstor.org/stable/3868441

The depletion of many marine fisheries has created a new impetus to expand seafood production through fish farming, or aquaculture. Marine aquaculture, especially of salmon and shrimp, has grown considerably in the past two decades, and aquaculturists are also beginning to farm other marine species. Production data for salmon and shrimp indicate that farming supplements, rather than substitutes for fishing. Since most farmed marine fish are carnivores, farming them relies on the capture of finite supplies of wild fish for use in fish feeds. As aquaculture is not substituting for wild fisheries, heavy dependence on wild fish inputs is a concern as marine aquaculture grows. Other likely impacts include escapes of farmed fish and large-scale waste discharges from fish farms. A viable future for marine ecosystems will require incorporation of eco? logical perspectives into polices that integrate fishing, aquaculture, and conservation.

Guclusoy, H., & Savas, Y. (2003). Interaction between Monk Seals Monachus Monachus (Hermann, 1779) and Marine Fish Farms in the Turkish Aegean and Management of the Problem. *Aquaculture Research, 34*(9), 777-783 https://doi.org/10.1046/j.1365-2109.2003.00884.x

Mediterranean monk seals Monachus monachus attacked fish on 11 marine fish farms in the Turkish Aegean between 1992 and 2000. There were 40 attacks on fish farms where gilthead sea bream Sparus auratus and European sea bass Dicentrarchus labrax were raised in holding cages. Single seals usually attacked cages at night, regardless of the size of fish in the cages. The seals damaged both holding nets of the cages and fish and, on most occasions, fish escaped as a result of the attacks. With the exception of only one facility, all fish farms attacked by monk seals were concentrated on the large peninsulas including Karaburun and Bodrum Peninsulas, and the number of seal attacks was higher during the winter months. A direct intervention to deter seals such as the use of lights, feeding with pesticide-injected fish, noise generation, warning and direct shots with rifles and physical exclusion of seals from holding cages by installing antipredator nets were applied to prevent or reduce seal attacks. Our study shows that deterrents such as lights and warning shots were not effective in preventing monk seal attacks. However, both curtain- and bag-type antipredator nets were found to be effective.

Haarr, M. L., Charlton, L. D., Terhune, J. M., & Trippel, E. A. (2009). Harbour Porpoise (Phocoena Phocoena) Presence Patterns at an Aquaculture Cage Site in the Bay of Fundy, Canada. *Aquatic Mammals, 35*(2), 203-211 https://doi.org/10.1578/am.35.2.2009.203

Finfish aquaculture is a prominent industry in the Bay of Fundy, Canada. The distribution of harbour porpoise (Phocoena phocoena) in the Bay during the summer and fall may be impacted by the presence of offshore cages or the activities of workers on the site. Harbour porpoise presence near and within an aquaculture cage site was studied using visual observations during the summer of 2006 and by monitoring echolocation signals using T-PODs during the summer and autumn of 2006 and 2007. At least one harbour porpoise was sighted per hour 61% of the time among or near the cages. Porpoise occasionally surfaced within the cage site when workers were present. Mother-calf pairs used the within-cages area proportionately more than adults and juveniles. The porpoise were temporarily displaced by high disturbance activities such as cage cleaning with pressure hoses, but quickly returned to the area when the disturbance ended. Echolocation activity was lowest during the day, increased in the evening, and peaked between midnight and dawn. This pattern was evident on the offshore and inshore side of the cages and, to a lesser extent, at a non-aquaculture location farther along the coastline (2007 only). In August of both years, the echolocation patterns were similar, even though in 2007 there were no fish in the cages and much less worker activity than in 2006 when all 15 cages contained Atlantic salmon (Salmo salar). Echolocation activity near a T-POD typically lasted for no more than 10 min or for at least 1 h, suggesting that the porpoise were either passing by the area or staying to feed, respectively. The presence of the aquaculture cage site under study did not appear to be displacing harbour porpoise from the area except during short intervals when high disturbance activities such as a food delivery by barge or cage cleaning were occurring.

Helsley, C. (2007). *Environmental Observations around Offshore Cages in Hawaii.* Paper presented at the Open ocean aquaculture - moving forward., Waimanalo, Hawaii. Retrieved from https://eos.ucs.uri.edu/EOSWebOPAC/OPAC/Common/Pages/GetDoc.aspx?ClientID=EOSMAIN&MediaCode=11253

Concern for possible environmental damage constrains development of the aquaculture industry in the United States. Potential environmental interactions, including degradation of water quality, introduction of exotic species, pollution of the seafloor, adverse interaction with the seafloor benthic community, adverse interactions with protected species, and genetic interactions of potential escapees are all generally viewed as negative interactions, and thus are of substantial concern to the public and to regulators. Certainly, the culture of finfish in cages can be detrimental to the local water quality and the benthos beneath the cages when the fish are overfed or when too many production units are located in an area of limited carrying capacity or restricted circulation, as has been demonstrated by numerous published reports (see Black 2001 for a summary). The focus of the Hawaii Open-ocean Aquaculture Research Program (HOARP) (Ostrowski and Helsley 2003) was to establish which, if any, of the above concerns are real in open circulation tropical conditions. Routine observations of water quality, health of the ecosystem outside the cages, interactions with protected species, and changes in the benthic assemblage were made to assess these potential impacts of open ocean aquaculture in tropical oceanic settings.

Holmer, M. (2010). Environmental Issues of Fish Farming in Offshore Waters: Perspectives, Concerns and Research Needs. *Aquaculture Environment Interactions, 1*(1), 57-70 https://doi.org/10.3354/aei00007

Offshore fish farming is predicted to increase in the near future driven by the lack of coastal space. In this review I discuss the environmental issues of offshore farming from experience in coastal farms. Even more so than in coastal farms, a rapid and wide dispersal of dissolved waste products is predicted for offshore farms. Despite wider dispersal of particulate waste products, fast sinking rates of feed pellets and faeces suggest organic enrichment of the bottom sediments in farm vicinities (hundreds of meters), although at lower loading rates than coastal farms. The benthic response to organic enrichment is unpredictable due to lack of knowledge from shelf areas. Most shelf sediments are considered carbon limited and fish farm waste products may stimulate the benthic communities, but due to the sparse abundance and absence of pollutant-tolerant benthic fauna, the capacity of benthic communities to assimilate organic matter may be limited. Instead, microbial decomposition of waste products could become important, leading to increased oxygen demand and accumulation of sulfides in the sediments. This may negatively affect benthic biodiversity. Interactions with wild fish (aggregation, genetic impacts, spreading of disease and parasites) are expected, but difficult to predict, as the composition of species attracted to offshore farms will be different from that of species attracted to coastal farms. Escapees are potentially a high risk due to farm failure under rough weather conditions in the open sea. The carbon footprint of farming offshore will increase (transportation) and the ecological footprint (fishing feed) will remain a severe constraint, as in coastal farming. Offshore farming is subject to high costs of operation, including those for monitoring environmental conditions. Research should focus on interactions with wild fish populations, mapping of sensitive benthic habitats and experimental studies of the response of benthic habitats to organic enrichments.

Jamieson, G. S., & Olesiuk, P. F. (2001). *Salmon Farm - Pinniped Interactions in British Columbia: An Analysis of Predator Control, Its Justification and Alternative Approaches.* Canadian Science Advisory Secretariat, D. O. F. A. Oceans & P. B. Station.2001/142. Nanaimo, B.C. Retrieved from http://www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/2001/2001_142-eng.htm

Predator control is widely practised in most forms of agriculture and aquaculture, including salmonid fish farming. Canada has a process whereby fish farmers can obtain authorisation to kill predators, particularly pinnipeds (seals and sea lions), but to date, the details of this process, how it is being used by industry, and alternative measures to minimise the need for such killing have not been scientifically assessed. Here, we describe existing Fisheries and Oceans Canada (DFO) policy and culling permit requirements associated with predator control; the impacts marine mammals are having on cultured fish production; the annual, seasonal and spatial pattern of kills; how this pattern is related to the abundance, distribution of haulouts and seasonal movements of pinnipeds; and the availability, effectiveness and use of alternate methodologies to deter pinniped impacts on fish farms. Establishment of Canada's Oceans Act in 1997 gave DFO the mandate for marine ecosystem management. With the recent growth in the coastal ecotourism industry and the economic value and public interest now associated with pinnipeds, there is a current need for this information. Pinnipeds are near the top of the marine food chain, and although they are not commercially exploited, their continued presence and occurrence in natural ecosystems at appropriate levels of abundance are important resource management objectives.

Keyser, F., Wringe, B. F., Jeffery, N. W., Dempson, J. B., Duffy, S., & Bradbury, I. R. (2018). Predicting the Impacts of Escaped Farmed Atlantic Salmon on Wild Salmon Populations. *Canadian Journal of Fisheries and Aquatic Sciences, 75*(4), 506-512 https://doi.org/10.1139/cjfas-2017-0386

The escape of Atlantic salmon (Salmo salar) from aquaculture facilities can result in both negative genetic and ecological interactions with wild populations, yet the ability to predict the associated risk to wild populations has remained elusive. Here we assess the potential of a spatiotemporal database of aquaculture facility locations, production estimates, and escape events to predict the distribution of escaped farmed salmon and genetic impacts on wild populations in the Northwest Atlantic. Industry production data, reported escape events, and in-river detections of escaped farmed salmon were collected from across the Northwest Atlantic. Genetic estimates ofimpact were obtained using single nucleotide polymorphisms (95 loci) representing aquaculture and wild salmon throughout the region (30 populations, 3048 individuals). Both the number of escaped farmed salmon detected at counting facilities and the magnitude of genetic impacts were positively correlated with a cumulative spatial measure of aquaculture production. Our results suggest that the risk of escapees and genetic introgression from wild–farmed salmon interactions can be assessed using information on farm production characteristics. This represents a first step in predicting the impact of existing cage-based farms on wild Atlantic salmon.

Kraufvelin, P., Sinisalo, B., Leppäkoski, E., Mattila, J., & Bonsdorff, E. (2001). Changes in Zoobenthic Community Structure after Pollution Abatement from Fish Farms in the Archipelago Sea (N. Baltic Sea). *Marine Environmental Research, 51*(3), 229-245 https://doi.org/10.1016/s0141-1136(00)00101-x

Long-term changes in sediment macrofauna communities at two sites a□ected by ®sh farming in the Archipelago Sea, south-west Finland have been investigated. Sampling stations in the SaÈrkaÈnsalmi Strait and Kaukolanlahti Bay, previously investigated 1982±1991, were revisited in 1994, 1995 and 1998 to detect signs of recovery following a decrease in organic load since 1990 and 1991, respectively. The results indicate a partial recovery in SaÈrkaÈnsalmi during post-pollution years, whereas no improvement has taken place in Kaukolanlahti. The improvement in SaÈrkaÈnsalmi is shown by a signi®cant increase in the number of species and total abundance, and by the community structures becoming more similar over time. On the other hand, a signi®cantly decreased number of species, abundance and biomass values over time as well as the occurrence of defaunated anoxic sediments, are clear signs of continued deterioration in Kaukolanlahti. Di□erences in the recovery potential of the two water areas are interpreted as consequences of topography and water exchange patterns causing differences in oxygen saturation.

Loiseau, N., Kiszka, J. J., Bouveroux, T., Heithaus, M. R., Soria, M., & Chabanet, P. (2016). Using an Unbaited Stationary Video System to Investigate the Behaviour and Interactions of Bull Sharks Carcharhinus Leucas under an Aquaculture Farm. *African Journal of Marine Science, 38*(1), 73-79 https://doi.org/10.2989/1814232x.2016.1156578

Bull sharks Carcharhinus leucas are common along the coast of Reunion Island (South-West Indian Ocean) and were suspected to aggregate in the vicinity of an aquaculture farm in Saint-Paul Bay on the west coast. In order to understand the behaviour and interaction of bull sharks near aquaculture cages at Saint-Paul Bay, we deployed an experimental unbaited stationary video camera. From 175 hours of

recording during daylight hours from March to April 2012, eight individual female bull sharks (seven adults and one immature) were identified based on their natural markings. These sharks were resighted between 3 and 45 times. Residency analysis revealed site attachment under the aquaculture cages for at least three individuals over the course of the study. Recorded behaviours included intraspecific social interactions such as synchronised swimming. Social interactions and relatively strong paired associations for two pairs of females suggest some level of sociality among bull sharks around Reunion Island. Overall, our results demonstrate the utility of unbaited video systems to monitor the behaviour of adult coastal sharks.

Morton, A., Routledge, R. D., & Williams, R. (2005). Temporal Patterns of Sea Louse Infestation on Wild Pacific Salmon in Relation to the Fallowing of Atlantic Salmon Farms. *North American Journal of Fisheries Management, 25*(3), 811-821 https://doi.org/10.1577/M04-149.1

We report on a 3-year study of the infestation rates of the sea louse, Lepeophtheirus salmonis, on wild juvenile pink salmon Oncorhynchus gorbuscha and chum salmon O. keta in the Broughton Archipelago, British Columbia. In 2002, the British Columbia Ministry of Agriculture, Fisheries, and Food ordered farm fallowing (i.e., the removal of farmed Atlantic salmon Salmo salar from net-cages) along the presumed migration route of wild juvenile Pacific salmon in this area. The goal was to protect wild juvenile fish from sea louse infestation. We assessed the effectiveness of this decision by comparing sea louse infestation rates on wild juvenile salmon near three Atlantic salmon farm sites prior to, during, and after fallowing. Overall, L. salmonis levels were significantly reduced ($P < 0.0001$) at the study sites during fallowing but returned to the original level after fallowing. The decline was age specific. While the abundance of the earliest attached sea louse phase (the copepodid stage) declined by a factor of 42, the mean abundance of adult L. salmonis did not decline significantly. Changes in salinity and temperature could not account for the decline. This study provides evidence that the fallowing of Atlantic salmon farms during spring juvenile salmon migrations can be an effective conservation and management tool for protecting wild salmon. While this correlation adds to the increasing weight of evidence linking Atlantic salmon farms to increased parasite loads on wild salmon, greater cooperation between researchers and farmers will be necessary to isolate the causal mechanisms and provide safe seaward passage to wild juvenile salmon.

Nash, C. E., Burbridge, P. R., & Volkman, J. K. (2005). Guidelines for Ecological Risk Assessment of Marine Fish Aquaculture : Prepared at the NOAA Fisheries Service Manchester Research Station International Workshop, April 11-14, 2005. Retrieved from https://repository.library.noaa.gov/view/noaa/3446

Risk assessment is frequently defined as a tool for making decisions under conditions of uncertainty. Therefore it is far from being an exact science and yet it thrives on exact information. At this period in the emergence of the field of marine fish aquaculture, the scientific and technical knowledge of aquaculture's effects on the environment are a growing compendium of information, but at times the information appears to be ambiguous, conflicting, and incomplete. This is because it is being gleaned continuously from a diverse range of marine ecosystems where there are different fish and shellfish species being produced under a variety of systems and practices which, in some cases, are themselves still being developed.

But the time when knowledge is apparently deficient is arguably the right time for seriously addressing risks, and the constraint of incomplete scientific and technical knowledge has to be offset by the practical knowledge and professional experience of individuals in order to make balanced judgments. In the near future it will be possible to model the interactive ecological effects of marine aquaculture activities, and decisions will be made based on risks quantified numerically for different ecosystems. However, for the moment, informed decisions will have to be made by risk managers with the help of responsible individuals guided mostly by their past experiences and research.

The purpose of this document is to provide a basic set of guidelines for risk managers and other decision makers to use all information available to assess the different ecological risks of marine fish aquaculture in a variety of marine ecosystems. Ten areas of substantive risk in the interaction between marine fish aquaculture are perceived by the public and public administrators to be of most concern. In no order of priority they are: increased organic loading, increased inorganic loading, residual heavy metals, transmission of disease organisms, residual therapeutants, biological interaction of escapes with wild populations, physical interaction with marine wildlife, physical impact on marine habitat, using wild juveniles for grow-out, and harvesting industrial fisheries for aqua-feeds. In this technical memorandum each of these 10 areas of risk is assessed for its degree of potential adversity, together with its mitigation, in an identical step-by-step process. This common analytical framework, which is first described and illustrated in detail, was developed by the World Health Organization many years ago, and its generic nature and international acceptance make its use for the risk assessment of marine fish aquaculture an ideal application.

Northridge, S., Coram, A. & Gordon, J. . (2013). *Investigations on Seal Depredation at Scottish Fish Farms.* Scottish Government Edinburgh. Retrieved from https://synergy.st-andrews.ac.uk/smru/files/2015/10/1758.pdf

The project has several overlapping objectives, with the overall aim of improving our understanding of seal depredation at fish farm sites, including aspects addressing mitigation of the problem.

Oviedo Correa, L. E., Pacheco, J. D., & Herra Miranda, D. (2009). Assessment of Disturbance Risks Due to the Establishment of Tuna Farms Respect to the Cetaceans Spatial Distribution in Golfo Dulce, Costa Rica. [Evaluacion de los riesgos de afectacion por el establecimiento de granjas atuneras en relacion con la distribucion espacial de cetaceos en el Golfo Dulce, Costa Rica]. *Revista Ciencias Marinas y Costeras, 1*, 159-174 Retrieved from http://www.revistas.una.ac.cr/index.php/revmar/article/view/248/204

This paper describes the potential risk of disturbances due to the establishment of mariculture operations and corresponding infrastructure: tuna feed lots. Through a mixed theoretical and empirical approach, this research corroborates how the maximum depth, a limiting factor in the definition of cetacean trophic niches off the study area, overlaps with the values for depths from an area proposed as the focal location of a tuna feed lot facility. The latter implies two particular scenarios: the translocation of the local predator population from a potential foraging habitat-niche, and the progressive negative interaction between predators and the accompanying fish fauna around of the cages, with a high probability of incidental capture of those predators by entanglement. Additionally, the occurrence of humpback whales during the rainy season associated with a migratory route from feeding grounds off Chile-Antarctica, that would pass through the area projected to harbor the mariculture operation. The

results illustrated the need of considering a precautionary approach and relocate mariculture projects to areas of lesser value in terms of marine biodiversity.

Papastamatiou, Y. P., Itano, D. G., Dale, J. J., Meyer, C. G., & Holland, K. N. (2011). Site Fidelity and Movements of Sharks Associated with Ocean-Farming Cages in Hawaii. *Marine and Freshwater Research, 61*(12), 1366-1375 https://doi.org/10.1071/MF10056

Sharks are found in association with main Hawaiian Island ocean fish farms more frequently and at higher densities than is typical for coastal Hawaiian waters. Sharks attracted to fish farms could potentially threaten human water users, interact negatively with other fisheries, and seasonal migrations could be disrupted ifindividuals become entrained around farms throughout the year. We hypothesised that smaller coastal species would reside near farms, whereas more wide-ranging species would associate with farms only for short periods. We utilised passive acoustic telemetry to monitor the movements and behaviour ofsandbar (Carcharhinus plumbeus) and tiger (Galeocerdo cuvier) sharks adjacent to two open ocean fish farms in Hawaii. Approximately half the tagged sandbar sharks showed site fidelity to the farms, with some individuals being detected repeatedly for 2.5 years. Sandbar sharks moved seasonally to the west coast of Oahu, suggesting that fish farms are not disrupting natural seasonal cycles in this species. Tiger sharks tagged near the cages were more transient, and showed much shorter residence times although some individuals returned sporadically to the cages over the 3-year period. Ocean fish cages appear to aggregate sandbar sharks, but are only 'visited' by tiger sharks. Although threats to public safety are probably minimal, the ecological effects of aggregating top-predators are still unknown.

Piroddi, C., Bearzi, G., & Christensen, V. (2011). Marine Open Cage Aquaculture in the Eastern Mediterranean Sea: A New Trophic Resource for Bottlenose Dolphins. *Marine Ecology Progress Series, 440*, 255-266 https://doi.org/10.3354/meps09319

Over the last 2 decades marine open cage aquaculture in the Mediterranean Sea has grown rapidly, leading to increased productivity in the water column near fish farms. Here we investigated the effect of such increase in productivity on the common bottlenose dolphin Tursiops truncatus. We developed an ecosystem model for the inner Ionian Sea Archipelago, western Greece, to: (1) evaluate the trophic interactions between bottlenose dolphins and their surrounding ecosystem, including cage-associated organisms; (2) investigate simultaneously 3 hypotheses that could explain bottlenose dolphin dynamics: (a) increasing fishing effort and changes in ocean productivity, (b) competition with other species, and (c) increase in number of fish farms; and (3) explore spatial trends in bottlenose dolphins distribution using the increased number of fish farms as an explanatory variable. Comparisons of model predictions with historical time-series data indicate that only the increase in number of cages and thereby in productivity near fish farms contributed to the trends observed in dolphin numbers. Spatial analysis also confirmed an increase in occurrence of these dolphins in the proximity of the farms. These outcomes suggest that high productivity in waters surrounding fish cages—within a coastal area that is markedly oligotrophic—may attract bottlenose dolphins. The present study shows that open cage aquaculture has benefited bottlenose dolphins by easing their way of catching prey. Further studies should be conducted in other areas of the Mediterranean Sea to investigate whether the higher occurrence of bottlenose dolphins around fish cages is a common pattern and if it is driven by the trophic status of the ecosystem or by the type of fishes that surround the cages.

Polefka, S., Richmond, S., & Dutton, J. (2007). *Open Ocean Aquaculture in the Santa Barbara Channel: An Emerging Challenge for the Channel Islands National Marine Sanctuary.* Environmental Defense Center Santa Barbara, CA. Retrieved from https://nmschannelislands.blob.core.windows.net/channelislands-prod/media/archive/sac/pdfs/7-27-07.pdf

Designated in 1980, the Channel Islands National Marine Sanctuary (CINMS or the Sanctuary) encompasses the waters from the Mean High Water Line to six nautical miles (NM) offshore around the five northern Channel Islands-- Anacapa, Santa Cruz, Santa Rosa, San Miguel and Santa Barbara Islands, as well as Richardson Rock and Castle Rock. This 1,113-square-NM region is one of 13 sites overseen by the National Marine Sanctuary Program (NMSP), which is authorized by Congress to "identify, designate, and manage areas of the marine environment of special national, and in some cases international, significance due to their conservation, recreational, ecological, historical, research, educational, or aesthetic qualities." Congress ordered the NMSP to "maintain the natural biological communities" of designated Sanctuaries, and "to protect and, where appropriate, restore and enhance the natural habitats, populations, and ecological processes." Based on these responsibilities, the stated primary goal of CINMS managers "is to protect the natural and cultural resources contained within [Sanctuary] boundaries."

Price, C. S., & J.A. Morris, J. (2013). *Marine Cage Culture and the Environment: Twenty-First Century Science Informing a Sustainable Industry.* Retrieved from https://www.noaa.gov/stories2013/pdfs/2013_PriceandMorris_MarineCageCultureandTheEnvironment(5).pdf

Technological innovation has made it possible to grow marine finfish in the coastal and open ocean. Along with this opportunity comes environmental risk. As a federal agency charged with stewardship of the nation's marine resources, the National Oceanic and Atmospheric Administration (NOAA) requires tools to evaluate the benefits and risks that aquaculture poses in the marine environment, to implement policies and regulations which safeguard our marine and coastal ecosystems, and to inform production designs and operational procedures compatible with marine stewardship.

Quiñones, R. A., Fuentes, M., Montes, R. M., Soto, D., & León-Muñoz, J. (2019). Environmental Issues in Chilean Salmon Farming: A Review. *Reviews in Aquaculture, 11*(2), 375-402 https://doi.org/10.1111/raq.12337

The growth of Chilean salmon production has not been free of important sanitary and environmental shortcomings. To ensure sustainability, it is necessary to understand the environmental impacts of salmon production on the Patagonian ecosystems. Currently, there is limited regulation or monitoring of impacts in the freshwater phase compared to the marine fattening stage, and there is some evidence of local eutrophication impact and diversity changes downstream the farms. Eutrophication of Patagonian channels and fjords from marine farms has been recognized as crucial environmental risk, although most scientific evidence comes from local effects below and around farms. So far, there are no regulations based on carrying capacity estimates to limit maximum fish biomass per area or water body. There is controversy regarding the potential role of nutrients derived from farming in triggering harmful algal blooms, yet current environmental monitoring and available information does not allow establishing or

rejecting a cause– effect relationship. Pesticides used to control sea lice infestation have been shown to be deleterious to some non-target species. There is evidence that the use of high quantities of antibiotics has allowed the development of antibiotic-resistant bacteria in sediments and there is concern that salmon aquaculture has the potential to increase the proportion of antimicrobial-resistant bacteria to antibiotics that are used in human medicine. There is an urgent need for more comprehensive ecosystem (beyond farm) studies on the impacts of antibiotics. Escapes of salmon (exotic species) from farms are a relevant environmental risk, although the most farmed species, Salmo salar, has shown little success in establishing wild populations. The review identifies critical knowledge gaps whose fulfilment is essential to advance towards an ecosystem approach to aquaculture and to protect Patagonian ecosystems.

Rust, M. B., Amos, K. H., Bagwill, A. L., Dickhoff, W. W., Juarez, L. M., Price, C. S., . . . Rubino, M. C. (2014). Environmental Performance of Marine Net-Pen Aquaculture in the United States. *Fisheries, 39*(11), 508-524 https://doi.org/10.1080/03632415.2014.966818

The United States has a small net-pen salmon industry dating back over 40 years and a nascent net-pen industry for other marine fish. The United States net-pen aquaculture sector has improved its resource efficiency in terms of the amount of fish meal and fish oil used in feeds and reduced its environmental impacts in terms of the mass loading and impact of nutrient discharge on the receiving ecosystem, the incidence and treatment of fish diseases, the use of antibiotics, and the number and impact of fish escapes, while increasing production. These changes can be attributed to a combination of advances in science and technology, rising cost of fish meal/ oil, improved management, and informed regulatory practices. Net-pen aquaculture has become an efficient food production system. Existing laws and regulations in the United States effectively address most of the potential adverse environmental effects of net-pen aquaculture.

Sanchez-Jerez, P., Fernandez-Jover, D., Bayle-Sempere, J., Valle, C., Dempster, T., Tuya, F., & Juanes, F. (2008). Interactions between Bluefish Pomatomus Saltatrix (L.) and Coastal Sea-Cage Farms in the Mediterranean Sea. *Aquaculture, 282*(1-4), 61-67 https://doi.org/10.1016/j.aquaculture.2008.06.025

Coastal sea-cage farms aggregate large concentrations of pelagic and demersal fish. The large numbers of cultured fish and aggregated wild fish often attract a range of marine mammal predators which may break into cages and attack the cultured fish. To date, predation by a finfish species within sea-cages has not been documented. In the Mediterranean Sea, the bluefish Pomatomus saltatrix (L.) aggregates around sea-cage farms and enters into cages to predate on the cultured fish. We obtained information about the effects of bluefish predation on aquaculture production through a questionnaire that was completed by fish farmers in Spain, Italy, Malta, Turkey, Greece and Cyprus. In addition, we identified the abundance, size and stomach contents of bluefish aggregated around three fish farms on the coast of Spain through visual counts, and from captured bluefish both inside and outside of the sea-cages. Bluefish occurred around fish farms in Spain, Italy, Malta and Turkey. Farmers in SE Spain reported its presence only inside seabream (Sparus aurata) cages, while in Turkey bluefish were reported from inside seabass (Dicentrarchus labrax) and seabream cages. Greatest aggregated biomass of bluefish reached 1049 and 3191 kg at the Altea and Guardamar farms, respectively, with abundance peaking at 4500 individuals at both farms. Size structures differed markedly between farms, with smaller individuals aggregating at Altea. Stomach content analysis revealed that bluefish on the outside of sea-cages

consumed pelagic species such as Sardinella aurita and Trachurus mediterraneus, while they predated on seabream once they incurred into cages, often consuming only the tails of many fish. The interaction of bluefish with sea-cage aquaculture is, at present, a problem of local concern restricted to some areas of the Mediterranean Sea, but its widespread distribution suggests this piscivore may be a problematic predator in other regions.

Scholl, M., & Pade, N. (2005). *Salmon Farming in Gansbaai an Ecological Disaster.* White Shark Trust Retrieved from https://www.whitesharktrust.org/pages/salmonfarm.html

Salmon farming is a relatively new industry that has emerged in the last 30-40 years. It arose in response to a growing demand for luxury fish that could no longer be satisfied by a decreasing fishery. In countries such as Scotland, the industry has grown to become a vital resource of employment for fragile rural economics and produced about 130,000 tons of salmon in 2000 (Rae, 2002). Today, nearly one third of the fish and shellfish products commercially available worldwide come from aquaculture (FAO The State of World Fisheries and Aquaculture, 1998, Fisheries Department, Food and Agriculture Organization, Rome, 128pp.).
Aquaculture, and particularly salmon farming, has been a hot topic in many countries on numerous occasions, and usually it is not in a positive light. Though aquaculture is a highly lucrative industry, which provides people with employment and potential for improvements of living conditions, it is a relatively new industry that still has a large amount of flaws and short-comings that have yet to be resolved. Thus, the salmon industry poses a severe risk to the environment and has in many areas had a severe impact on local flora and fauna (Crawford et al., 2001)
In August 2002, a license for a salmon farm pilot project was issued by Marine and Coastal Management (MCM) to the Norwegian Aquaculture giant Salmon Salar. The pilot farm was to be set up in the small fishing village, Gansbaai, about 190 km south east of Cape Town. Gansbaai is home to the extremely lucrative shark cage diving industry, as well as being renowned for the excellent whale watching possibilities.
When enquiries about the license issuing and a request to review the Environmental Impact Assessment (EIA) were made with MCM, it became apparent that none had been made for this project. In light of this, this paper was written in order to highlight some of the major environmental problems associated with salmon farming and the potential impact that such an installation could have on the local wildlife (much of which is already endangered), but also to the local community and economy. All aspects, environmental as well as anthropogenic are outlined below.

Skaala, O., Besnier, F., Borgstrom, R., Barlaup, B., Sorvik, A. G., Normann, E., . . . Glover, K. A. (2019). An Extensive Common-Garden Study with Domesticated and Wild Atlantic Salmon in the Wild Reveals Impact on Smolt Production and Shifts in Fitness Traits. *Evol Appl, 12*(5), 1001-1016 https://doi.org/10.1111/eva.12777

Interactions between domesticated escapees and wild conspecifics represent a threat to the genetic integrity and fitness of native populations. For Atlantic salmon, the recurrent presence of large numbers of domesticated escapees in the wild makes it necessary to better understand their impacts on native populations. We planted 254,400 eggs from 75 families of domesticated, F1-hybrid, and wild salmon in a river containing up- and downstream traps. Additionally, 41,630 hatchery smolts of the same pedigrees were released into the river. Over 8 years, 6,669 out-migrating smolts and 356 returning adults were recaptured and identified to their families of origin with DNA. In comparison with wild salmon,

domesticated fish had substantially lower egg to smolt survival (1.8% vs. 3.8% across cohorts), they migrated earlier in the year (11.8 days earlier across years), but they only displayed marginally larger smolt sizes and marginally lower smolt ages. Upon return to freshwater, domesticated salmon were substantially larger at age than wild salmon (2.4 vs. 2.0, 4.8 vs. 3.2, and 8.5 vs. 5.6 kg across sexes for 1, 2, and 3 sea-winter fish) and displayed substantially lower released smolt to adult survival (0.41% vs. 0.94% across releases). Overall, egg-to-returning adult survival ratios were 1:0.76:0.30 and 1:0.44:0.21 for wild:F1-hybrid:domesticated salmon, respectively, using two different types of data. This study represents the most updated and extensive analysis of domesticated, hybrid, and wild salmon in the wild and provides the first documentation of a clear genetic difference in the timing of smolt migration-an adaptive trait presumed to be linked with optimal timing of entry to seawater. We conclude that spawning and hybridization of domesticated escapees can lead to (i) reduced wild smolt output and therefore wild adult abundance, through resource competition in freshwater, (ii) reduced total adult abundance due to freshwater competition and reduced marine survival of domesticated salmon, and (iii) maladaptive changes in phenotypic traits.

Vilata, J., Oliva, D., & Sepúlveda, M. (2009). The Predation of Farmed Salmon by South American Sea Lions (Otaria Flavescens) in Southern Chile. *ICES Journal of Marine Science, 67*(3), 475-482 https://doi.org/10.1093/icesjms/fsp250

The South American sea lion Otaria flavescens is abundant off southern Chile. Because Chilean salmon farming has experienced an explosive growth in the past two decades, interactions between O. flavescens and this industry have increased. Fieldwork, including in situ behavioural observations, was carried out at three salmon farms off southern Chile from May to July 2008. The aim was to analyse possible patterns in the interactions and to evaluate whether they were influenced by the endogenous circa-rhythms of the species, prey size, tidal flux, and the use of an acoustic harassment device (AHD). The results showed that the attacks by O. flavescens followed seasonal patterns, with salmon predated more in autumn and winter, and daily patterns, with more interactions at night. In addition, attacks were more frequent on larger salmon, suggesting the existence of a prey-size preference. More sea lions were sighted at the ebb and flow tide peaks, when currents are stronger, suggesting that currents linked to tidal flux might facilitate the access of the sea lions to the farmed salmon. Although the use of AHDs appeared positive at one site, there is a strong suspicion that their efficacy may be site-specific.

Waldemar Nelson International Inc. (2001). *Offshore Mariculture in the Gulf of Mexico: A Feasibility Report* L. S. G. C. ProgramBaton Rouge, LA. Retrieved from https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2002103150.xhtml

Offshore mariculture in the Gulf of Mexico region holds much attraction for both public and private entities, but its feasibility remains untested. A major hindrance to such development is the lack of easily accessible information about the environment of the northern gulf and the conditions surrounding offshore platform operations. Louisiana Sea Grant decided to republish this report, originally produced by Waldemar Nelson International, both to fill some of the knowledge gaps and to serve as a point of departure for those who want to investigate mariculture opportunities more thoroughly. It is by no means an exhaustive treatment of the subject but can be considered an incremental step toward the implementation of offshore mariculture.

Wallace, I. S., Gregory, A., Murray, A. G., Munro, E. S., & Raynard, R. S. (2008). Distribution of Infectious Pancreatic Necrosis Virus (Ipnv) in Wild Marine Fish from Scottish Waters with Respect to Clinically Infected Aquaculture Sites Producing Atlantic Salmon, Salmo Salar L. *J Fish Dis, 31*(3), 177-186 https://doi.org/10.1111/j.1365-2761.2007.00886.x

This study represents the first large-scale investigation of IPNV in Scottish wild marine fish. Kidney samples were taken from 30 627 fish comprising 37 species and 45 isolations were made from nine different species, illustrating these as reservoirs of IPNV in Scottish waters. The estimated prevalence of IPNV in the Scottish marine environment was low at 0.15% (90% confidence intervals, (CI) of 0.11-0.19%). This was significantly greater in fish caught less than 5.0 km from IPN-positive fish farms in Shetland, at 0.58% (90% CI of 0.45-0.77%). This prevalence persisted and did not significantly decrease over the 16-month period of study. The estimated prevalence of IPNV for each positive species was less than 1% with the statistically non-significant exceptions of flounder, Platichthys flesus (L.), at 12.5% (90% CI of 0.64-47.06%) and saithe, Pollachius virens (L.), at 1.11% (90% CI of 0.49-2.19%). The 45 isolates were titrated and all but two were below the detection limit of the test (<55 PFU g(-1)). Titres of 3.8 x 10(2) PFU g(-1) and 2.8 x 10(1) PFU g(-1) were calculated from common dab, Limanda limanda (L.), and saithe, respectively. This study provides evidence that clinical outbreaks of IPN in farmed Atlantic salmon may cause a localized small increase in the prevalence of IPNV in wild marine fish.

B. Shellfish Aquaculture

Becker, B. H., Press, D. T., & Allen, S. G. (2009). Modeling the Effects of El Niño, Density-Dependence, and Disturbance on Harbor Seal (Phoca Vitulina) Counts in Drakes Estero, California: 1997-2007. *Marine Mammal Science, 25*(1), 1-18 https://doi.org/10.1111/j.1748-7692.2008.00234.x

Harbor seal (Phoca vitulina) haul-out site use may be affected by natural or anthropogenic factors. Here, we use an 11-yr (1997–2007) study of a seal colony located near a mariculture operation in Drakes Estero, California, to test for natural (El Ni˜no-Southern Oscillation (ENSO), density-dependence, long-term trends) and anthropogenic (disturbance or displacement related to oyster production activities) factors that may influence the use of haul-out subsites. Annual mariculture related seal disturbance rates increased significantly with increases in oyster harvest (rs = 0.55). Using generalized linear models (GLMs) ranked by best fit and Akaike's Information Criteria, ENSO and oyster production (as a proxy for disturbance/displacement) best explained the patterns of seal use at all three subsites near the mariculture operations, with effects being stronger at the two subsites closest to operations. Conversely, density-dependence and linear trend effects poorly explained the counts at these subsites. We conclude that a combination of ENSO and mariculture activities best explain the patterns of seal haul-out use during the breeding/pupping season at the seal haul-out sites closest to oyster activities.

Becker, B. H., Press, D. T., & Allen, S. G. (2011). Evidence for Long-Term Spatial Displacement of Breeding and Pupping Harbour Seals by Shellfish Aquaculture over Three Decades. *Aquatic Conservations: Marine and Freshwater Ecosystems, 21*(3), 247-260 https://doi.org/10.1002/aqc.1181

1. Shellfish mariculture is increasing worldwide and often occurs adjacent to marine mammal breeding and feeding habitat. To better understand breeding pinniped vulnerability to potential shellfish mariculture disturbance and displacement effects in a US National Park, potential mechanisms were explored that may affect the proportion of harbour seals (Phoca vitulina) selecting high quality haul-out

sites near shellfish aquaculture within a large colony, and overall seal utilization of that colony in relation to other regional colonies. 2. Seal haul-out sites isolated from the mainland (no predator access) had higher pup:adult ratios, indicating they are generally more important for pupping. Short-term human disturbance did not have a significant effect on spatial use, but rather spatial use was pre-determined by general sandbar isolation. Using multiple competing hypothesis and an information-theoretic approach, it was found that within the estuary, after removing effects of El Nin˜o, the proportion of seals (total seals and pups only) hauled out near mariculture sites was 872% lower during years of higher oyster harvest. Annual oyster harvest was used as a measure of aquaculture activity that could result in direct disturbance or indirect displacement of harbour seals. 3. At the regional scale, oyster harvest, seal counts at a nearby colony, and loss of a major haul-out site withinthe estuary, best explained pup and total seal use compared with the region. Regional population size, short-term human disturbance rate, and other factors were not important. Concurrent with higher oyster harvest, the proportion of regional seals using the estuary declined by 772% for seal pups (–65718 total pups), and 572% for total counts (192758 total seals). These findings (both within the estuary and at the regional scale) were essentially identical whether modelling oyster harvest as either a continuous or categorical (low/high) variable and when using either frequentist or Bayesian statistical analyses. 4. Marine reserves set aside for wildlife may be less effective when the highest quality breeding and pupping sites are adjacent to regular aquaculture activities. These effects may not be detectable until additional natural variation lowers the quality of nearby habitats.

Berg, K. S. (2009). *Endangered Species Act - Section 7 Consultation Biological Opinion U.S. Fish and Wildlife Service Reference: 13410-2008-F-0461 Nationwide Permit #48 for Shellfish Aquaculture State of Washington.* U.S. Army Corps of Engineers U.S. Fish and Wildlife Service. Western Washington Office Portland, OR. Retrieved from https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2011111978.xhtml

This document transmits the U.S. Fish and Wildlife Service's (Service) Biological Opinion (Opinion) based on our review of the U.S. Corps of Engineers (Corps) proposal to implement the Nationwide Permit 48 for Shellfish Aquaculture (NWP 48) in Washington State for a 5-year period. The NWP 48 will be implemented under the authority of Section 404(e) of the Clean Water Act (33 U.S.C. 1344) and Section 10 of the Rivers and Harbors Act of 1899 (33 CFR 322.3(a)). This Biological Opinion addresses effects to listed resources under the Service's jurisdiction, in accordance with section 7 of the Endangered Species Act (Act) of 1973, as amended (16 U.S.C. 1531 et seq.). This Opinion is based on information provided in the Corps' Biological Assessment (BA) received on July 3, 2008, telephone conversations, meetings, field investigations, and other sources of information. A complete record of this consultation is on file at the Western Washington Fish and Wildlife Office in Lacey, Washington.

Bloch, P., Meaders, M., & Cziesla, C. (2017). *Coast Seafoods Company, Humboldt Bay Shellfish Aquaculture: Permit Renewal and Expansion Project California Environmental Quality Act (CEQA) Addendum.* Coast Seafoods/Pacific Seafood C. E. Company, Seattle, WA. Retrieved from http://humboldtbay.org/coast-seafoods-company-humboldt-bay-shellfish-aquaculture-permit-renewal-and-expansion-project

The Coast Seafoods Company (Coast), Humboldt Bay Shellfish Aquaculture: Permit Renewal and Expansion Project (Project) has evolved through public and agency feedback. This feedback and evolution has occurred from June 2014 when the original application was submitted to the Humboldt

Bay Harbor, Recreation and Conservation District (Harbor District) up until the culmination of the California Coastal Commission (Commission) process in September 2017. This California Environmental Quality Act (CEQA) Addendum evaluates the project proposal approved by the Commission (herein identified as the "Revised Project"), and compares it to the environmentally superior alternative identified in the certified Final Environmental Impact Report (FEIR) and approved by the Harbor District under CEQA (identified herein as the "Approved Project"). The FEIR and Revised Draft Environmental Impact Report (R-DEIR) prepared for the Approved Project are collectively referred to herein as the "Certified EIR."

Canada. Department of Fisheries and Oceans. (2006). *Assessing Habitat Risks Associated with Bivalve Aquaculture in the Marine Environment.* Fisheries and Oceans Canada Ottawa Retrieved from http://publications.gc.ca/collections/collection_2011/mpo-dfo/Fs70-6-2006-005-eng.pdf

Open-water, marine bivalve aquaculture is conducted in British Columbia and in all five provinces of Atlantic Canada, including Quebec. The term bivalve is preferred to shellfish because in Canada most shellfish species used in aquaculture are bivalves. On the Pacific coast almost all of these species are non-indigenous. The opposite is true on the Atlantic coast, where, with the exception of the flat oyster and bay scallop, bivalve culture is conducted with native species. This industry is important in coastal communities and is growing rapidly. In contrast to finfish aquaculture, bivalves are sustained on food that occurs naturally in the ecosystem. A wide range of practices and habitats are used in the culture of bivalves. A national workshop was held in Moncton NB, February 28 – March 3, 2006, to consider methods available to assess potential environmental risks of bivalve aquaculture in the marine environment. The workshop was based on the peer review of five working papers. Referees included scientists from around North America and Europe. Five teams, formed in August 2005, wrote the papers. Each paper focused on a particular theme and each theme was divided into a suite of questions. The themes were to identify:
1. positive and negative impacts of marine bivalve aquaculture on fish habitat;
2. chemical, biological or physical indicators to measure these effects;
3. modeling methodologies available to predict any impacts of bivalve aquaculture;
4. cumulative and far-field effects; and, 5. sensitive habitats that may be affected by bivalve aquaculture.

Díaz López, B., & Methion, S. (2017). The Impact of Shellfish Farming on Common Bottlenose Dolphins' Use of Habitat. *Marine Biology, 164*(4) https://doi.org/10.1007/s00227-017-3125-x

Shellfish farming is an expanding segment of marine aquaculture, but the impact of this industry on coastal cetacean species is only beginning to be considered. The interaction between mussel farming and coastal cetaceans in one of the world's leading producers of this bivalve (Galicia, NW Spain) was studied. Specifically, the habitat use of common bottlenose dolphins (Tursiops truncatus) was evaluated in relation to environmental, geographical, and anthropogenic variables. Over a period of 22 months spent in the field, 154 daily boat surveys and 353 common bottlenose dolphin encounters were done. Results of this study confirm that areas of mussel production are frequently utilized by common bottlenose dolphins. Of the investigated factors, shellfish farms appeared to have a clear effect, with increased bottlenose dolphin occurrence at mussel farm locations and in waters close to the aquaculture zones. These observations contrast with previous studies where the occurrence and distribution of coastal cetacean species decreased in association with shellfish aquaculture representing

a source of habitat loss and causing potentially negative effects. These differences suggest that the interactions between shellfish aquaculture and cetaceans are affected by the culture method and cetacean species involved. The positive relationships between dolphins' occurrence and mussel aquaculture zones are presumably the result of large aggregations of fish species around mussel rafts, which provide high densities of high-quality prey for dolphins. This study provides new insights into the understanding of how shellfish aquaculture influences coastal dolphins and hence support the design of policies aimed at implementing ecosystem management principles.

Duprey, N. M. T. (2007). *Dusky Dolphin (Lagenorhynchus Obscurus) Behavior and Human Interactions: Implications for Tourism and Aquaculture.* (Masters), Texas A&M University, Retrieved from http://hdl.handle.net/1969.1/ETD-TAMU-1388

Interactions between humans and dusky dolphins in the coastal waters of New Zealand are increasing. My research focused on tourism interactions, with Kaikoura as the study site; and, on habitat use in an active aquaculture area, with Admiralty Bay as the study site. In Kaikoura, companies engaged in commercial cetacean tourism (For Hire Company) have permits issued by the New Zealand's Department of Conservation, allowing them to take paying customers out to view and swim with wild dusky dolphins. During summer and fall of 2005, I assessed the effectiveness of a voluntary 'rest period' established to give time free of humans to the dolphins. I used a theodolite to track the movements of large groups of dusky dolphins and recorded the arrival, departure and behaviors of all vessels approaching within 400 m of the group. The 'rest period' resulted in a reduction of vessel visits compared to non-rest periods, yet one For Hire Company and private recreational vessels continued to visit dusky dolphin groups during this time. To increase compliance with the voluntary regulation, more education is needed targeting private recreational vessels. Weekend traffic was higher compared to weekday traffic, during both rest and non-rest periods; a large increase occurred in weekend non-commercial vessel traffic. Swimming with calves is prohibited by New Zealand's Marine Mammal Protection Regulations of 1992, yet 71.4 percent of the swim attempts I observed on-board For Hire Company tours were conducted with groups containing calves. More should be done to reduce the number of swims conducted with groups of dusky dolphins containing calves. In winter of 2005, I used hourly theodolite scans to record the number of dusky dolphin groups using Admiralty Bay, a different near-shore environment with less tourism than off Kaikoura, and with near-shore mussel farms. Groups of dusky dolphins were observed in Admiralty Bay using the full extent of the bay. This re-enforces previous findings that Admiralty Bay is an important winter foraging ground for dusky dolphins, and further aquaculture development in the bay would remove available foraging habitat.

Dutra, J. (1996). Truro Sea Scallop Aquaculture Project. *Journal of Shellfish Research, 15*(2), 452 Retrieved from https://www.biodiversitylibrary.org/page/3034772#page/466/mode/1up

The purpose of the Truro Aquaculture Project is to demonstrate the feasibility of cultured growth and development of the giant sea scallop (Placopecten magellanicus) in Cape Cod Bay, Massachusetts. The 10 acre site is located 2 miles off Truro, MA in water 60-70 feet deep and, as a designated critical habitat for the northern right whale, requires certain adaptations to minimize hazards and risk encounters for the whales. Working with National Marine Fisheries Service, the U.S. Army Corps of Engineers, and Cape Cod Resources, the facility design has eliminated all vertical lines, all hanging mid-water gear and 'spar buoys' have replaced traditional buoys. Plans for monitoring, emergencies and entanglements have been developed. Spat were produced by the Martha's Vineyard Shellfish Group for grow-out at the

Truro site. Spat collecting in the wild, using traditional methods, is also being investigated. Grow-out will consist of bottom enhancement, bottom caged culture and a bottom technique in which scallop spat is glued to ribbons of plastic mesh. The project director is a commercial fishermen and has experience and expertise in handling heavy gear in deep water. His understanding of structures in seawater and repair of marine structures are important assets for a project of this type. Underwater video and still photography are being used to document and monitor the facility as well as the habitat and animals. The restrictions placed upon the Massachusetts fisherman and the impact of the industry on stocks have lead to the development of alternative methods of shellfish and pelagic harvesting. Sea scallop aquaculture has the potential to prove an economically sound business venture thereby attracting interest from the local fishing community. Sea scallop ranching and farming is one option for an industry in need of change.

Elliott, M., & Hoagland, P. (1998, November 1998). *Exposed Longline Aquaculture of Mytilus Edulis - a Risk Analysis.* Paper presented at the First Annual Northeast Aquaculture Conference and Exposition, Rockport, ME. Retrieved from https://eos.ucs.uri.edu/seagrant_Linked_Documents/meu/meuw98001.pdf

A major problem hindering the expansion of aquaculture is the numerous user-conflicts that limit the availability of near-shore sites. A potential solution to this obstacle is the expansion of aquaculture to the open ocean, with its larger dilution capacity and the decreased risk of pollution and human interference. Scientists and engineers at WHOI currently are applying for permits to deploy a prototype submerged longline in Rhode Island Sound, in order to test the biological, engineering, and economic feasibility of raising blue mussels (Mytilus edulis) in an exposed environment. The longline design is being modeled after existing semi-exposed mussel aquaculture in the Baie de Chaleur, Quebec. Because the physical and biological forces at work in the open ocean vary significantly from near-shore environments, the risks involved are not well understood. This study is an attempt to characterize the potential hazards facing the project. These include biological risks, such as the lack of adequate food sources, predation, disease, entanglement with endangered species, and parasitism. The study also attempts to address the engineering hazards including anchor drift, line wear due to wave action or fish bite, the possibility of the longline being cut by boats, and consumption hazards including shellfish poisoning. By reviewing the literature and through extensive personal communication, this study surnma.rizcs and quantifies these risks where possible. Results an -presented in a time-line format, which includes an assessment of the variable risks for several decision nodes.

Fisher, P. R., & Boren, L. J. (2012). New Zealand King Shag (Leucocarbo Carunculatus) Foraging Distribution and Use of Mussel Farms in Admiralty Bay, Marlborough Sounds. *Notornis, 59*, 105-115 Retrieved from http://notornis.osnz.org.nz/new-zealand-king-shag-leucocarbo-carunculatus-foraging-distribution-and-use-mussel-farms-admiralty-b

To date there has been no published information describing the relative abundance, behaviour or distribution of the New Zealand king shag (Leucocarbo carunculatus) within mussel farm areas, despite the sensitivity of the species to human disturbance and the potential overlap of its range with proposed development of marine aquaculture. Four survey methods were employed as part of a multi-species research programme to develop methods for surveying marine mammals and seabird populations in aquaculture management areas. Two of the techniques, involving continuous timelapse photography of mussel farms and boat-based surveys through coastal farms were developed for this study. Timelapse

cameras showed that mussel farms buoys were used by king shags as temporary resting sites only. King shags were recorded on 36% of the farms (n = 44) from 13 surveys within inner Admiralty Bay. The low number of sightings within mussel farms suggests that farms are not important foraging or resting areas for king shags, at least in Admiralty Bay. The foraging range and density of king shags was not known before farms were developed, so no direct comparison or impact assessment can be made. Boat-based surveys were used to estimate the density of foraging shags, which showed that daily locations of foraging birds at sea can vary considerably on consecutive days and over the season. Previous environmental surveys to assess impacts of mussel farms on foraging areas are therefore unlikely to adequately represent the entire foraging range or most important feeding areas. The number of breeding pairs, chicks and nests was also found to vary considerably at colonies, dependent on when counts were undertaken during their protracted breeding season. Open water mid-bay aquaculture (shellfish and finfish) potentially poses a greater threat to king shags than 'coastal ribbon development', in terms of loss of open water habitat from farm structures, and loss of foraging habitat through modification to the water column (e.g., turbidity) and seabed. Given the lack of knowledge about the king shag population dynamics, diet and prey availability, there is an urgent requirement for more research to fill these gaps and also understand how we can conserve important shag feeding areas and associated marine environment through sustainable management of aquaculture.

Forrest, B. M., Keeley, N. B., Hopkins, G. A., Webb, S. C., & Clement, D. M. (2009). Bivalve Aquaculture in Estuaries: Review and Synthesis of Oyster Cultivation Effects. *Aquaculture, 298*(1-2), 1-15 https://doi.org/10.1016/j.aquaculture.2009.09.032

Oyster farming in estuaries is a globally important industry based primarily around the Pacific oyster Crassostrea gigas, for which a common technique is elevated culture on racks, trestles and other structures. We review literature on cultivation impacts, revealing a research focus and state of knowledge that largely parallels that for other aquaculture species and cultivation methods. Ecological studies of elevated culture effects have focused on changes to the benthos from biodeposition, and largely show that impacts are localized and minor by comparison with many other forms of aquaculture. The broader ecological issues associated with elevated oyster culture include the effects of pests (fouling pests, toxic/noxious microalgae, disease), creation of novel habitat (e.g. by fouling of farm structures and accumulation of shell), alteration to nutrient cycling, depletion of suspended particulate matter by oyster crops, and related effects on higher trophic level animals including fish, seabirds and marine mammals. These issues are less well understood for elevated culture systems, but ecological effects can be inferred from the few studies that have been conducted, from other forms of bivalve aquaculture (e.g. mussels), and to some extent from fundamental knowledge of the role of oysters as 'ecosystem engineers'. We use a risk ranking method to evaluate ecological risks (and associated uncertainty intervals) for each of the issues associated with estuarine oyster culture, based on subjective assessment of the likelihood and consequences (severity, spatial extent and duration) of adverse effects. Our assessment reveals that the introduction and spread of pest species are potentially important but often overlooked consequences of oyster cultivation. By comparison with most other sources of impact, the spread of pests by aquaculture activities can occur at regional scales, potentially leading to ecologically significant and irreversible changes to coastal ecosystems. We suggest that future studies of cultivation effects redress the balance of effort by focusing more on these significant issues and less on the effects of biodeposition in isolation. Furthermore, the acceptability of aquaculture operations or new developments should recognize the full range of effects, since adverse impacts may be compensated to some extent by the nominally 'positive' effects of cultivation (e.g. habitat creation), or may be reduced by appropriate planning and management. Even more broadly, aquaculture

developments should be considered in relation to other sources of environmental risk and cumulative impacts to estuarine systems at bay-wide or regional scales, so that the effects of cultivation are placed in context.

Gallardi, D. (2014). Effects of Bivalve Aquaculture on the Environment and Their Possible Mitigation: A Review. *Fisheries and Aquaculture Journal, 05*(03) https://doi.org/10.4172/2150-3508.1000105

Bivalve aquaculture, in particular oyster, clam, scallop and mussel culture, is a globally increasing activity. Increased bivalve production translates inevitably into increased impact on the environment surrounding the aquaculture activities. The effects of this type of aquaculture on the environment are often considered less important compared to those of finfish culture. However, bivalves due to their natural characteristics are considered keystone species in the ecosystem and therefore they have the ability to affect the surrounding environment in both negative and positive ways. They influence primary and secondary productivity and start a series of cascade effects on water column and sediment population and dynamics. The purpose of this article is to present a review of the effects of bivalve aquaculture on the surrounding environment and the current mitigation strategies. In addition, this review highlights how the same natural characteristics of bivalves can positively interact with the environment, and the possible use of bivalve aquaculture as restoration and remediation tool for marine environments.

Humboldt Bay Harbor Recreation and Conservation District. (2017). *Final Environmental Impact Report Coast Seafoods Company Humboldt Bay Shellfish Aquaculture Permit Renewal and Expansion Project Humboldt County, California.* Humboldt Bay Harbor, Recreation and Conservation District Eureka, CA Retrieved from http://humboldtbay.org/coast-seafoods-company-humboldt-bay-shellfish-aquaculture-permit-renewal-and-expansion-project

The Project proposes a comprehensive management plan for Coast's owned and leased area and shellfish farm expansion in Humboldt Bay. The Project involves: (1) extending regulatory approvals for Coast's existing approximately 300 acres of shellfish culture; (2) increasing shellfish culture within an already permitted floating upwelling system by adding eight culture bins; (3) authorizing culture of Pacific and Kumamoto oysters within Coast's existing clam rafts; (4) relocating approximately 5 acres of existing cultch-on-longline culture; and (5) permitting up to an additional 622 acres of intertidal culture in two phases.

Lloyd, B. (2003). *Potential Effects of Mussel Farming on New Zealand's Marine Mammals and Seabirds : A Discussion Paper*. Wellington, N.Z: Dept. of Conservation. Retrieved from https://catalogue.nla.gov.au/Record/3255706

Mussel farming is an important and expanding industry in New Zealand. In the year 2000, there were nearly 3000 ha of mussel farms, with proposals for a further 39 000 ha including offshore farms of up to 4000 ha each. There have been no concerted attempts to investigate the effects of mussel farms on marine mammals and seabirds. However, there is growing evidence of adverse effects as these animals are in direct competition for space in the most productive coastal waters. Mussel farms deplete phytoplankton and zooplankton; modify the benthic environment, species assemblages, and local hydrodynamics; increase marine litter; and facilitate the spread of unwanted organisms. Thus, the

establishment of mussel farms may lead to loss and degradation of wildlife habitat, either by exclusion or as a consequence of changes to the ecosystem. Thus far, the only adverse effects reported within New Zealand are the exclusion of dusky dolphins from mussel farms areas, and the entanglement and deaths of two Bryde's whales in mussel spat-catching lines. Because of the limited extent of mussel farms to date, effects on wildlife were dismissed as inconsequential. However, the proposed increase in the area used for mussel farming changes the scale of effects and prompts concern. The construction of large offshore farms across the seasonal migration routes of large whales is particularly worrying. An ecologically sustainable mussel farming industry requires a programme to monitor the industry's effects on wildlife and other forms of marine biodiversity. This report provides a resource to assist the mussel farming industry, coastal planners and researchers in the development of an ecologically sustainable industry.

Marine Mammal Commission. (2011). *Mariculture and Harbor Seals in Drakes Estero, California.* Retrieved from https://www.mmc.gov/wp-content/uploads/drakes_estero_report.pdf

In 2012 the Secretary of the Interior will determine whether to renew a Reservation of Use and Occupancy and a Special Use Permit issued to Drakes Bay Oyster Company for operations in Drakes Estero, an estuary on the West Coast just north of San Francisco, or convert the estuary to full wilderness status. The Secretary's determination is a matter of policy. Science, however, has a role in informing the Secretary about the potential consequences of his decision for resources within the estuary.

Markowitz, T. M., Harlin, A. D., Würsig, B., & McFadden, C. J. (2004). Dusky Dolphin Foraging Habitat: Overlap with Aquaculture in New Zealand. *Aquatic Conservation: Marine And Freshwater Ecosystems, 14*(2), 133-149 https://doi.org/10.1002/aqc.602

1. Marine farms have the potential to affect dolphin foraging in the coastal environment, yet this issue has been largely omitted from aquaculture management models. Data on the subject are minimal. This study was conducted to examine potential overlap between dusky dolphin habitat use and New Zealand's growing green-lipped mussel farming industry. 2. Data on dusky dolphin occurrence, distribution, abundance, and behaviour were collected from small vessels over five successive winters in the Marlborough Sounds, the centre of New Zealand's mussel farming industry. 3. Locations and movements of dolphin groups were recorded at 2 min intervals with a global positioning system receiver to examine the overlap of dusky dolphin use of coastal areas with existing and proposed marine farms. All cases of dolphins entering the boundaries of mussel farms and total time spent in farms were recorded. Over 8500 dolphin dorsal fin photographs were analysed to develop a catalogue of 421 marked individuals utilizing the area. All instances of dolphin feeding were noted, and focal group behaviour was recorded at 2 min intervals for groups observed 51h. 4. Within the Marlborough Sounds, dusky dolphins were most often encountered during the winter in Admiralty Bay, the area with the greatest density of proposed farming activity in the region. Mark-recapture data indicate that more than 1000 dusky dolphins used Admiralty Bay over the course of the 5 year study, with an average of 220 individuals inhabiting the bay on any given week during the winters of 1998–2002. As many as 55% of individuals returned to Admiralty Bay in consecutive winters. 5. Overlap of dusky dolphin habitat use with proposed marine farms is high, and dolphins rarely used areas within the existing farms. If dusky dolphin distribution with respect to farms were random, an expected 180.5 of 436 groups would be encountered in existing Inner Admiralty Bay farms; however, no dolphin groups were first encountered

in farms. 6. In 5 years, only eight of 621 dusky dolphin groups monitored in Admiralty Bay were observed to enter the boundaries of mussel farms at any point. Dolphins entering mussel farms moved rapidly up the lanes between rows of lines and floats. Dolphins were observed a total of 14.2 min inside farms versus 147.5 h outside of farms in Admiralty Bay. Correcting for area, dolphins were observed spending significantly less time per survey inside than outside of farms.

Methion, S., & Díaz López, B. (2019). Natural and Anthropogenic Drivers of Foraging Behaviour in Bottlenose Dolphins: Influence of Shellfish Aquaculture. *Aquatic Conservation: Marine And Freshwater Ecosystems, 29*(6), 927-937 https://doi.org/10.1002/aqc.3116

In the coastal environment, marine mammals are exposed to one of the fastest growing food production sectors; namely, the shellfish farming industry. Identification of critical habitats, such as foraging grounds in highly human-impacted areas, is essential to species conservation. Therefore, understanding the variables that influence a species' foraging behaviour is important for their conservation, especially for long-lived mammals such as cetaceans. The aims of this study were (a) to identify and quantify the environmental and anthropogenic drivers of wild bottlenose dolphin (Tursiops truncatus) foraging behaviour, and (b) to investigate whether the shellfish farming industry influences the behaviour of this species. Behavioural observations were conducted along the north-western coast of Spain, an area affected by intensive human activities, particularly the shellfish aquaculture industry. A multi-modelling approach highlighted the importance of shellfish farm areas as a foraging ground for bottlenose dolphins. Dolphins were predicted to be more likely found foraging inside shellfish farm areas than outside (57% vs. 43%). Variability in bottlenose dolphin behaviour is likely a result of the interactions of environmental and anthropogenic drivers with prey availability and the physiological needs of the dolphins. Although shellfish farm areas provide high prey density for dolphins, they can also pose threats in a number of ways (i.e. collisions with vessels, entanglement with ropes, habitat loss, noise and water pollution). From a conservation perspective, aquaculture management should consider the presence of dolphins foraging and minimize the associated risks that this industry may pose to these coastal cetaceans.

Pearson, H. C., Vaughn-Hirshorn, R. L., Srinivasan, M., & Wursig, B. (2012). Avoidance of Mussel Farms by Dusky Dolphins (Lagenorhynchus Obscurus) in New Zealand. *New Zealand Journal of Marine and Freshwater Research, 46*(4), 567-574 https://doi.org/10.1080/00288330.2012.712977

We describe fine-scale interactions between dusky dolphins and mussel farms in Admiralty Bay, New Zealand. We examined dusky dolphin presence in nearshore mussel farms, coordinated feeding behaviours in and near mussel farms, and long-term changes in regional population abundance. Sampling methods included boat-based surveys, focal follows, underwater observations, and photo-identification. Correcting for area, dusky dolphins spent significantly less time inside mussel farms versus outside mussel farms and other nearshore areas (both $P<0.001$). Prey balls entered or moved adjacent to mussel farms during 2/52 feeding bouts, after which dusky dolphin feeding behaviour ceased. Total estimated abundance during winter 20052006 was 712 (95% CI: 5111134) with a declining trend in annual abundance after 2003. Results suggest that: (1) dusky dolphins rarely use mussel farms; (2) mussel farms may hinder coordinated feeding strategies; and (3) the number of dusky dolphins using this foraging habitat varies between years and may be declining.

Piwetz, S. (2011). *Case Story Oceania 02: Shellfish Aquaculture in a Marine Mammal Habitat. Seminar in Cross-Cultural Communication: Communities and Conservation.* Texas A&M University Biodiversity Stewardship Lab. Wildlife & Fisheries Sciences. Retrieved from http://wfsc.tamu.edu/jpackard/behavior/wfsc681/Documents/4cases/oceania02_shellfish_Piwetz.pdf

Havelock, a small coastal village in the South Island of New Zealand, has the distinguishing title of "green-lipped mussel farming capital of the world". This proud community harvests much of its internationally famous fare from the productive waters of the Marlborough Sounds. Mussel farming, an occupation that began on a small scale in the Sounds in the 1970's, is now the largest aquaculture industry in New Zealand.
Economic development is a high priority of the New Zealand Aquaculture Council, the voice of the marine farming industry, with a national goal of increasing annual profits from $380 million NZD (approximately $304 million USD) in 2010 to $1 billion NZD (approximately $800 million USD) by 2025. Mussel farms in the Marlborough Sounds currently take up 28,000,000 m² of space (extending out to 200 m or more from shore and up to 40 m in depth) and farm operators have recently applied for extensions to existing farms in an effort to increase profits.
Several stakeholders who pride themselves in conserving the natural environment have voiced concern over the proposed expansion. Diverse marine mammal species, including fur seals and bottlenose, common, and dusky dolphins, naturally occur in the Marlborough Sounds at various times throughout the year. One concern is that the addition of vertically-suspended mussel lines will restrict marine mammal movement by taking up threedimensional space, which may ultimately lead to displacement of some species from the habitat. Some fear that this will lead to alterations of the natural ecosystem with far-reaching impacts on the animals that utilize the bay.
Within the small Marlborough Sounds region, stakeholders with conflicting perspectives on aquaculture expansion often live in close proximity. One local community member stated that people are careful about expressing their opinions because of the conflict it can create among neighbors. The following sections describe several of the current stakeholder perspectives.

Price, C. S., Morris, J. A., Jr., Keane, E. P., Morin, D. M., Vaccaro, C., & Bean, D. W. (2017). *Protected Species and Marine Aquaculture Interactions.* United States, National Ocean Service https://doi.org/10.7289/V5/TM-NOS-NCCOS-211

This assessment summarizes the current state of knowledge regarding documented and potential interactions of species listed under the Endangered Species Act as amended (ESA; 16 U. S. C. ' 1531--1543), such as sea turtles and marine mammals, with offshore longline mussel culture gear. Its primary purpose is to strengthen the ability of the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) Greater Atlantic Regional Fisheries Office (GARFO) to make science-based decisions and recommendations as part of the review and consultation process required to permit aquaculture operations in federal waters. Although developed in coordination with GARFO staff, this assessment is highly relevant to efforts already underway and upcoming in other U. S. regions to permit longline mussel aquaculture. The information in this assessment is useful for guiding the regulatory process of Protected Resources Division (PRD) consultations to meet the agency goals of advancing aquaculture in the open ocean while still meeting its mandates under the ESA. In addition to summarizing what is known and providing a state of science analysis, the assessment includes a preliminary risk analysis to evaluate potential for harmful interactions between aquaculture and protected species. It also identifies knowledge gaps and areas of needed research. We gathered relevant

publications and data on protected species interactions with specific gear types used in commercial marine aquaculture and explored interactions with similar or analogous fishing gear. We used this information to provide management options to help coastal managers to make informed science-based recommendations about permitting, siting and managing aquaculture in a manner consistent with federal mandates to protect imperiled species, while also supporting the production of sustainably grown seafood

Richman, S. E. (2013). Sea Duck Predation on Mussel Farms: A Growing Conflict. Retrieved from https://www.mbl.edu/mrc/files/2013/05/richman13_predation.pdf

The cultivation of blue mussels (Mytilus edulis) is a growing industry worldwide; however predation by migrating sea ducks has become an enormous challenge to mussel growers causing extensive financial losses.

Tallis, H. M., Ruesink, J. L., Dumbauld, B., Hacker, S., & Wisehart, L. M. (2009). Oysters and Aquaculture Practices Affect Eelgrass Density and Productivity in a Pacific Northwest Estuary. *Journal of Shellfish Research, 28*(2), 251-261, 211 https://doi.org/10.2983/035.028.0207

The presence of bivalves and bivalve aquaculture can have positive and negative impacts on seagrass and associated benthic communities. Some oyster (Crassostrea gigas) aquaculture methods recently have been restricted to reduce benthic disturbance and protect native eelgrass (Zostera manna) in West coast (USA) estuaries. We argue that aquaculture, like all food production systems, involves tradeoffs with natural systems, but that the magnitude of those tradeoffs depends on the ecological details of the production system. Capitalizing on oyster aquaculture farms as large scale “manipulations” in Willapa Bay, WA (USA), we explored three different oyster aquaculture methods (mechanical harvest or “dredged” on-bottom, hand-picked on-bottom and long line off-bottom). We found that both the biological (oyster-eelgrass interactions) and physical (disturbance or structure) components of aquaculture led to changes in the eelgrass population. Eelgrass density declined with oyster density in all aquaculture areas, likely as a result of direct competition for space. Eelgrass relative growth rate, plant size, and production did not change with oyster density. However, all eelgrass measures were affected by aquaculture, and the type and magnitude of impacts varied among eelgrass measures and aquaculture methods. Throughout the bay, eelgrass in long line areas occurred at densities indistinguishable from nearby uncultivated areas, but in 2004, eelgrass in long line areas was smaller (32%) and had lower production per area (70%). Cultivating oysters in dredged or hand picked beds increased eelgrass growth rates slightly, but led to lower eelgrass density (70% and 30%, respectively), plant size (32%, both cases), and production (70%, both cases). In a large scale simulated mechanical harvest experiment, the temporal response of eelgrass density varied dramatically by site, ranging from 1 to >4 y. If eelgrass impact reduction, rather than avoidance, is identified as the management goal, the degree of tradeoff between eelgrass habitat and oyster production can be minimized by managing aquaculture methods or oyster planting densities, depending on the eelgrass measure of interest. Explicit management goals and appropriate eelgrass habitat indicators must be developed before our findings can be used to suggest best management practices for intertidal aquaculture in the Pacific Northwest.

Varennes, É., Hanssen, S. A., Bonardelli, J., & Guillemette, M. (2013). Sea Duck Predation in Mussel Farms: The Best Nets for Excluding Common Eiders Safely and Efficiently. *Aquaculture Environment Interactions, 4*(1), 31-39 https://doi.org/10.3354/aei00072

Shellfish aquaculture is a growing food-producing sector. The blue mussel Mytilus edulis is the primary farmed shellfish and is also a main prey for various species of sea ducks. With their large density of high-quality mussels, mussel farms attract these predators, and consequent depredation by ducks represents a substantial economic loss among mussel growers worldwide. Total exclusion with nets seems to be the only method that provides complete and long-term control of bird predation. The best nets for duck exclusion must be cost effective, efficient, easy to handle, and safe for bird populations. In order to identify the best net type, we tested 8 different nets under controlled conditions using captive common eiders Somateria mollissima, the largest sea duck species in the Northern Hemisphere. We identified a net with a maximum mesh size of 6 inches (~15 cm) and large twine size to be best in excluding common eiders considering the above-mentioned criteria. Nets with thin twine and large mesh size were more likely to cause bird entanglement. In addition to using the best nets for sea duck exclusion, it is necessary to identify a target zone where such nets are the most effective. Good knowledge of the predation problem as well as collaboration among mussel growers, bird specialists, and government authorities are essential to reduce the costs and effort of installing and maintaining exclusion nets.

Vaudrey, J. M. P., Getchis, T., Shaw, K., Markow, J., Britton, R., & Kremer, J. N. (2009). Effects of Oyster Depuration Gear on Eelgrass (Zostera Marina L.) in a Low Density Aquaculture Site in Long Island Sound. *Journal of Shellfish Research, 28*(2), 243-250, 248 https://doi.org/10.2983/035.028.0206

Oyster (Crassostrea virginica) aquaculture has a long history and tradition in Long Island Sound (Connecticut, USA). Although most of the producers practice traditional on-bottom aquaculture, there are a growing number of individuals utilizing bottom gear for cultivation and depuration. The use of this gear presents a potential conflict in eastern Long Island Sound where the last remaining populations of eelgrass (Zostera marina L.) exist. Shellfish aquaculture activity has been identified as a potential source for negative impacts to eelgrass populations. However, bivalve aquaculture has also been shown to provide an equivalent or greater degree of ecosystem services as submerged aquatic vegetation. The effects of short-term oyster depuration activity were gauged by comparing eelgrass reference sites and experimental plots (eelgrass areas containing oyster depuration cages with and without oysters) in triplicate. Changes in sheath length of the eelgrass 1 m from the cages were used as a proxy for growth rate. The aquaculture gear had no effect on this measure of growth rate of eelgrass in any of the deployments. Sediment characteristics (sediment chlorophyll, sediment % organics) in the cage footprint and 1m from the cages also failed to show an effect of the depuration cages on the local environment. Video monitoring of the footprints and local area indicated little physical damage to the eelgrass beds as a result of the short deployment of the aquaculture gear. The water column at all three sites was vertically well mixed and no effect of the cages on water column light and other characteristics was detectable. The results of this study indicated that at the current level of activity, short-term depuration of oysters has minimal effect on eelgrass growth, water quality and the sediment characteristics measured. However, if depuration activity expands in terms of the amount of gear and/or individual operations, it may result in measurable effects. Understanding the interactions between shellfish aquaculture activity and the marine environment is necessary for sustainable growth of the industry.

Watson-Capps, J. J., & Mann, J. (2005). The Effects of Aquaculture on Bottlenose Dolphin (Tursiops Sp.) Ranging in Shark Bay, Western Australia. *Biological Conservation, 124*(4), 519-526 https://doi.org/10.1016/j.biocon.2005.03.001

The increasing presence of aquaculture in coastal waters calls for a better understanding of its environmental effects. Currently little information is available on the impact of shellfish farms on cetaceans. Here we compare long-term ranging patterns of adult female bottlenose dolphins (Tursiops sp. in Shark Bay, Western Australia) before and during full-scale pearl oyster farming operations, to determine if they were displaced. When the exact location of the oyster farm was determined, the dolphins decreased their use of that area after the farm was in place. Tracks of adult female dolphin movement near the oyster farm were compared to tracks of dolphin movement near an ecologically similar area where no oyster farm existed. Tracks near the oyster farm were less likely to enter the oyster farm itself than tracks near an ecologically similar location. This suggests that shellfish aquaculture could have a large impact on small cetaceans. The analytical techniques discussed apply broadly to aquatic and terrestrial animals.

Weise, A. M., Cromey, C. J., Callier, M. D., Archambault, P., Chamberlain, J., & McKindsey, C. W. (2009). Shellfish-Depomod: Modelling the Biodeposition from Suspended Shellfish Aquaculture and Assessing Benthic Effects. *Aquaculture, 288*(3), 239-253 https://doi.org/10.1016/j.aquaculture.2008.12.001

By predicting the dispersal of particulate aquaculture wastes around farm sites, numerical modelling can provide an effective tool to assess the spatial extent of environmental effects. The present paper describes how the aquaculture waste model DEPOMOD (Cromey, C.J., Nickell, T.D., Black, K.D. 2002a. DEPOMOD — modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214, 211–239.), originally developed for finfish aquaculture sites, was adapted and validated for suspended shellfish aquaculture. Field data were collected for species-specific model input parameters (mussel biodeposition rates and particle settling velocities) and several finfish model parameters (farm representation and calculation of aquaculture wastes) were adjusted for the shellfish scenario. Shellfish-DEPOMOD was tested at three coastal mussel Mytilus edulis farms with differing hydrodynamic regimes in Quebec, Canada. For each site, model predictions were compared to observed deposition measured in situ with sediment traps. Sedimentation rates under the three mussel culture sites were ca. two to five times those observed at corresponding reference sites. Mussel biodeposits were predicted to accumulate within 30 m of the farms in the shallow depositional sites while being dispersed more than 90 m in the deeper dispersive site. At the farm site in Great-Entry Lagoon, model predictions agreed well with field data for the 0+ and 1+ mussel cohorts when the maximum biodeposit production parameter was used. At the farm site in House-Harbour Lagoon, model predictions did not agree with observed sedimentation rates, due most likely to the resuspension and advection of non farm-derived material and complex hydrodynamics. The model correctly predicted the pattern of waste dispersal at the third farm site in Cascapedia Bay, although it underestimated biodeposition. Predicted fluxes may have been underestimated at this site because biodeposits from biofouling communities were not included in the calculation of aquaculture wastes. The relationship between modelled long-term biodeposition and benthic descriptors was assessed for the three farms. Alterations to the benthic community were observed at high biodeposition rates (>15 g m−2 d−1). At the most disturbed site, predicted fluxes were best correlated with the Infaunal Trophic Index (ITI) (R=−0.79, P<0.001), followed by AZTI's marine disturbance index (AMBI) (R=0.64, P<0.001). The potential application of Shellfish-DEPOMOD in terms of the management of shellfish aquaculture sites is discussed.

Wells, F. E., & Jernakoff, P. (2006). An Assessment of the Environmental Impact of Wild Harvest Pearl Aquaculture (Pinctada Maxima) in Western Australia. *Journal of Shellfish Research, 25*(1), 141-150 https://doi.org/10.2983/0730-8000(2006)25[141:AAOTEI]2.0.CO;2

Typical operating procedures used in the wild harvest pearl aquaculture (Pinctada maxima) industry in Western Australia are described as a basis for examining the potential environmental impact of the industry. A risk analysis workshop was held, which included industry representatives, marine scientists, regulatory agencies and conservation interests. The goal of the workshop was to document the main potential environmental and ecological risks that arise from the various activities carried out by the P. maxima industry. Thirteen environmental and ecological issues were identified across the P. maxima fishery. None were considered to be high risks; all were ranked as either moderate (23%) or low (77%). Moderate risk rankings included: introduction of disease from seeding; attraction of other fauna and introduction of exotic organisms. Low risks were: spread of disease; introduction of disease from hatchery; introduction of disease from translocation; impact to protected and endangered species resulting from entanglement; impact of habitat; impact to protected and endangered species resulting from farm lighting; nutrient impacts in sediment; perceived change in water quality; potential for litter and reduction of primary productivity. The low ratings given to disease risks took into account current strict regulatory controls for minimizing disease risks. The industry is considered to be environmentally benign. However, recommendations are made on how to further minimize risk.

Wisehart, L. M., Dumbauld, B. R., Ruesink, J. L., & Hacker, S. D. (2007). Importance of Eelgrass Early Life History Stages in Response to Oyster Aquaculture Disturbance. *Marine Ecology Progress Series, 344*, 71-80 https://doi.org/10.3354/meps06942

Seagrasses are a critical element in many estuaries and act as drivers of abiotic and biotic processes. One species, Zostera marina L., has been declining globally. A potential contributor to this decline is shellfish aquaculture, although we know little about its impacts. On the US west coast, shellfish aquaculture co-occurs with protected eelgrass habitats. Many aquaculture practices constitute a periodic disturbance, and a key concern is eelgrass recovery. We used observations and experiments to understand how oyster aquaculture practices (i.e. dredging [oysters grown on the bottom and harvested mechanically via dredging] and off-bottom longline culture [oysters suspended off the bottom on rope and harvested by hand]) influence eelgrass recovery. Studies of natural recruitment showed highest seedling densities in dredged beds (7 seedlings m–2) and lowest under longlines (0.1 seedlings m–2). Seed production was highest in dredged beds (295 seeds m–2) and lowest in longline beds (52 seeds m–2). Seed addition experiments were conducted to understand the effect of oyster aquaculture and adult eelgrass neighbors on seedling germination, growth, and survival. In March 2005, seedling germination was 146% higher in eelgrass removal treatments compared to control plots, with no difference among aquaculture and reference areas. By April 2005, there were no effects of neighbors, but reference areas had greater seed densities (11 seedlings m–2) compared to longline areas (3.2 seedlings m–2). By August 2005, seedling mortality in longline and reference control plots was 100%. In dredged areas, seedlings in removal plots had greater biomass (0.38 g) than seedlings in control plots (0.14 g). We propose that if eelgrass is to be disturbed by aquaculture, dredge beds may recover more successfully than longline beds.

Young, M. O. (2015). *Marine Animal Entanglements in Mussel Aquaculture Gear: Documented Cases from Mussel Farming Regions of the World Including First-Hand Accounts from Iceland.* (Masters), University of Akureyri, Reykjavík. Retrieved from http://hdl.handle.net/1946/22522

Mussel aquaculture utilizes various ropes in the water column that may pose an entanglement risk to cetaceans and sea turtles. In contrast to fishing gear, however, there are far fewer documented entanglement cases in mussel aquaculture gear. With that being said, there has been little data collected on this issue to date. Due to the growing demand for aquaculture and potential expansion into offshore areas, interactions with cetaceans and sea turtles are likely to continue and even increase into the future. In Iceland, the mussel aquaculture industry is currently small and largely experimental, but there is potential for expansion. The development of a successful management plan is dependent on understanding what type and part of the gear poses the greatest entanglement risk, as well as the location and timing of events in relation to cetacean feeding and migration patterns. The objective of this thesis is to lay the foundation for future studies regarding cetacean and sea turtle entanglements in mussel aquaculture gear. Documented entanglement cases were collected from mussel farming regions of the world via media outlets, academic articles, secondary sources, and informal interviews. Primary data collection was then undertaken in Iceland using online surveys and semi-structured interviews with mussel operators. In total, seven entanglement reports were collected, including four baleen whales, one harbour porpoise, and two leatherback turtles. A majority of cases involved mussel spat collecting ropes, which suggests this part of the gear may pose the greatest entanglement risk. Two entanglement reports were from Iceland, where there is likely proximity between cetacean distributions and mussel farming sites. Summer spat collection also coincides with the highest densities of cetaceans in Icelandic waters. Management suggestions for Iceland may include the implementation of a reporting system for entanglements in aquaculture gear and studies looking into areas where spat collection can occur with low likelihood of encountering cetaceans.

C. Algae Aquaculture

Hughes, S. N., Tozzi, S., Harris, L., Harmsen, S., Young, C., Rask, J., . . . Trent, J. D. (2014). Interactions of Marine Mammals and Birds with Offshore Membrane Enclosures for Growing Algae (Omega). *10*(1), 3 https://doi.org/10.1186/2046-9063-10-3

Background: OMEGA is an integrated aquatic system to produce biofuels, treat and recycle wastewater, capture CO2, and expand aquaculture production. This system includes floating photobioreactors (PBRs) that will cover hundreds of hectares in marine bays. To assess the interactions of marine mammals and birds with PBRs, 9 × 1.3 m flat panel and 9.5 × 0.2 m tubular PBRs were deployed in a harbor and monitored day and night from October 10, 2011 to Janurary 22, 2012 using infrared video. To observe interactions with pinnipeds, two trained sea lions (Zalophus californianus) and one trained harbor seal (Phoca vitulina richardii) were observed and directed to interact with PBRs in tanks. To determine the forces required to puncture PBR plastic and the effects of weathering, Instron measurements were made with a sea otter (Enhydra lutris) tooth and bird beaks. Results: A total of 1,445 interactions of marine mammals and birds with PBRs were observed in the 2,424 hours of video recorded. The 95 marine mammal interactions, 94 by sea otters and one by a sea lion had average durations of three minutes (max 44 min) and represented about 1% of total recording time. The 1,350 bird interactions, primarily coots (Fulica americana) and gulls (Larus occidentalis and L. californicus) had average durations of six minutes (max. 170) and represented 5% of recording time. Interactive behaviors were characterized as passive (feeding, walking, resting, grooming, and social activity) or proactive (biting,

pecking, investigating, and unspecified manipulating). Mammal interactions were predominantly proactive, whereas birds were passive. All interactions occurred primarily during the day. Ninety-six percent of otter interactions occurred in winter, whereas 73% of bird interactions in fall, correlating to their abundance in the harbor. Trained pinnipeds followed most commands to bite, drag, and haul-out onto PBRs, made no overt undirected interactions with the PBRs, but showed avoidance behavior to PBR tethers. Instron measurements indicated that sea-otter teeth and gull beaks can penetrate weathered plastic more easily than new plastic. Conclusions: Otter and bird interactions with experimental PBRs were benign. Large-scale OMEGA systems are predicted to have both positive and negative environmental consequences.

Poonian, C. N. S., & Lopez, D. D. (2016). Small-Scale Mariculture: A Potentially Significant Threat to Dugongs (Dugong Dugon) through Incidental Entanglement. *Aquatic Mammals, 42*(1), 56 https://doi.org/10.1578/AM.42.1.2016.56

Dugongs (Dugong dugon) are threatened by incidental capture in small-scale fisheries, but other static underwater structures could present a similar entanglement risk. In December 2013, an adult male dugong was entangled in the ropes of a sea-weed farm in Busuanga, Palawan, Philippines, and drowned. Anecdotal reports of similar incidents suggest that this was not an isolated occurrence. Given that dugong populations are slow to reproduce and cannot sustain even low levels of mortality, effective marine spatial planning is essential to minimize overlap between dugong habitat and mariculture operations.

D. Multiple Cultured Species Considered

Baker, A. N. (2005). *Sensitivity of Marine Mammals Found in Northland Water to Aquaculture Activities Report to the Department of Conservation, Northland Conservancy.* Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.576.9339&rep=rep1&type=pdf

1268 sighting records of marine mammals around the Northland coast are examined in relation to possible detrimental impacts from proposed aquaculture developments. An attempt is made to identify any critical habitats for marine mammals and assess whether aquaculture will modify the behaviour of the animals significantly. The Bay of Islands and Whangarei Harbour produced the most localized and detailed sightings, and both areas are judged to be critical habitats. Other parts of the Northland coast have the potential to be critical habitats, but at present such a categorization is not supported by the data. Potential threats to marine mammals from aquaculture are reviewed and suggestions for mitigation are made in some instances. A need for further research is identified, particularly to identify critical marine mammal habitats and to quantify impacts from proposed developments.

Borg, J., Crosetti, D., & Massa, F. (2011). *Site Selection and Carrying Capacity in Mediterranean Marine Aquaculture: Key Issues. Draft Report Gfcm:Xxxv/2011/Dma.9.* Paper presented at the General Fisheries Commission for the Mediterranean, Rome, Italy. http://gfcmsitestorage.blob.core.windows.net/documents/web/GFCM/35/GFCM_XXXV_2011_Dma.9.pdf

This document is a draft version of the report for the first year of the SHoCMed Project “Developing

site selection and carrying capacity guidelines for Mediterranean aquaculture within aquaculture appropriate areas", which is funded by the EU's DG Mare, and implemented within the GFCM CAQ Working Group on Site Selection and Carrying Capacity. The report has two components: the first, covered by Chapter 1, deals with the SHoCMed Project rationale and outlines the activities carried out during the first year. Various experts have contributed to and/or attended the various meetings held as part of the SHoCMed Project. A list of participants of the meetings is presented in Appendix 1. The second component of the present report, covered by Chapters 2 - 8, comprises a series of reviews by Mediterranean experts that are aimed at providing a regional inventory of information and a source of reference which are useful for participants of the SHoCMed Project and for professionals involved in aquaculture in general. Chapter 2 covers various aspects of interactions between aquaculture and the environment, and also includes a list of international initiatives and projects on aquaculture environment topics, and site selection and carrying capacity issues, and a bibliographical list (as an appendix) of published works that are relevant to the theme. Chapter 3 comprises a review of aspects of environmental monitoring of aquaculture activities and includes a guide on useful variables and parameters that can be used to monitor aquaculture activities. Chapter 4 covers thresholds for environmental change that may be applied in monitoring of aquaculture activities. Various aspects of environmental criteria and other important considerations, including bottlenecks, in relation to site selection for aquaculture, are reviewed in Chapter 5. Aspects of interactions between aquaculture and other uses of the coastal zone, and economic bottlenecks are respectively covered in Chapters 6 and 7. Finally, Chapter 7 comprises a review of procedures for site selection, regulatory schemes and EIA procedures that are used in the various Mediterranean countries. This last chapter also presents the results of surveys, carried out as part of the SHoCMed project, that were aimed at establishing the guidelines, laws and other relevant procedures (including the EIA) and administrative procedures that are used by various countries in the Mediterranean.

Buck, B. H., & Langan, R. (2017). *Aquaculture Perspective of Multi-Use Sites in the Open Ocean*: Springer Open. https://doi.org/10.1007/978-3-319-51159-7

This edited volume "Aquaculture Perspective of Multi-Use Sites in the Open Ocean: The Untapped Potential for Marine Resources in the Anthropocene" comes at a critical time for our planet. A 2015 article in Science updated the long-range population projections of the United Nations in 1992. In contrast to the 1992 UN estimate, the Science paper showed no stabilization of the world's population by 2100, and that there was an 80% chance that the world's population, currently 7.2 billion, will reach 9.6 billion by 2050, and up to 12.3 billion in 2100. Much of the increases result from growth in Africa and Asia. Many of the nations on these two continents consume aquatic foods as their main sources of animal proteins. Accelerated demands for aquatic proteins in these regions will mean that in the future they will not export their products to Europe and North America anymore but use them in domestic markets.

Callier, M. D., Byron, C. J., Bengtson, D. A., Cranford, P. J., Cross, S. F., Focken, U., . . . McKindsey, C. W. (2018). Attraction and Repulsion of Mobile Wild Organisms to Finfish and Shellfish Aquaculture: A Review. *Reviews in Aquaculture, 10*(4), 924-949 https://doi.org/10.1111/raq.12208

Knowledge of aquaculture-environment interactions is essential for the development of a sustainable aquaculture industry and efficient marine spatial planning. The effects of fish and shellfish farming on sessile wild populations, particularly infauna, have been studied intensively. Mobile fauna, including

crustaceans, fish, birds and marine mammals, also interact with aquaculture operations, but the interactions are more complex and these animals may be attracted to (attraction) or show an aversion to (repulsion) farm operations with various degrees of effects. This review outlines the main mechanisms and effects of attraction and repulsion of wild animals to/from marine finfish cage and bivalve aquaculture, with a focus on effects on fisheries-related species. Effects considered in this review include those related to the provision of physical structure (farm infrastructure acting as fish aggregating devices (FADs) or artificial reefs (ARs), the provision of food (e.g. farmed animals, waste feed and faeces, fouling organisms associated with farm structures) and some farm activities (e.g. boating, cleaning). The reviews show that the distribution of mobile organisms associated with farming structures varies over various spatial (vertical and horizontal) and temporal scales (season, feeding time, day/night period). Attraction/repulsion mechanisms have a variety of direct and indirect effects on wild organisms at the level of individuals and populations and may have implication for the management of fisheries species and the ecosystem in the context of marine spatial planning. This review revealed considerable uncertainties regarding the long-term and ecosystem-wide consequences of these interactions. The use of modelling may help better understand consequences, but long-term studies are necessary to better elucidate effects.

Cornelisen, C. (2013). Effects on Wild Fish. In *Literature Review of Ecological Effects of Aquaculture.* R. Ford (Ed.): Ministry for Primary Industries Retrieved from https://www.mpi.govt.nz/dmsdocument/4300-overview-of-ecological-effects-of-aquaculture

Aquaculture in New Zealand involving the addition of feed is currently focused on finfish and, in particular, the farming of king salmon within coastal embayments along New Zealand's South Island. The effects of finfish farms on wild fish are expected to be generally similar across the other species likely to be farmed in New Zealand.

Early, G. (2001). *The Impact of Aquaculture on Marine Mammals.* Paper presented at the Marine Aquaculture and the Environment: A Meeting for Stakeholders in the Northeast., Falmouth, Massachusetts.

A popularly recognized point of conflict between marine mammals and aquaculture centers around the potential impact of predators, particularly seals, on marine aquaculture sites. A real or perceived need to control predators puts aquaculturists in conflict with many of the general public who are concerned with the conservation and welfare of the same animals. The actual or potential impacts of aquaculture facilities on marine mammals, while less commonly articulated, puts the same stakeholders in a similar conflict. This paper addresses the impacts of aquaculture on marine mammals. In either case, the stakeholders are the same and the regulatory framework unforgiving.
Marine mammals are protected by the Marine Mammal Protection Act (and in some cases the Endangered Species Act) making it illegal to kill, harass, or disrupt marine mammals without authorization. There is little scientific data to support either side of each controversy. Only potential direct and indirect hazards to marine mammals can be readily identified. Direct impacts due to entanglement in sea pens have been reported in several instances including; common and bottlenose dolphins in blue fin tuna grow out pens in South Australia, grey whales in temporary net pens for herring on the US west coast, and a Bryde's whale in a mussel farm at Port Fitzroy on great Barrier Island New Zealand. While these events appear to involve a limited number of individuals, they span a wide range of geographic locations, types of aquaculture operation and impacted species.

Gentry, R. R., Lester, S. E., Kappel, C. V., White, C., Bell, T. W., Stevens, J., & Gaines, S. D. (2017). Offshore Aquaculture: Spatial Planning Principles for Sustainable Development. *Ecol Evol, 7*(2), 733-743 https://doi.org/10.1002/ece3.2637

Marine aquaculture is expanding into deeper offshore environments in response to growing consumer demand for seafood, improved technology, and limited potential to increase wild fisheries catches. Sustainable development of aquaculture will require quantification and minimization of its impacts on other ocean-based activities and the environment through scientifically informed spatial planning. However, the scientific literature currently provides limited direct guidance for such planning. Here, we employ an ecological lens and synthesize a broad multidisciplinary literature to provide insight into the interactions between offshore aquaculture and the surrounding environment across a spectrum of spatial scales. While important information gaps remain, we find that there is sufficient research for informed decisions about the effects of aquaculture siting to achieve a sustainable offshore aquaculture industry that complements other uses of the marine environment.

Goldburg, R., Triplett, T., & Environmental Defense, F. (1997). *Murky Waters : Environmental Effects of Aquaculture in the United States.* Environmental Defense Fund Washington, D.C. Retrieved from https://web.archive.org/web/20090114021004/http://www.edf.org/documents/490_AQUA.PDF

The international seafood industry is undergoing a major transition. The percentage of seafood from wild fisheries is steadily decreasing, and fish farming is the source of a steadily increasing percentage of seafood in the United States and worldwide. Unfortunately, existing aquaculture operations can be a significant source of chemical and biological pollutants and nutrient wastes. Untreated fish wastes have the potential to add to coastal pollution problems such as recent outbreaks of the toxic microbe Pfiesteria piscicida, which some experts believe are linked to wastes from hog and poultry farms. If the U.S. aquaculture industry is to expand and thrive, its operations must be financially profitable as well as environmentally safe in order to be acceptable to the communities in which they are located. Otherwise the industry may fail because community members will believe that all they receive from aquaculture facilities is their pollution. This report identifies environmental problems caused by aquaculture and recommends approaches to establishing an aquaculture industry that is environmentally and economically sound.

Goldburg, R. J., Elliott, & Naylor, R. L. (2001). *Marine Aquaculture in the United States. Environmental Impacts and Policy Options*. Arlington, Virginia: Pew Oceans Commission. Retrieved from https://www.iatp.org/documents/marine-aquaculture-in-the-united-states-environmental-impacts-and-policy-options-1

The aquaculture industry in the United States, which is dominated by freshwater catfish (Ictalurus punctatus) production, generates about one billion dollars each year. Marine aquaculture comprises roughly one-third of U.S. production by weight, and despite rapid increases in salmon and clam production, growth of U.S. marine aquaculture has been slow on average. Aquaculture has a number of economic and other benefits. But if it is done without adequate environmental safeguards it can cause environmental degradation. The main environmental effects of marine aquaculture can be divided into

the following five categories: 1) Biological Pollution: Fish that escape from aquaculture facilities may harm wild fish populations through competition and interbreeding, or by spreading diseases and parasites. Escaped farmed Atlantic salmon (Salmo salar) are a particular problem, and may threaten endangered wild Atlantic salmon in Maine. In the future, farming transgenic, or genetically modified, fish may exacerbate concerns about biological pollution. 2) Fish for Fish Feeds: Some types of aquaculture use large quantities of wild-caught fish as feed ingredients, and thus indirectly affect marine ecosystems thousands of miles from fish farms. 3) Organic Pollution and Eutrophication: Some aquaculture systems contribute to nutrient loading through discharges of fish wastes and uneaten feed. Compared to the largest U.S. sources of nutrient pollution, aquaculture's contribution is small, but it can be locally significant. 4) Chemical Pollution: A variety of approved chemicals are used in aquaculture, including antibiotics and pesticides. Chemical use in U.S. aquaculture is low compared to use in terrestrial agriculture, but antibiotic resistance and harm to nontarget species are concerns. 5) Habitat Modification: Marine aquaculture spreads over 26,000 marine hectares, or roughly 100 square miles. Some facilities attract marine predators, and can harm them through accidental entanglement or intentional harassment techniques.

Heinrich, S. (2006). *Ecology of Chilean Dolphins and Peale's Dolphins at Isla Chiloé, Southern Chile.* (Doctor of Philosophy), University of St Andrews, Retrieved from http://hdl.handle.net/10023/365

Information on the ecology of sympatric species provides important insights into how different animals interact with their environment, with each other, and how they differ in their susceptibility to threats to their survival. In this study habitat use and population ecology of Chilean dolphins (Cephalorhynchus eutropia) and sympatric Peale's dolphins (Lagenorhynchus australis) were investigated in the Chiloe Archipelago in southern Chile from 2001 to 2004. Distribution data collected during systematic boat-based sighting surveys revealed a distinct pattern of small-scale habitat partitioning, probably reflecting differences in foraging strategies and habitat preference. Chilean dolphins were sighted consistently in the same selected bays and channels in southern Chiloe. Peale's dolphins were distributed over wider areas, and were more frequently encountered in central Chiloe. Spatial overlap between both dolphin species and mariculture farms (for mussels and salmon) was extensive. Predictive habitat modelling using logistic regression in a model selection framework proved a useful tool to determine critical habitat from absence-presence data and enviromental parameters. Chilean dolphins preferred shallow waters (< 20 m) close to shore (< 500 m) with estuarine influence. Peale's dolphins also occurred predominantly in shallow nearshore waters, but preferred more exposed shores with sandy shoals and were found further from rivers and mussel farms than Chilean dolphins. Analysis of ranging and movement patterns revealed small-scale site fidelity and small ranging patterns of individually identifiable Chilean dolphins. Individuals differed in their site preference and range overlap suggesting spatial partitioning along environmental and social parameters within the population. Individual Peale's dolphins were resighted less regularly, showed only limited or low site fidelity and seemed to range beyond the boundaries of the chosen study areas. Mark-recapture methods applied to photo-identification data produced estimates of local population sizes of 59 Chilean dolphins (95% CI= 54 - 64) and 78 Peale's dolphins (95% CI= 65 - 95) in southern Chiloe, and 123 Peale's dolphins (95% CI= 97 - 156) in central Chiloe. An integrated precautionary approach to management is proposed based on scientific monitoring, environmental education in local schools, and public outreach to promote appropriate conservation strategies and ensure the dolphins' continued occupancy of important coastal habitat.

Huntington, T. C., Roberts, H., Cousins, N., Pitta, V., Marchesi, N., Sanmamed, A., . . . Brockie, N. (2006). *Some Aspects of the Environmental Impact of Aquaculture in Sensitive Areas.* Report to the DG Fish and Maritime Affairs of the European Commission. Poseidon Aquatic Resource Management Ltd., U.K. Retrieved from https://ec.europa.eu/fisheries/sites/fisheries/files/docs/publications/aquaculture_environment_2006_en.pdf

Objective: The tender document indicates that there are a number of objectives of this study:
• To better understand the interactions between different farming systems and the species / habitat complexes in their vicinity. This in itself needs an understanding of (i) the scale and nature of aquaculture being undertaken and (ii) the site-specific and cumulative impacts that might occur.
• To assess the often apparently conflicting goals of aquaculture development and nature conservation in order to identify common aims and policy objectives. A practical output from this will be propose measures that should be included in the management plans foreseen in the Habitat's Directive in order to cope with the possible interactions between aquaculture and environment.
• To provide a framework for a practical 'Code of Practice' for use by marine aquaculture operators and regulatory authorities.
The geographic scope of this study is the coastal states of the European Union and does not include freshwater aquaculture. However the lessons learned will be broadly applicable, especially in the case of cage farming in semi-enclosed water bodies.

Keeley, N., Forrest, B., Hopkins, G., Gillespie, P., Clement, D., Webb, S., . . . Gardner, J. (2009). *Sustainable Aquaculture in New Zealand: Review of the Ecological Effects of Farming Shellfish and Other Non-Finfish Species. Ministry of Fisheries.* Cawthron report Retrieved from https://fs.fish.govt.nz/Page.aspx?pk=113&dk=22056

A final report from Cawthron for the Ministry of Fisheries completed in April 2009 reviewing the ecological effects of farming shellfish and other non-finfish species in New Zealand.

Kemper, C. M., Pemberton, D., Cawthorn, M., Heinrich, S., Mann, J., Würsig, B., . . . Gales, R. (2003). Aquaculture and Marine Mammals: Co-Existence or Conflict? In *Marine Mammals: Fisheries, Tourism, and Management Issues.* N. Gales, M. Hindell, & R. Kirkwood (Eds.), (pp. 208-225): CSIRO Publishing Retrieved from http://hdl.handle.net/102.100.100/191436?index=1

Marine and freshwater aquaculture is the fastest growing world food industry; 11% per year during the 1990s (Newton 2000). In part, this is a result of the reduction of both major and minor wild fisheries (Pauly et al. 2002) and an increased demand for seafood. An estimated 25% of seafood consumed is produced by aquaculture and this is set to rise to 40% by 2010 (FAO 2000). One of the justifications given for turning to aquaculture is that it will relieve the pressure on wild fish stocks, but Naylor et al. (2000) have produced good evidence that this will not be realised unless non-marine sources of food are found for the aquaculture industry. In addition, most finfish aquaculture produces high-grade premium products targeting the gourmet market and will not relieve food shortages in third world countries.

McCormack E, Roche C, & E, N. (2009). *Assessment of Impacts of Mariculture.* Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) Commission London.

Retrieved from http://qsr2010.ospar.org/media/assessments/p00442_Impacts_of_Mariculture.pdf

No abstract

Moore, K., & Wieting, D. (1999). Marine Aquaculture, Marine Mammals, and Marine Turtles Interactions Workshop, Held in Silver Spring, Maryland, 12-13 January, 1999. Retrieved from https://repository.library.noaa.gov/view/noaa/3367

The purpose of this workshop is to bring together regional experts in marine mammals, marine turtles, and marine aquaculture operations to develop recommendations on specific guidelines and standards for aquaculture siting and operation to minimize adverse impacts to marine protected species from nearshore and offshore aquaculture operations.

Nash, C. E., Iwamoto, R. N., & Mahnken, C. V. W. (2000). Aquaculture Risk Management and Marine Mammal Interactions in the Pacific Northwest. *Aquaculture, 183*(3), 307-323 https://doi.org/10.1016/S0044-8486(99)00300-2

This paper reviews current aquatic farm production in the USA and estimates an annual financial exposure of US$350 million in the marine and coastal environments made up of sales, standing crop value and capital investment. In addition, nationwide aquatic farming creates almost 200,000 jobs and, with secondary and downstream activities combined, contributes about US$5600 million to the GNP. The paper then reviews the increasing risk that elements of the coastal aquaculture industry in the Pacific Northwest face from interactions with populations of marine mammals. These are particularly California sea lions and seals, which have greatly increased in the last 20 years from California to British Columbia. Specifically: (i) shellfish from traditional beds have been contaminated by fecal coliforms from seals and made unfit for human consumption, and have been experiencing increasing losses to river otters and sea otters; (ii) culture-based salmon fisheries, including endangered salmon stocks, have been exposed to heavy predation by sea lions and seals, resulting in both direct losses and reduced market value of wounded survivors; (iii) net-pen farms have been exposed to the same heavy losses from predatory sea lions and seals attacking fish in the pens, together with added financial burdens for anti-predator nets, increased maintenance and labor; and (iv) workers in aquaculture and fisheries, and other waterborne industries, have been observing less fear of humans by sea lions and seals, and more direct damage to servicing facilities. The four issues are discussed both technically and economically, and a number of solutions proposed for managing and controlling these increasing risks.

National Marine Fisheries Service. (2015). *Potential Protected Resources Interactions with Longline Aquaculture Workshop Summary.* NOAA Fisheries Greater Atlantic Regional Office. Retrieved from https://www.greateratlantic.fisheries.noaa.gov/sed/aquaculture/doc/aquacultureworkshopsummaryreport2016.pdf

Experts in aquaculture, commercial fishing gear technology, marine sciences and protected species (see participant list, Appendix I) met to discuss the potential for interactions, including entanglements, of sea turtles and marine mammals with longline aquaculture gear. Aquaculture is increasing in both near and

offshore waters, making it important to assess the potential risk of interactions and to determine ways to minimize or reduce harmful and fatal events. The goals of the workshop were to:
• Collectively review a draft NOAA Technical Memorandum regarding interactions of protected species, such as sea turtles and marine mammals, with longline aquaculture operations.
• Develop tools and strategies to support development of longline aquaculture while conserving protected resources.
• Collect and discuss information that federal, state and local regulators and coastal managers can use to assess the potential risks that longline aquaculture poses to protected species.

New Zealand Ministry for Primary Industries. (2013). *Overview of Ecological Effects of Aquaculture* Wellington, New Zealand. Retrieved from https://www.mpi.govt.nz/dmsdocument/4300-overview-of-ecological-effects-of-aquaculture

The Overview of Ecological Effects of Aquaculture summarises the key potential ecological effects of aquaculture in New Zealand, gives comment on their likely significance, and suggests management and mitigation options. The purpose of the overview is to communicate, in an easy-to-understand manner, the key technical details of the Literature Review. The overview is not intended to replace the scientific content of the Literature Review and readers should refer to the Literature Review for more in-depth information.

NOAA Fisheries West Coast Regional Office. (2019). *Southern California Offshore Aquaculture and Protected Species Interactions Workshop Summary.* No URL available.

As marine offshore aquaculture is positioned to expand in United States waters, there is growing interest to determine how farms can be designed, monitored and managed in a way that minimizes interaction with and harm to protected marine species. Experts in aquaculture, farm design and engineering, and marine science gathered for a multi-day workshop to improve understanding of protected species and aquaculture farm interactions, including gear types and associated function, knowledge gaps, and research priorities (see participant list - Appendix II). This collaborative engagement is expected to inform research and monitoring, future siting and permitting practices, and adaptive management considerations that support sustainable growth of the industry.
The workshop provided a wide range of information to participants on protected marine species in the southern California region, aquaculture farm design and operational management, and both available and desired tools to assess risk, inform the permitting process and develop appropriate monitoring protocols (see workshop agenda - Appendix I). Participants engaged in a series of small group interactive sessions, followed by open group discussion, which identified knowledge gaps and research needs, explored how to assess risk in the absence of data and information, and highlighted challenges and opportunities to using a newly developed species model and farm simulator tool. The workshop culminated with a discussion of key takeaway messages, insights and emerging considerations that will guide future collaboration across agencies and with industry practitioners and experts.
This workshop summary presents an overview of informational presentations, issues of interest and concern held by participants, and proposed next steps put forward at the workshop. Outcomes are expected to guide further exploration and understanding of how to assess risk, advance sustainable farm design and continue learning ways in which regulators and industry practitioners can avoid or mitigate potential aquaculture gear and protected species interactions in southern California. NOAA

plans to reengage the Southern California Offshore Aquaculture Interagency Working Group as a forum to continue dialogue on this important issue.

Parkhurst, J. A. (1994). *Bird and Mammal Predation in Aquaculture.* National Technical Information Service Springfield, VA. Retrieved from https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB96107602.xhtml

Conflicts have occurred between operators of aquacultural facilities and a variety of wild animals that prey upon organisms being reared since the inception of artificial culture and propagation endeavors. There is great speculation about the extent and severity of the physical damage and economic impact inflicted by these animals upon such operations, yet very little hard scientific data presently exist to document the true effect of depredation on aquaculture. Aquaculturists soon recognized the need for protection of their stocks from predators, but the search for efficient, reliable, and cost-effective methods still continues today. The report is structured to provide coverage in the following areas: (1) identification of predators believed to be responsible for losses in aquaculture, a description of their feeding behaviors, and review of suspected trends in population status as related to aquaculture; (2) examination of the relationships between predators and various types of aquacultural endeavors in terms of predator behavior, implication in the transmission of disease, economics, and public perceptions and conflicts; and (3) a comprehensive examination of current deterrent strategies and techniques and summary of expectations and research needs for the future.

Ribeiro, S., Viddi, F. A., Cordeiro, J. L., & Freitas, T. R. O. (2007). Fine-Scale Habitat Selection of Chilean Dolphins (Cephalorhynchus Eutropia): Interactions with Aquaculture Activities in Southern Chiloé Island, Chile. *Journal of the Marine Biological Association of the United Kingdom, 87*(1), 119-128 https://doi.org/10.1017/s0025315407051594

Fine-scale habitat selection of Chilean dolphins was studied between January and April 2002 through shorebased theodolite tracking in order to investigate the environmental and behavioural determinants of habitat use, and to evaluate the interactions between this species and aquaculture activities in Yaldad Bay, southern Chile. During 293.5 h of effort, movement and habitat selection patterns of dolphins exhibited a significantly concentrated use of only 21% of the entire study area. Correspondence analysis showed that shallow waters (5–10 m), proximity to coast and rivers were the most significant environmental parameters determining finescale dolphin distribution patterns, with foraging the most frequently observed activity. Aquaculture activities in the area were observed to affect dolphin habitat use patterns by restricting space available for biologically important dolphin behaviours.

Ross, L. G., Telfer, T. C., Falconer, L., Soto, D., & Aguilar-Manjarrez, J. (2010). *Site Selection and Carrying Capacities for Inland and Coastal Aquaculture.* Paper presented at the FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, Stirling, the United Kingdom of Great Britain and Northern Ireland. Retrieved from http://www.fao.org/3/i3099e/i3099e00.htm

An FAO-sponsored Expert Workshop on Site Selection and Carrying Capacities for Inland and Coastal Aquaculture was held at the Institute of Aquaculture, University of Stirling, the United Kingdom of Great Britain and Northern Ireland, in December 2010. The workshop was attended by 20 internationally recognized experts, including two staff members of FAO, and covered a number of relevant core topics

and represented aquaculture in different regions of the world. Expertise within the group included the academic, regulatory and consultative sectors of the industry, giving a wide perspective of views on the core topics. Seven global reviews and ten regional reviews on site selection and carrying capacity encompassing inland aquaculture and coastal aquaculture were presented and discussed at the workshop. Supplementary inputs were provided by the experts who were unable to attend the workshop for the reviews on "Environmental Impact, Site Selection and Carrying Capacity Estimation for Small-scale Aquaculture in Asia" and "Guidelines for Aquaculture Site Selection and Carrying Capacity for Inland and Coastal Aquaculture in Mid- and Northern Europe". Definitions of carrying capacity appropriate for different types of aquaculture were discussed and agreed based upon four categories: physical, production, ecological and social. The range and capability of modelling tools, including spatial tools, available for addressing these capacities were discussed. The prioritization and sequence for addressing site selection and the different categories of carrying capacity were considered in detail in terms of both regional or national priorities and site-specific considerations. Two major outcomes have been developed from the workshop: (i) a comprehensive record of the workshop proceedings (this document), which includes global and regional reviews and a summary of major findings and recommendations; and (ii) a set of guidelines for addressing site selection and carrying capacity in the context of the framework of the ecosystem approach to aquaculture (EAA), including summaries of the key findings and recommendations for aquaculture site selection and carrying capacity with an EAA perspective. Recommendations were made for promotion of these concepts and approaches by FAO. This publication is organized in two parts. One part contains the workshop report and the first global review entitled "Carrying capacities and site selection within the ecosystem approach to aquaculture", while the second part is the full document. The latter part is available on a CD–ROM accompanying the printed part of this publication.

Tucker, C. S., & Hargreaves, J. A. (2008). *Environmental Best Management Practices for Aquaculture*: John Wiley & Sons, Inc. https://doi.org/10.1002/9780813818672

The rapid growth of aquaculture worldwide and domestically has caused concerns over social and environmental impacts. Environmental advocacy groups and government regulatory agencies have called for better management to address potentially negative impacts and assure sustainable aquaculture development. Best Management Practices (BMPs) combine sound science, common sense, economics, and site-specific management to mitigate or prevent adverse environmental impacts. Environmental Best Management Practices for Aquaculture will provide technical guidance to improve the environmental performance of aquaculture. This book will be the only comprehensive guide to BMPs for mitigation of environmental impacts of aquaculture in the United States. The book addresses development and implementation of BMPs, BMPs for specific aquaculture production systems, and the economics of implementing best management practices. Written by internationally recognized experts in environmental management and aquaculture from academia, government, and non-governmental organizations, this book will be a valuable reference for innovative producers, policy makers, regulators, research scientists, and students.

Weitzman, J., Steeves, L., Bradford, J., & Filgueira, R. (2019). Chapter 11 - Far-Field and near-Field Effects of Marine Aquaculture. In *World Seas: An Environmental Evaluation (Second Edition).* C. Sheppard (Ed.), (pp. 197-220): Academic Press https://doi.org/https://doi.org/10.1016/B978-0-12-805052-1.00011-5

Aquaculture for finfish, bivalves, and seaweed is an important and growing food producing sector globally. However, culturing of species in the marine environment implies multiple interactions between farmed species and their environment. This has led to concerns over the ecological effects of aquaculture, which include benthic organic loading, changes to water quality, habitat modification, disease spread, and introduction of exotic or invasive species, interaction with wild species, coastal eutrophication, and marine litter. Over the years, governments and international organizations have recognized the need to identify, mitigate, and reduce these ecological effects. The Food and Agriculture Organization of the United Nations proposes an Ecosystem Approach to Aquaculture (EAA), which implies recognizing its effects at multiple spatial scales, including near-field effect (farm scale) and far-field (bay scale and global scale) effect. This chapter reviews ecological effects of finfish, bivalve, and seaweed aquaculture in marine coastal waters, and describes the mitigation efforts currently used to improve its sustainable management.

Wursig, B., & Gailey, G. (2002). Marine Mammals and Aquaculture: Conflicts and Potential Resolutions. In *Responsible Marine Aquaculture.* R. R. Stickney & J. P. McVey (Eds.), (pp. 45-59). New York: CAB. International Retrieved from https://www.cabi.org/bookshop/book/9780851996042

Two main types of marine-based aquaculture come into potential conflict with marine mammals (and, in some areas, marine turtles and seabirds): (i) extensive raising of shellfish, such as oysters, mussels and shrimp; and (ii) intensive raising of finfish, such as salmon, sea bass and sea bream. The first takes up space in near-shore waters but does not generally require nets or cages that can entangle or otherwise hurt airbreathing vertebrates. It also does not require supplementary feeding, and therefore is not generally a major attractant for marine mammals and others. However, shellfish aquaculture puts extra nitrogen into the ecosystem, and can change local ecology where tidal and other flushing is minimal. It takes up extensive space in inlets, fjords and the like, and may compete for limited habitat access with foraging, resting, socializing and nurturant mammals. The intensive but generally more localized farming of finfish often requires supplementary feeding, and both the stock in holding pens and the feed serve as powerful attractants especially to pinnipeds (but toothed cetaceans, river and sea otters, marine turtles, and seabirds are often involved as well). As such, major problems are caused to the industry by destruction of gear and the target aquaculture species; and to the marine animals by shooting and other techniques, such as large-scale use of Acoustic Deterrent Devices (ADDs) and Acoustic Harassment Devices (AHDs). No technique has proved highly successful, and the widespread use of ADDs and AHDs is particularly problematic and largely untested. We recommend that owing to potential for entanglement, chemical and sound pollution, habitat loss or gross alteration, traffic, and changes in species interactions, all proposed development of marine aquaculture in nature should be subjected to initial evaluations and – as needed – scientific research relative to interactions between the food being raised by humans and the predators that attempt to take advantage of this. The loss of habitat to marine mammals by both shellfish and fish aquaculture facilities needs to be investigated on a case-by-case basis.

E. Integrated Multi-Trophic Aquaculture (IMTA)

Meyer Glitzenstein & Eubanks LLP (2019). [60-Day Notice of Intent to Sue NOAA under the Endangered Species Act Regarding Sea Grant's Funding of Offshore Aquaculture Projects]. No URL available.

Friends of the Earth ("FOE") and Center for Food Safety ("CFS") hereby notify you of violations of the Endangered Species Act ("ESA"), 16 U.S.C. §§ 1531-1544, in connection with Project 107-NH-Chapman ("Project"), an offshore aquaculture project proposed by the University of New Hampshire and funded by a grant from the National Sea Grant College Program's ("Sea Grant") 2018 Ocean, Coastal, and Great Lakes National Aquaculture Initiative. The Project calls for the construction and deployment of an Aquafort system approximately 12 kilometers offshore in a depth of 52 meters of water. The Aquafort system consists of a floating platform occupying over 1650 square feet, and supports two nets to grow steelhead trout.1 Additionally, around the perimeter of the platform, 112 lines, approximately 10 meters in length, will be suspended to collect mussel spat for shellfish aquaculture.
This project will have serious adverse consequences for federally endangered and threatened species and their critical habitat, yet Sea Grant never assessed those risks in any legally required consultation with the National Marine Fisheries Service ("NMFS") and the U.S. Fish and Wildlife Service ("FWS"), thereby resulting in ongoing violations of the ESA. Consequently, FOE and CFS are notifying Sea Grant, the Office of Oceanic and Atmospheric Research ("OAR"), and the Department of Commerce ("DOC")— as well as NMFS and FWS— of these violations so that Sea Grant, OAR, and the DOC, along with the consulting agencies, can take the necessary steps to correct them.

F. Deterrent Devices

Coram, A., Gordon, J., Thompson, D., & Northridge, S. P. (2014). *Evaluating and Assessing the Relative Effectiveness of Acoustic Deterrent Devices and Other Non-Lethal Leasures on Marine Mammals.* Scottish Government. Retrieved from http://www.nls.uk/scotgov/2014/9781784128739.pdf

Acoustic Deterrent Devices (ADDs) have long been used to try to keep animals away from human activities. They have been developed in the marine environment particularly to keep marine mammals away from fishing operations, aquaculture sites and more recently to keep marine mammals away from industrial operations that might be harmful to the animals themselves. This review attempts to synthesise the costs and benefits of the acoustic deterrent approach, drawing on a wide range of examples and types of deterrent device, but the primary focus is on the use of ADDs in aquaculture.

Gotz, T., & Janik, V. M. (2013). Acoustic Deterrent Devices to Prevent Pinniped Depredation: Efficiency, Conservation Concerns and Possible Solutions. *Marine Ecology Progress Series, 492*, 285-302 https://doi.org/10.3354/meps10482

Acoustic deterrent devices (ADDs) to prevent pinniped predation on fish farms and fisheries are widely used, but show highly varying success. Recently, ADDs have also been highlighted as a conservation concern due to their adverse impact on toothed whales. We review the available literature on the efficiency of commercial ADDs, evaluate the unintended impact on behaviour, communication and hearing of marine life, and suggest solutions based on psychophysiological predictions. The main problems associated with ADDs are a lack of long-term efficiency, introduction of substantial noise pollution to the marine environment and long-term effects on target and non-target species. Odontocetes have more sensitive hearing than pinnipeds at the frequencies where most ADDs operate, which may explain the reported large-scale habitat exclusion of odontocetes when ADDs are used. Furthermore, long-term exposure to ADDs may damage the hearing of marine mammals. Fish and invertebrates have less sensitive hearing than marine mammals and fewer efforts have been made to quantify the effects of noise on these taxa. Solutions can be found by decreasing sound exposure, exploiting neuronal reflex arcs associated with flight behaviour and making use of differences in species'

hearing abilities to increase target specificity. To minimise adverse effects, environmental impact assessments should be carried out before deploying ADDs and only effective and target-specific devices should be used.

Gotz, T., & Janik, V. M. (2016). Non-Lethal Management of Carnivore Predation: Long-Term Tests with a Startle Reflex-Based Deterrence System on a Fish Farm. *Animal Conservation, 19*(3), 212-221 https://doi.org/10.1111/acv.12248

Carnivore depredation on human livestock is a worldwide problem with few viable solutions. Non-lethal management tools such as acoustic devices show highly varying success and often pose a conservation risk due to noise pollution and habitat degradation. We tested the long-term effectiveness of a deterrence system which harnesses an autonomous reflex (startle) to selectively inflict avoidance responses in a target species (phocid seals) by emitting band-limited noise pulses with sharp onset times. Seal predation was monitored at a marine salmon farm (test site) over a full production cycle (19 month) with a multitransducer deterrent system deployed for the final year. Predation was also monitored for several months at two control sites and additional short-term tests were carried out at sites which suffered higher predation rates. Generalized linear (mixed) models revealed that sound exposure caused a 91% reduction in lost fish when comparing predation levels within the test site and 97% when comparing the test site against both control sites. Similarly, sound exposure led to a 93% reduction in the number of fish lost due to seal damage at a short-term test site. Visual monitoring of marine mammals around the long-term test site showed that the number of seal surfacings within 100 m from the loudspeakers was only slightly lower during sound exposure. Harbour porpoise and otter distribution around the farm was not affected by sound exposure. By adjusting the frequency composition of startle stimuli, our method has the potential to provide solutions for managing human-wildlife conflicts in terrestrial and marine habitats by selectively deterring target species.

Northridge, S., Gordon, J., Booth, C., Calderan, S., Cargill, A., Coram, A., . . . Webb, A. (2010). *Assessment of the Impacts and Utility of Acoustic Deterrent Devices.* Paper presented at the Final Report to the Scottish Aquaculture Research Forum, Project Code SARF044. Retrieved from http://www.sarf.org.uk/cms-assets/documents/28820-18834.sarf044---final-report.pdf

This project aimed to determine the extent to which Acoustic Deterrent Devices used at Scottish salmon farms affect harbour porpoise distribution, and how effective ADDs are at deterring seals from causing damage to nets and to farmed stock. The interactions between seals and salmon farms were also examined through direct observations of seal activity around two sites and by examining trends in numbers of seals in relation to their distance from farm sites throughout Scotland.

Terhune, J. M., Hoover, C. L., & Jacobs, S. R. (2002). Potential Detection and Deterrence Ranges by Harbor Seals of Underwater Acoustic Harassment Devices (AHD) in the Bay of Fundy, Canada. *Journal of the World Aquaculture Society, 33*, 176-183 https://doi.org/10.1111/j.1749-7345.2002.tb00492.x

Underwater acoustic harassment devices (AHDs) are designed to deter seals from attacking fin-fish aquaculture cages. They may also be unintentionally disturbing non-target marine mammals. As the distance from the sound source increases, the rate at which the sound pressure level (SPL) drops per

unit distance decreases. This prohibits presenting loud sounds near the cages without also creating sounds that can be detected kilometers away. In situ measurements of the sound fields of two AHDs in the Bay of Fundy, Canada, were made. The distances at which a loud AHD with short duration pulses (1.8 msec, 195 dB re 1 µPa at 1 m) and a quieter AHD with longer pulse durations (>50 msec, 166 dB re 1 µPa at 1 m) would be 80 dB or more above the detection threshold of a harbor seal Phoca vitulina were 10 and 3.5 m, respectively. On a quiet day with no nearby vessel traffic, these AHDs would be clearly detectable by harbor seals at ranges up to 2.9 and 1.3 km, respectively. By increasing the pulse length of the louder AHD to >50 msec, the sound would be more than 80 dB above the seal's detection threshold at 100 m but the sound would also be clearly detectable up to 7.2 km. It is technically possible to produce AHDs that are louder. Using very high amplitude sounds to protect finfish aquaculture cages from seal predation without encountering prohibitively large capital and operating costs may not be feasible.

Section II: Fisheries

A. Impacts to Cetaceans

Citta, J. J., Burns, J. J., Quakenbush, L. T., Vanek, V., George, J. C., Small, R. J., . . . Brower, H. (2014). Potential for Bowhead Whale Entanglement in Cod and Crab Pot Gear in the Bering Sea. *Marine Mammal Science, 30*(2), 445-459 https://doi.org/10.1111/mms.12047

Bowhead whales (Balaena mysticetus) of the western Arctic stock winter in ice-covered continental shelf regions of the Bering Sea, where pot fisheries for crabs (Paralithodes and Chionoecetes spp.) and Pacific cod (Gadus macrocephalus) pose a risk of entanglement. In the winter of 2008-2009 and 2009-2010 the spatial distribution of 21 satellite tagged bowhead whales partially overlapped areas in which pot fisheries for cod and blue king crab (Paralithodes platypus) occurred. However, these fisheries ended before whales entered the fishing areas, thus avoiding temporal overlap. A fishery for snow crab (Chionoecetes opilio) typically runs from January to May and provides the greatest potential for bowhead whales to encounter active pot gear. Tagged whales did not enter the area of the snow crab fishery during this study and generally remained in areas with >90% sea ice concentration, which is too concentrated for crab boats to penetrate. Pack ice sometimes overruns active fishing areas, resulting in lost gear, which is the most likely source of entanglement. The western Arctic stock of bowhead whales was increasing as of 2004; as such, incidental mortality from commercial pot fisheries is probably negligible at this time. Regardless, entanglement may increase over time and should be monitored.

de Vos, A., Brownell, R. L., Jr., Tershy, B., & Croll, D. (2016). Anthropogenic Threats and Conservation Needs of Blue Whales, Balaenoptera Musculus Indica, around Sri Lanka. *Journal of Marine Biology, 2016* https://doi.org/10.1155/2016/8420846

Blue whales in the Northern Indian Ocean are a morphologically and acoustically distinct population restricted to these waters. Off Sri Lanka a portion of the population concentrates near shore where they are exposed to a range of anthropogenic threats. We review available data to determine anthropogenic threats/stressors faced by this population and assign subjective rankings for the population-level severity of each threat/stressor based on severity, scope, and immediacy. With the cessation of direct illegal catches on this population in the late 1960s, we ranked ship strike as the most important

population-level threat. Incidental catch, which includes entanglement and bycatch, is also important as it can result in death. Other less important stressors that may negatively impact this population include threats resulting from oil and gas development and pollution. However, some stressors can have a long-term cumulative impact that is difficult to assess. The most important research needed for the conservation of these whales is to obtain an estimate of the size of the population using photo-identification methods.

Themelis, D., Harris, L., & Hayman, T. (2016). *Preliminary Estimates of Human-Induced Injury to and Mortality of Cetaceans in Atlantic Canada.* DFO Can. Sci. Advis. Sec. Res. Doc 2016/085. Dartmouth, Nova Scotia. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40575287.pdf

Information on human-induced injuries to cetaceans occurring in Atlantic Canada is required to evaluate the effectiveness of recovery strategies for species at risk and to support management decisions on measures to mitigate entanglement risk from commercial fisheries. Cetaceans reported stranded or entangled in fishing gear in Canadian waters include mysticete (baleen) and odontocete (toothed whales, dolphins and Harbour Porpoise) (Hooker et al. 1997, Reeves et al. 2013). An objective of all recovery strategies published for Atlantic Canadian cetaceans protected under the Species at Risk Act [North Atlantic Right Whale (DFO 2014), Scotian Shelf population of Northern Bottlenose Whale (DFO 2010), Atlantic Blue Whale (Beauchamp et al. 2009) and the St Lawrence estuary population of Beluga Whale (DFO 2012)], is the reduction of mortality and injury due to interactions with fishing gear.

Wang, Y., Li, W., & Van Waerebeek, K. (2015). Strandings, Bycatches and Injuries of Aquatic Mammals in China, 2000–2006, as Reviewed from Official Documents: A Compelling Argument for a Nationwide Strandings Programme. *Marine Policy, 51*, 242-250 https://doi.org/10.1016/j.marpol.2014.07.016

In the present study, the species composition, geographical and seasonal patterns of strandings, bycatches and injuries of aquatic mammals reported in Chinese mainland waters, from 2000 to 2006, were analyzed based on national official documents. A total of 97 strandings, 66 bycatches and 30 injuries, involving at least 18 species (possibly 20) in eight families of Cetacea and two families of Carnivora, were recorded. Finless porpoises (Neophocaena spp.), spotted seal (Phoca largha) and bottlenose dolphins (Tursiops spp.) were the most common species in all three categories, in total comprising 59.8% of strandings, 97.0% of bycatches and 86.7% of injuries. Strandings occurred throughout the year, but records of both bycatches and injuries peaked in spring (March to May), corresponding to the major fishing season and may reflect the negative impacts of fishing activities. The highest species diversity found in Fujian Province may be linked to upwelling and high production in the Strait of Taiwan. Serious difficulties were encountered in overall data interpretation and between-provinces comparability, mainly due to a lack of quantified observer effort and variable expertise levels. Hence the establishment of a coordinated nationwide network is recommended, providing a mechanism for the instant reporting of aquatic mammal events, as well as the adoption of a standardised data recording system including necropsy protocols. Better-quality data should allow quantitative analyses leading to an improved understanding of anthropogenic threats in China's aquatic mammal populations. The need to upgrade reserve management, such as the Dalian protected area in Liaoning, is also stressed.

B. Deterrent Devices

Cox, T. M., Read, A. J., Solow, A., & Tregenza, N. (2001). Will Harbour Porpoises (Phocoena Phocoena) Habituate to Pingers? *Journal of Cetacean Research and Management, 3*(1), 81-86 Retrieved from https://porpoise.org/library/will-harbour-porpoises-phocoena-phocoena-habituate-pingers/

Large bycatches of harbour porpoises (Phocoena phocoena) occur in gillnet fisheries throughout the Northern Hemisphere. Several mitigation measures, including acoustic deterrent devices or 'pingers', have been used in efforts to reduce this bycatch. The potential exists for harbour porpoises to habituate to pingers, thus reducing their effectiveness over time. A field experiment was conducted to test the hypothesis that porpoises habituate to the sound produced by pingers. Porpoise echolocation and movements were monitored around a mooring equipped with a pinger (Dukane NetMark™ 1000) for three months in summer 1998 in the Bay of Fundy. Using a mean-shift model it was estimated that porpoises were initially displaced 208m from the pinger ($p = 0.019$), but this displacement diminished by 50% within four days ($p = 0.019$). Using a probability model it was demonstrated that the probability of porpoises within 125m of the pinger initially decreased when the pinger was turned on, but then increased to equal the control in 10-11 days. Echolocation rate ($p < 0.001$) and occurrence ($p < 0.001$) were significantly reduced in the vicinity of the pinger. These results indicate that porpoises habituated to the Dukane NetMark™ 1000 pinger and are not alerted to echolocate in the presence of nets by pingers.

Section III: Mixed

Food and Agriculture Organization of the United Nations. (2018). *Expert Workshop on Means and Methods for Reducing Marine Mammal Mortality in Fishing and Aquaculture Operations, Rome, Italy, 20-23 March 2018.* Retrieved from http://www.fao.org/publications/card/en/c/I9993EN/

One of the greatest threats to species and population survival of marine mammals with their relatively slow growth and low fecundity comes from inadvertent interaction with, or capture in, fishing and aquaculture operations. FAO members have expressed great concern about bycatch of marine mammals at recent sessions of the Committee on Fisheries (COFI). At its Thirty-First Session in 2014 the Committee reiterated its support for FAO's ongoing work on bycatch management and reduction of discards, and requested FAO to expand its efforts to effectively implement the International Guidelines on Bycatch Management and Reduction of Discards, addressing all fishing gears where bycatch, including, inter alia, that of marine mammals, and discards were a problem. At its Thirty-Second Session in 2016, the committee welcomed the offer of the United States of America to fund an expert workshop to review the findings of recent international marine mammal bycatch workshops. Within this context, FAO convened the Expert Workshop on Means and Methods for Reducing Marine Mammal Mortality in Fishing and Aquaculture Operations in Rome, Italy from 20 to 23 March 2018, which was attended by twenty-seven experts in marine mammal science and bycatch mitigation. The workshop reviewed the current state of knowledge on the issue of marine mammal bycatch, and evaluated the efficacy of different strategies and measures for mitigating bycatch and their implementation. The workshop produced some key technical outputs, including an extensive review of techniques across different gear types and species, together with a summary table and a draft decisionmaking tool (decision tree) which

could be used to support management decision-making processes. The workshop recommended that FAO develop Technical Guidelines on means and methods for prevention and reduction of marine mammal bycatch and mortality in fishing and aquaculture operations in support of FAO's Code of Conduct for Responsible Fisheries and as a supplement to International Guidelines on Bycatch Management and Reduction of Discards. The workshop also recommended that FAO consider establishing a global capacity development programme to support developing States in the application of the proposed guidelines.

Groom, C. J., & Coughran, D. K. (2012). Entanglements of Baleen Whales Off the Coast of Western Australia between 1982 and 2010: Patterns of Occurrence, Outcomes and Management Responses. *Pacific Conservation Biology, 18*(3), 203-214 https://doi.org/10.1071/PC130203

Baleen whale population sizes have increased in Western Australian waters since the cessation of commercial whaling activities. This has been followed by a coincident increase in the number of reported entanglements of baleen whales in fishing gear. During their annual migration, whales pass through Western Australian waters used by commercial fisheries targeting rock lobster, octopus and shark as well as aquaculture industries producing abalone, pearls and mussels. We reviewed the 63 baleen whale entanglement records in the Western Australian Cetacean Strandings Database (1982-2010). Of the four baleen whale species observed entangled in fishing gear in Western Australian waters, the Humpback Whale Megaptera novaeangliae accounted for 56 (89%) entanglements, followed by the Southern Right Whale Eubalaena australis, five (8%) entanglements, and one record each for both the Bryde's Balaenoptera edeni and Minke Whale Balaenoptera acutorostrata. Almost half of entanglements occurred in rock lobster fishing gear (n = 31; 49%). There is an upward trend in the number of entanglements reported since 1990 in rock lobster fishing gear despite fishing effort reducing over the same period of time. This can, at least partly, be attributed to the increase in humpback whale population size. Fisheries and conservation agencies have responded by developing cooperative relationships and protocols that reduce entanglement risk and improve outcomes when entanglement does occur.

International Whaling Commission. (2015). *Report of the Third Workshop on Large Whale Entanglement Issues. IWC/66/Wk-Wi-Rep01.* Provincetown, MA. Retrieved from https://archive.iwc.int/?r=5600&k=d37f723109

No abstract

Kemper, C., Flaherty, A., Gibbs, S., Hill, M., Long, M., & Byard, R. (2005). Cetacean Captures, Strandings and Mortalities in South Australia 1881-2000, with Special Reference to Human Interactions. *Australian Mammalogy, 27*(1), 37-47 https://doi.org/10.1071/AM05037

This study summarizes 660 events involving captured, live-stranded and dead cetaceans in South Australia between 1881 and 2000. Emphasis is placed on records (n = 361) during 1985-2000 when an active necropsy programme was underway. Average number of events per year was 30.4 and the most common species were the short-beaked common dolphin (Delphinus delphis) and Indo-Pacific bottlenose dolphin (Tursiops aduncus). Records were assigned to nine categories of circumstance/cause of death. Summarizing the total database, 60% were unknown circumstance, 22% not obviously

anthropogenic, 13% unintentional human-related and 5% intentional human-related. In the data set of records for 1985-2000, 50% were unknown, 25% were not obviously anthropogenic, 20% were unintentional humanrelated and 5% were intentional killings. Non-anthropogenic circumstances included neonatal deaths, live strandings, significant diseases, shark attacks and choking. Cornynebacterium ulcerans is recorded for the first time in a cetacean. Unintentional circumstances included entanglement in fishing and aquaculture equipment (17% of necropsied carcasses from 1985-2000) and boat strikes. Intentional human-related circumstances were captures for live display and illegal killing. Five percent of the necropsied carcasses during 1985-2000 were attributed to shootings or stabbings/spearings. There is need for a formal reporting procedure for marine mammal deaths and human interaction involving injury and for steps to be taken to reduce human impacts.

MacNicoll, M., Akers, R., Goudey, C., & Ieee. (2017). *Simulation of Marine Entanglement a Software Tool Used to Predict Entanglement of Leatherback Turtles*. Paper presented at the Oceans 2017 - Anchorage, Anchorage, AK. https://ieeexplore.ieee.org/document/8232193

A software tool has been developed to simulate the entanglement of leatherback sea turtles (Dermochelys coriacea) in fishing and aquaculture gear. Entanglements are well documented and are increasing in frequency due to greater fishing effort and with the use of synthetic materials in marine applications. However relatively little is known about how entanglements occur and how they might be prevented. The objective of the present study is to develop a computer simulation model, using the software program MSC Adams, to realistically mimic the behavior of adult leatherback sea turtles as they become entangled with a mooring line. Such a tool can assist designers to develop and advance mooring and fishing line technology to reduce the number of leatherback turtle entanglement events.

Rehn, A. C., Barnett, A. J., & Wiber, M. G. (2018). Stabilizing Risk Using Public Participatory Gis: A Case Study on Mitigating Marine Debris in the Bay of Fundy, Southwest New Brunswick, Canada. *Marine Policy, 96*, 264-269 https://doi.org/10.1016/j.marpol.2017.11.033

While large-scale studies have quantified the extent of marine debris problems, the social factors that create and inhibit mitigation are understudied. In Canada's Southwest New Brunswick Bay of Fundy, marine debris originates from the interaction of multiple industries within a small area, including aquaculture and inshore fisheries. Conflict between these two stakeholders contributes to both debris production and failure to mitigate. Their gear entanglements create debris that threatens transportation safety, wildlife and the local economy. Public Participation Geographic Information Systems (PPGIS) mapping was used to assemble and stabilize a common view of what constituted debris, debris locations and threats. This paper reports on a subsequent project that monitored the effects of working with the PPGIS map over three years, using participant observation, stakeholder roundtables, and interviews with stakeholders. The paper first reports on the differences in risk perceptions that were barriers to collaboration, followed by the tactics used by stakeholders to influence priorities and actions and finally on how PPGIS stabilized stakeholder definitions of debris and of responsibilities. The conclusions argue that PPGIS incorporates diverse data sets generated by different stakeholders, thereby motivating interactions, reducing conflict, and encouraging negotiated understandings of risks posed by marine debris.

Robbins, W. D., Huveneers, C., Parra, G. J., Möller, L., & Gillanders, B. M. (2017). Anthropogenic Threat Assessment of Marine-Associated Fauna in Spencer Gulf, South Australia. *Marine Policy, 81*, 392-400 https://doi.org/10.1016/j.marpol.2017.03.036

Assessing the vulnerability of species to anthropogenic threats is an essential step when developing management strategies for wild populations. With industrial development forecasted to increase in Spencer Gulf, South Australia, it is crucial to assess the ongoing effects of anthropogenic threats to resident and migratory species. Expert elicitation was used to assess 27 threats against 38 threatened, protected, and iconic marine-associated species. Species and threat interactions were assessed individually, and as taxonomic or functional groups. Climate change had the greatest overall exposure (c.f. risk) across species, followed by disturbance, pollution, disease/invasive species, and fishing/aquaculture threats. The largest overall sensitivities (c.f. consequences) were pollution and disease/invasive species, followed by climate change, disturbance and fishing/aquaculture threats. Vulnerability scores (exposure x sensitivity) showed the climate change group posing the greatest overall threat in Spencer Gulf, with individual climatic threats ranking as three of the top four biggest threats to most animal groups. Noise, shipping, and net fishing were considered the greatest region-specific individual threats to marine mammals; as were trawl fishing, line fishing, and coastal activities to fish/cuttlefish; trawl fishing, line fishing, and net fishing to elasmobranchs; and oil spill, disease, and coastal activities to sea/shorebirds. Eighteen of the 20 highest vulnerability scores involved the short-beaked common dolphin, Indo-Pacific bottlenose dolphin, and Australian sea lion, highlighting the particular susceptibility of these species to specific threats. These findings provide a synthesis of key threats and vulnerable species, and give management a basis to direct future monitoring and threat mitigation efforts in the region.

Roycroft, D., Cronin, M., Mackey, M., Ingram, S. N., & O'Cadhla, O. (2007). Risk Assessment for Marine Mammal and Seabird Populations in South-Western Irish Waters (Ramssi). Unpublished final report to HEA by Coastal & Marine Resources Centre UCC. 198 pp. Retrieved from https://www.ucc.ie/research/crc/publications/reports/RAMSSI.pdf

The rugged coastline of southwest Ireland is home to the highest concentrations of breeding seabirds in the country, as well as high numbers of resident and migrating cetacean species, many of which are of conservation concern. Furthermore, the sheltered inlets of Bantry Bay and the Kenmare River provide a base for important populations of Harbour seals, an Annex II species under the EU Habitat's Directive. This inshore environment contains a variety of potential risks to seabirds and marine mammals, most notably from surface & acoustic pollution, fisheries and the rapidly expanding mariculture industry.

Ryan, C., Leaper, R., Evans, P. G., Dyke, K., Robinson, K. P., Haskins, G. N., . . . Froud, K. (2016). *Entanglement: An Emerging Threat to Humpback Whales in Scottish Waters*. Retrieved from http://www.crru.org.uk/cust_images/pdfs/ryan_etal_IWC.pdf

Entanglement in static fishing gear, especially shellfish creels (pots), is a known source of mortality and injury for humpback whales (Megaptera novaeangliae) with an apparent rise in recent entanglements of this species in Scottish coastal waters. All available sighting records in Scottish waters from 1992 to 2016 were collated to determine the distribution of the species. A subset of sightings with associated boat-based search effort from the west of Scotland indicated the relative abundance of humpback whales in this region was very low (just four sightings from 86,000 km of search effort). Of the 213 incidental

sighting records from 1992 to 2016, 5.6 % (n = 12) comprised known entanglements. For the five most recent years (2012 to 2016), this proportion was higher 7.5 % (n = 10). Over half of the known entanglements (n = 7) involved creels, three others were of ropes consistent with creels, and one involved an aquaculture (salmon) pen. Rescue responses to six of the 12 entangled whales resulted in successful disentanglements, although their long-term survival remains unknown. Three of the 12 entanglement cases (i.e. 25%) were fatal. A gamma distribution was fitted to the frequency of humpback whale 'visits' based on the number of different days on which humpbacks were reported. From this, the number of unreported visits in inshore Scottish waters was estimated. Based on the minimum number of reported entanglements, the daily probability that a whale that is present in the area would become entangled was estimated at 0.0017. An independent estimate of entanglement risk, using a subset of effort-related sightings and an assumed effective strip half-width, also suggested the same daily entanglement probability. If a whale were to be resident year-round, these estimates would equate to an annual entanglement probability of 0.46. Based on this probability and the observed proportion of fatal entanglements would suggest a fatal entanglement probability of 0.12. This source of mortality alone is an order of magnitude higher than sustainable levels. A positive correlation between the annual estimates of the number of visits and reported entanglements ($r=0.79$, $df=22$, $p<0.001$) suggests that the method for estimating humpback whale days is a valid approach for assessing risk. In the present scenario, Scottish inshore waters could not support a population of humpback whales and these waters currently act as a high mortality sink for the species in the NE Atlantic. The entanglement issue is also a concern for other species, particularly minke whales. Measures to reduce entanglement risk could also benefit the creel fishing industry by minimising the loss of gear.

Thomsen, F., McCully, S. R., Weiss, L. R., Wood, D. T., Warr, K. J., Barry, J., & Law, R. J. (2011). Cetacean Stock Assessments in Relation to Exploration and Production Industry Activity and Other Human Pressures: Review and Data Needs. *Aquatic Mammals, 37*(1), 1-93 https://doi.org/10.1578/AM.37.1.2011.1

The impacts of manmade underwater sound on cetaceans have become an important environmental issue. A number of studies have documented effects on individuals such as behavioural response; masking of biologically relevant signals; and hearing loss, either temporary or permanent (reviews by Richardson et al., 1995; Southall et al., 2007). Little is known, however, about the population-level consequences of acoustic impacts. Methodologies addressing this issue, such as risk-based and cumulative impact assessments, are still in their infancy (e.g., National Research Council [NRC], 2005; Boyd et al., 2008; Wright, 2009). There is also limited information on levels of human activities generating sound and uncertainties in cetacean stock assessments that hamper quantitative investigations. Yet, sound generating industries are active in many parts of the world's oceans and, therefore, qualitative assessments could provide a first step in managing potential conflicts between industry sectors generating sound and cetacean conservation. The Exploration and Production industry (E&P industry) generates underwater sound potentially affecting individual cetaceans, with most concerns expressed about the effects of seismic surveys (review by OSPAR, 2009). However, the relationship between E&P industry activities and trends in cetacean stocks has rarely been investigated. We provide a global overview of E&P industries and cetacean stock data in order to identify hot spots for more detailed investigations. Thus, in four case studies, we quantified the E&P industry activity in a specific region, investigated the status and trends of seven cetacean stocks therein, and assessed other factors presumably influencing the populations in question.