Update for 2014 Methodology Review:
Ongoing Revisions to the Spatially Explicit Atlantis Ecosystem Model of the California Current

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Purpose of this Document

This document summarizes ongoing efforts to revise the California Current Atlantis ecosystem model. It is intended as a technical working document describing the Atlantis modeling work. Supporting research (related to experimental studies of ocean acidification and economics) is described briefly to set the context for the Atlantis model.

Model Purpose:

The revised California Current Atlantis ecosystem model adapts previous versions (Horne et al. 2010; Brand et al. 2007) to address two topics: ocean acidification and ecosystem-based management of forage fish.

Global scenarios for fossil fuel emissions suggest a 1.8 - 4°C increase in sea surface temperature and a decline in pH of 0.14-0.35 (IPCC 2007). Changes to seawater pH and saturation states of aragonite and calcite (the minerals many organisms use to build protective structures) will not occur uniformly over space (Feely 2004). In particular ecosystems or areas, changes in ocean carbon chemistry due to ocean acidification (OA) could lead to reduced populations of species including calcareous corals, benthos, and plankton groups (Fabry et al. 2008; Hall-Spencer et al. 2008).

Though numerous field and laboratory studies strive to understand direct effects of acidification on particular species, far fewer research efforts attempt to forecast the indirect and cumulative impacts of acidification, climate change, and harvest on whole food webs and fisheries. Previous simple representations of food web response to acidification include Kaplan et al. (2010), Ainsworth et al. (2011), and Griffith et al. (2011); however these caricatures exclude spatial or temporal variability in acidification impacts. Appropriate modeling of cumulative impacts may be particularly important for understanding the impacts of OA in a changing ocean.

To begin modeling the ecological impacts of OA on the California Current's ecology and fisheries, we have recently revised an Atlantis ecosystem model, detailed below. The overall project will:

- Use a **Regional Ocean Modeling System (ROMS)** to predict 50-100 year spatial projections of ocean acidification, as well as salinity, currents, and upwelling**.** ROMS will be coupled to global circulation models and IPCC CO_2 scenarios.
- Build on previous literature reviews (Kroeker et al. 2013; Kroeker et al. 2010) and ongoing experiments to develop bounded **scenarios for the biological response of calcifying organisms** (and other lower trophic level species) to pH.
- Use an **Atlantis ecosystem model** to project these direct impacts of acidification on lower trophic levels, the resulting food web response of harvested and protected stocks, and catches by US West Coast fisheries. Atlantis will be driven by dynamic, spatially explicit fields from ROMS.

- Estimate **spatial economic impacts** of acidification by linking output from the Atlantis ecosystem model to the **IO-PAC input-output model** (Leonard and Watson 2011). This translates seafood landings into economic impacts on the broader West Coast economy and on individual ports.
- Identify how stock productivity, fishery management **reference points** and **consequences of harvest policies** shift under alternate ocean conditions**.**
- **Test management strategy performance** in the face of ocean acidification and other global change. These strategies will range from current single-species fishery management rules to harvest control rules that respond to simple metrics of ecosystem productivity and susceptibility.

The second purpose of this modeling effort is to support ecosystem based management of forage fish. Forage fish such as anchovy, sardines, and herring are typically highly abundant plankton feeders, form dense schools, and play a key role in transferring production from phytoplankton and zooplankton to larger predators. On the global scale, harvests of forage fish total over 20 million metric tons annually and account for 25-30% of global fisheries landings. The key scientific challenges of capturing forage fish dynamics are to understand the high levels of population fluctuation of forage fish, to quantify their supporting role – both ecologically and economically-- in the fishery food web and ecosystem, and to develop management strategies that account for these factors.

Two recent studies have applied a suite of ecosystem models, including the previous California Current Atlantis model, to quantify the role of forage fish and the potential food web effects of their harvest. Smith et al. (2011) found that across five global regions and three ecosystem modeling types, harvest of forage groups had large impacts – positive and negative -- on many other species. This was particularly true for forage groups that comprised large portions of an ecosystem's biomass, or that were highly connected in the food web (e.g. had many predator/prey links). Consistent with Smith et al, Kaplan et al.(2013) found that harvest of forage fish and krill had large impacts in the Atlantis ecosystem model and the Ecopath model of the California Current (J. C. Field, Francis, and Aydin 2006). Depleting krill to 40% of unfished levels altered the abundance of 13–30% of the other functional groups by > 20%. Depleting forage fish to 40% altered the abundance of 20–50% of the other functional groups by > 20%. Despite these initial results, we acknowledge that these models were parameterized to represent groundfish management questions, and that taxonomic resolution, data, and geography do not capture all key aspects of sardine, anchovy, herring, and mackerel stocks.

Conscious of the need to need to avoid 'recycling' existing models (Essington and Plagányi 2014) in attempts to represent forage fish, the new Atlantis model presented below avoids these shortfalls. The effort will be incorporated into a new multi-model study of forage fish (Ocean Modeling Forum, *P. Levin NOAA NWFSC pers. comm.)* and has been informed by the criteria for ecosystem models determined by a Pacific Fishery Management Council Sardine Harvest Parameters Workshop (PFMC Agenda Item I.1.b Attachment 1 , April 2013 Briefing Book[1]).

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[1] http://www.pcouncil.org/resources/archives/briefing-books/april-2013-briefing-book/

A description of the Atlantis ecosystem model, tailored for modeling forage fish and ocean acidification, is detailed below.

Atlantis Model Extent

The California Current Atlantis model domain was based on the geometry of earlier Atlantis models for this region (Brand et al. 2007; Horne et al. 2010), but with substantial modifications. The revised geometry supports added focus on ocean acidification and pelagic species, in addition to groundfish focus from Brand et al. (2007). Additional considerations included improved representation of ecological processes (especially movement of organisms and foraging of predators) and reducing computer processing time.

The two-dimensional model domain extends from Triangle Island, off the north coast of Vancouver Island, British Columbia Canada, to Punt Eugenia, Baja California, Mexico. This domain covers the extent of the California Current, beginning with the origin of the current where the North Pacific Current reaches the coast of North America approximately at Vancouver Island (Checkley and Barth 2009). This domain includes the entire US portion of the large marine ecosystem identified by the NOAA Ecoregional Delineation Workgroup (2004), as well as by US-GLOBEC(1992). We extend the model slightly north, to northern Vancouver Island to include large populations of sooty shearwaters *Puffinus griseus*, rhinocerous auklets *Cerorhinca monocerata*, and Cassin's auklets *Ptychoramphus aleuticus* near Triangle Island (William J. Sydeman et al. 2013); we expect foraging movements of these birds to extend farther southward into the main body of the California Current. Checkley and Barth (2009) suggest a southern limit to the California Current ranging from 15-25°N; we use Punta Eugenia (27.83 °N) as the southern extent of the model, based on the oceanographic impacts of Punta Eugenia. This southern extent allows inclusion of the full range of the 'cold stock' of Pacific sardine (Felix-Uraga et al. 2004), as well as major bird colonies at Isla Natividad and Isla San Benito (Wolf, Keitt, Aguirre-MuñOz, et al. 2006). It is also a logical division for fishery catch records, which are recorded at the state level, with Baja California extending from this point north.

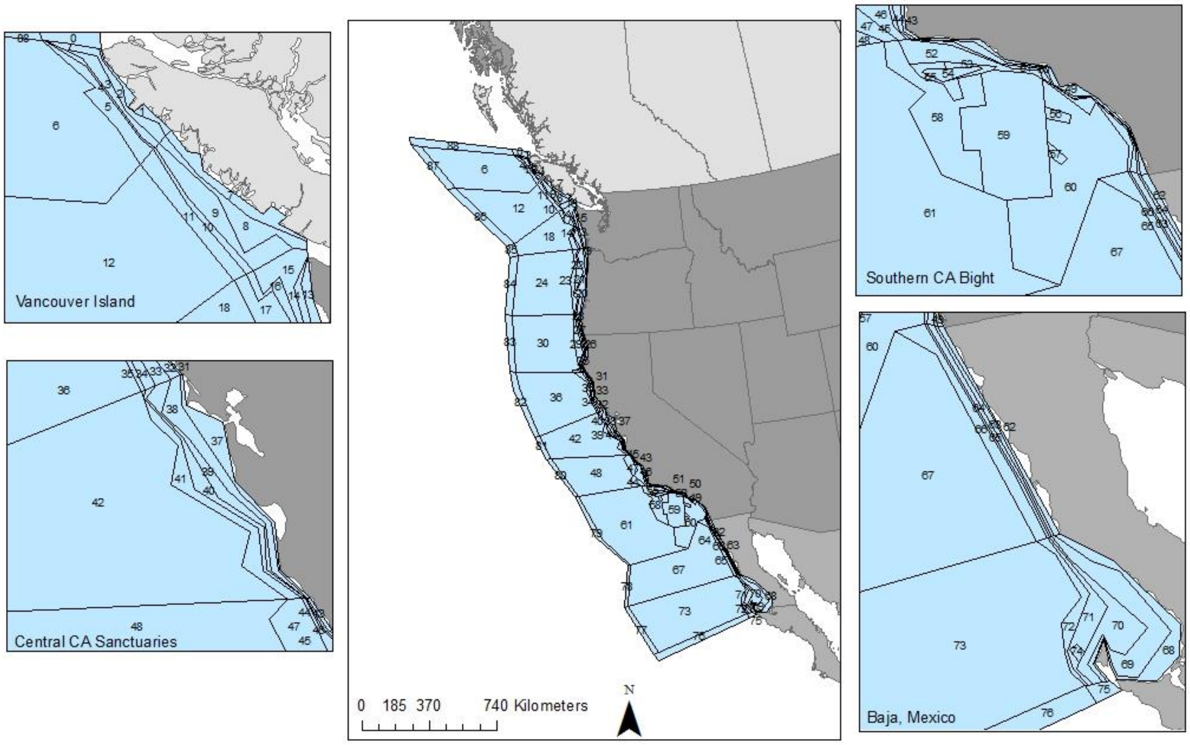

Figure 1. Atlantis model domain and polygons.

Longitudinal breaks follow the bathymetry of the 50m, 100m, 200m, 550m, and 1200m isobaths, and the 200 nm limit of the Exclusive Economic Zone (EEZ). The 50 m isobath separates the nearshore habitat from deeper regions that are most consistently sampled by the NOAA Northwest Fisheries Science Center FRAM groundfish trawl survey (Bradburn, Keller, and Horness 2011). The continental shelf is divided between a nearshore shelf (50m-100m) and deeper shelf (100-200m). The 200m isobath represents the shelf/slope break; key groundfish target species such as sablefish (*Anoplopoma fimbria*) and thornyheads (*Sebastolobus spp.*) are harvested from the shelf/slope break to a maximum depth of 700 fathoms (deeper fishing is prohibited), which is roughly approximated here as 1200m. We include an isobath break at 550m, in part to allow representation of the zone from 200-550m, which has particularly high abundance of corals (Guinotte and Davies 2013). In some regions and time periods this area of the slope between 200-550m is also closed to trawl fishing as part of the Rockfish Conservation Area (RCA), which does not extend to deeper slope waters. In addition to these longitudinal breaks that follow bathymetry, we include large offshore boxes that extend to the limit of the 200 nautical mile Exclusive Economic Zone. These boxes are intended to represent key offshore habitat for pelagic species such as mackerel, and also the habitat likely used by Pacific whiting (Bailey, Francis, and Stevens 1982; Agostini et al. 2006) and sardine as they move southward during autumn migrations.

The polygons have depth layers (in the z or vertical dimension) at the same interval as the isobaths listed above: 50m, 100m, 200m, 550m, and 1200m. The offshore pelagic box, which extends from the 1200m isobaths to 200 nautical miles, is assumed to be 2400m deep.

Latitudinal breaks are based on a compromise between biogeography, fishery management and catch reporting areas, and areas utilized by particular fleets and fisheries. Latitudinal breaks within British Columbia roughly match Department of Fisheries and Oceans management areas (http://www.pac.dfo-mpo.gc.ca/fm-gp/maps-cartes/areas-secteurs/index-eng.htm), with breaks selected so that major bird colonies off northern Vancouver would be separated from sites farther south on Vancouver island (and would not have immediate forage access to these without explicit movement). The US/Canadian border was used as a latitudinal break due to differences in fishery management between nations. Atlantis polygons extend inland to include inlets with high sardine catch (DFO regions 123 and 125, J. Mah, Dept Fisheries and Oceans Canada, Vancouver BC Canada).

Within the US, we selected latitudinal divisions that matched headlands and persistent oceanographic features at the Columbia River, Cape Blanco, Cape Mendocino, and Point Conception. The break at Cape Mendocino is also consistent with the division at 40° 10' N division used by the Pacific Fishery Management Council (PFMC) (http://www.pcouncil.org/wp-content/uploads/georock.pdf). The area most directly influenced by San Francisco Bay and Monterey Bay is demarcated by latitudinal breaks at approximately Pt Reyes and 36° N, with the northern limit based on the northern boundary of Cordell Bank and the Gulf of the Farallones National Marine Sanctuaries. The division at 36° N matches PFMC management and catch reporting areas, and approximates the southern extent of the Monterey Bay National Marine Sanctuary. Though seamounts are known to be areas of high biodiversity, and McClain and colleagues (2009) have identified dense aggregations of corals and sponges, we do not segregate these from the large offshore boxes. However, these aggregations of corals and sponges are included in the Atlantis model representation of these polygons, particularly off Central California, that include Davidson, Pioneer, Gumdrop, and Guide Seamounts.

The Southern California Bight is bathymetricallyy complex and required several simplifications within the model. We included the Cowcod Conservation Area (http://www.dfg.ca.gov/marine/cowcod.asp), which prohibits most bottom fishing in a large portion of the Bight. To reduce model complexity and improve simulation time, a simplified geometry of the Channel Islands merged the land portion of Santa Rosa, San Miguel, Santa Cruz, and Anacapa Islands. Based on an east-west gradient in water temperature and biogeography (Alison Haupt and Scott Hamilton, pers. comm), in the model a western nearshore shallow zone surrounds San Miguel and part of Santa Rosa Islands, with a separate zone for the nearshore zone around Santa Cruz and Anacapa Islands. Santa Catalina and San Clemente Islands are represented as seamounts (with no explicit land box), and two smaller offshore islands (Santa Barbara and San Nicolas Islands) are not detailed in the model geometry. At a crude level the overall Bight geometry captures one of the main spatial management areas for fisheries, and represents localized effects and needs of foraging predators.

Within Mexico, we included a latitudinal division at roughly 30°N (Punta Baja), in part to demarcate the southern extent of the range of the 'cold stock' of sardine (Felix-Uraga et al.

2004). Simplifications required to reduce simulation time included defining Isla San Benito as a 200m shallow oceanic box. Isla Guadalupe is not explicitly in the model, but we include seal and albatross populations that enter the Atlantis domain from that island.

Data Sources

This model updates and improves on data sources used in Horne et al. (2010), and functional groups were added to allow better representation of processes related to ocean acidification and forage fish (**Tables 1 and 2**). In particular, groups that were added to address ocean acidification include three coral taxa (stony corals, soft corals, and black corals), Dungeness crab, pteropods, and coccolithophores , and market squid.

Forage fish and some of their major predators are now modeled with finer taxonomic resolution. Sardine, anchovy, herring, Pacific mackerel, and jack mackerel are now included as single-species functional groups. Two predators, California sea lions and harbor seals, are now modeled at the species level and are not aggregated with other pinnipeds. Since predation by birds on forage fish may also be a focus of this model, the two main bird functional groups now distinguish between pelagic feeders that tend to be farther offshore (e.g. murres and aukelets) from birds that feed on both benthic and pelagic prey (e. g. cormorants).

Given the shift in groundfish fisheries in 2011 to individual transferable quotas, bycatch of individual species may play a critical role in the future in terms of limiting fishing effort and driving fleet dynamics. In addition to several single-species groundfish functional groups in Horne et al. (2010), we therefore now represent darkblotched, bocaccio, Pacific ocean perch, Petrale sole, and spiny dogfish as single species. Arrowtooth flounder was previously aggregated with halibut based on taxonomy and diet, but we now separate these based on the extremely different fishery value of these species.

For functional groups that have been added or updated since Horne et al. (2010), summaries are provided in **Appendix A** for biomass and life history parameters. Major sources drawn upon for this effort include updated stock assessments for fish and marine mammals, Northwest Fisheries Science Center Bottom Trawl Survey data (Bradburn, Keller, and Horness 2011), and spatial modeling of groundfish distributions (provided by A. Shelton, NOAA NWFSC, and B. Kinlan, NOAA NOS). Coral distributions were incorporated from the Five Year Review of Essential Fish Habitat (http://efh-catalog.coas.oregonstate.edu/overview/. Marine epifauna estimates were improved by the addition of databases provided by the Southern California Coastal Water Research Project. Extensive revisions were made to estimates of seabird abundance and spatial distribution. Details and additional data sources are noted in **Appendix A.**

Diets draw on the diet database compiled by Dufault et al. (2009) to parameterize the previous Atlantis ecosystem model for the California Current (Horne et al. 2010). We updated the database in 2013, matching the new functional group structure of the model as well as adding new literature sources. Those additions are noted in **Appendix A.**

We converted our diet matrix (proportion of each predator's diet consisting of each prey species) to a matrix of availability parameters required by the Atlantis functional response. Previously, for the Horne et al. (2010) model we had calculated the availability parameters from the diet matrix, using an Atlantis Availability Calculator algorithm (R. Gamble, NOAA NEFSC, pers. comm.). However, we found that during model calibration these availabilities were modified substantially, as we matched model predicted size-at-age and diets to observations. Anticipating this calibration process for the new effort, we are now taking a simpler approach. To make the conversion between diet compositions and availability parameters, we compared the quartiles of the distribution of tuned availability parameters from the previous version of the model (Horne et al. 2010), with the quartiles of the distribution of our new weighted diet proportions. This comparison suggested that dividing the diet proportions by 10 would allow the quartiles to approximately match. This approach provides the base estimates that are presented below.

Process Dynamics

Ecological processes are modeled as described in Horne et al. (2010). In summary, primary producers and invertebrates are modeled as biomass pools per spatial (three dimensional) cell within the model domain. Vertebrate growth (increase in size-at-age) is driven by consumption of prey. Population age structure of vertebrates is driven by recruitment and mortality. Numbers-at-age is explicitly tracked per spatial cell, and individuals migrate between cells seasonally and to optimize forage. Recruitment is based on the global abundance of adults, and recruits are currently distributed spatially proportional to that adult abundance. Recruitment of fish follows Beverton Holt stock-recruitment dynamics. When stock assessments were available, initial parameter estimates for Beverton Holt alpha and beta parameters were calculated based on estimates of steepness (h) and unfished recruitment (R_0). Recruitment of marine mammals, sharks, and birds were based on estimates of a fixed number of offspring per adult per year.

Mortality includes predation mortality (which arises based on the functional response parameters and predator and prey abundances) and senescence, meaning that individuals cannot persist past some maximum life span. Estimates of natural mortality (M) were used only to initialize the age structures used in the simulation. Linear and quadratic mortality terms were set to 0, and only added in the calibration stage of model development. Linear and quadratic mortality, respectively, represent density independent and density dependent factors that are not explicitly modeled, such as disease or a migratory predator not included in the model.

Oceanography

Scenarios presented at this Methodology Review are not yet forced by realistic oceanography. The model operates with a constant field of temperature and salinity, and no advection.

Ongoing work: Regional Ocean Modeling System

To forecast changes in future Northeast Pacific ocean conditions, a Regional Ocean Modeling System (ROMS) has been coupled to global circulation models and IPCC CO_2 scenarios to yield 50 year projections of ocean conditions. These conditions will include effects of global change (including acidification, temperature, nutrients, and oxygen) on an ecologically relevant spatial scale. ROMS is well-suited to resolve small-scale coastal phenomena, and has been successfully used in a wide range of regional studies worldwide (Haidvogel et al. 2008).

The primary output of ROMS will be a spatial time series of temperature, salinity, water flux (currents), and pH in the California Current, based on the work of Hermann et al. (2009, and **Figure 2**). Recent efforts have expanded this model geography to the southern extent of the Atlantis domain, as well as re-gridding the ROMS output onto the Atlantis geometry (**Figure 1**).

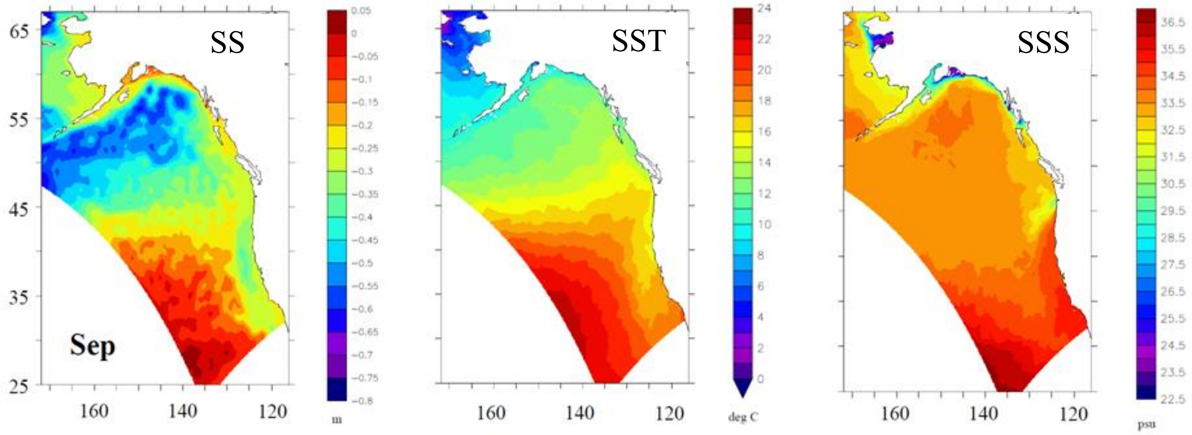

Figure 2. September climatologies of Sea Surface Height (SSH), Sea Surface Temperature (SST), and Sea Surface Salinity (SSS), from a 6-year (1997-2002) ROMS simulation (from Hermann et al. [2009]).

To project future effects of global change, ROMS will be forced with atmospheric and ocean boundary conditions that incorporate IPCC projections of global CO2. In particular, we will utilize output from the GFDL Earth System Model (ESM2.1) under IPCC emission scenarios. The ESM2.1 forecasts include coupled atmospheric and oceanic models; the latter includes a biogeochemical component based on the Tracers of Phytoplankton with Allometric Zooplankton (TOPAZ) model of Dunne et al. (2010).

We will use a module within ROMS (Fennel et al. 2008) to directly simulate lower trophic level dynamics (nutrient-phytoplankton-zooplankton), oxygen, and pH. The resulting pH fields, along with temperature and water flux, will be imported into Atlantis and will drive resulting dynamics of upper trophic levels, fleet catches, and productivity of harvested stocks.

Initial Scenarios presented at the Methodology Review

Scenarios presented at this Methodology Review begin on January 1st 2013, and project model dynamics forward with no fishing. Initial conditions represent 2013 (e.g. from 2013 groundfish stock assessments) or the most recent data available. The model is run on 12 hour time steps, with the differential equations solved by a simple adaptive forward difference method.

Table 1. Invertebrate functional groups. Each functional group (with a unique Code and Group name) includes multiple species.

Code	Group	Species In Functional Group
BC	**Benthic Carnivore**	Polychaetes,Nematodes, Burrowing Crustacea, Peanut Worms, Flatworms
BD	**Deposit feeders**	Amphipods, Isopods, Ghost Shrimp, Sea Cucumbers, Worms, Sea Mouse
TCR	**Stony corals**	Scleractinia (stony corals)
SCR	**Soft corals**	Alcyonacea (soft corals), Gorgonacea (sea whips or sea fans), Pennatulacea (sea pens)
BCR	**Black corals**	Antipatharia (black corals)
BFD	**Deep benthic filter feeder**	Anemones, Lampshells, Sponges Reticulate Sea Anemone, Rough Purple Sea Anemone, Swimming Sea Anemone, Gigantic Sea Anemone
BFS	**Shallow benthic filter feeders**	Barnacles, Green Colonial Tunicate,Sea Potato, Vase Sponge,
BFF	**Bivalves**	Geoducks, Clams, Scallops, Mussels
BG	**Benthic herbivorous grazers**	Sea snails, Abalone, Nudibranchs, Sand Dollars, Nake Solarelle, Limpets, non-harvested urchins: *Allocentrotus fragilis, Lytechinus pictus*
NUR	**Nearshore sea urchins**	*Strongylocentrotus purpuratus, Strongylocentrotus franciscanus, Lytechinus anamesus*
PSP	**Pandalid shrimp**	*Pandulus jordani*
PWN	**Crangon shrimp**	Crangon and Mysid Shrimp, ridgeback prawns, cleaner shrimp, spot prawns.
BMD	**Sea stars moonsnail whelk**	Sea Stars, brittle stars, Moonsnail, Whelk
BMS	**Octopus**	Giant, Bigeye, Yellowring, and Smoothskin Octopus, and Flapjack Devilfish
BML	**Crabs**	Grooved Tanner Crab, Brown box crab, hermit crab, shamefaced crab, Long horned decorator crab, Spiny Lobster, Pinchbug Crab, Red Rock Crab, Graceful Rock Crab, Spider Crab, Grooved Tanner Crab, Bairid, Scarlet King Crab, California King Crab, Squat lobster. All crab except Dungeness.
DUN	**Dungeness crab**	*Cancer magister*
BO	**Meiobenthos**	Flagellates, Cilliates, Nematodes

CEP	**Squid**	Bobtail squid, flapjack squid, octopus squid, Japetella, Gonatus, Chiroteuthis, Abraliopsis, Robust Clubhook, Rhomboid squid, Sandpaper squid, Vampire Squid
MSQ	**Market squid**	*Loligo opalescens*
HSQ	**Humboldt squid**	*Dosidicus gigas*
ZG	**Gelatinous zooplankton**	Salps, Jellyfish, Ctenophores, Comb Jellies
ZL	**Large zooplankton**	Euphausiids, Chaetognaths, Pelagic Polychaetes, Crimson Pasiphaeid
ZM	**Mesozooplankton**	Copepods, Cladocera
PTE	**Pteropods**	Shelled (Thecosome) pteropods including *Limacina helicina*
ZS	**Microzooplankton**	Ciliates, Dinoflagellates, Nanoflagellates, Gymnodinoids, Protozoa
COC	**Coccolithophore**	Coccolithophore
PL	**Large phytoplankton**	Diatoms
PS	**Small phytoplankton**	Microphytoplankton
SG	**Seagrass**	
MA	**Macroalgae**	Kelp
BB	**Benthic bacteria**	
PB	**Pelagic bacteria**	
BO	**Meiobenthos**	
DC	**Carrion**	
DL	**Labile detritus**	
DR	**Refractory detritus**	

Table 2. Vertebrate functional groups. Grey rows indicate functional groups, while white rows indicate species that are included within a multi-species functional group. ‘Proportion of group’ was used to weight species history parameters to calculate life history parameters for the functional group.

CODE	Functional Group	Species	Atlantis Biomass (metric tons)	Proportion of Group
FDP	Dover sole	Dover Sole	931172	
FPO	Canary rockfish	Canary rockfish	19994	
FVV	Shortbelly rockfish	Shortbelly rockfish	108800	
SHC	Cowcod	Cowcod	4322	
YEL	Yelloweye rockfish	Yelloweye	2968	
FBP	Myctophids		22735421	
		northern lampfish: lanternfish		0.60
		blue lantern fish		0.10
		CA Smoothtongue (deepsea smelt)		0.15
		Argentina sialis		0.15
FDD	Deep demersal fish		160190	
		CA slickhead	31553	0.27
		twoline eelpout	5388	0.05
		bigfin eelpout	4243	0.04
		black eelpout	1743	0.01
		giant grenadiers	28024	0.24
		blackbelly eelpout	1411	0.01
		Pacific grenadiers	45425	0.39
		Pacific hagfish		0.00
		Black hagfish		0.00
		snakehead eelpout		0.00
		blacktail snailfish		0.00
FDC	Deep small rockfish		218247	
		Aurora	4366	0.03
		Sharpchin	12767	0.08
		longspine thornyhead	68571	0.43
		Splitnose	74772	0.47
FDO	Deep large rockfish		357293	
		Bank		0.00
		Blackgill	6595	0.03
		Redbanded		0.00
		Rougheye	12271	0.05
		shortspine thornyhead	243850	0.93
DAR	Darkblotched rockfish	Darkblotched rockfish	20600	
FDF	Small flatfish		146775	
		Pacific sanddab	13500	0.13
		rex sole	18497	0.17

		slender sole	10270	0.10
		flounder, starry	9029	0.08
		English sole	46968	0.44
		DeepSea Sole	9659	0.09
FDE	Shallow miscellaneous fish		41440	
		croaker, white		
		Plain midshipman		
		threadfin sculpin		
		Red Irish Lord		
		Brown Irish Lord		
		white sea bass		
FDS	Midwater rockfish		440967	
		Chilipepper	33619	0.13
		Vermillion	14661	0.06
		Widow	68238	0.26
		Yellowtail	143384	0.55
BOC	Bocaccio	Bocaccio rockfish	17673	
POP	Pacific Ocean perch	Pacific Ocean Perch	30482	
FDB	Shallow small rockfish		61336	
		Flag		
		Gopher	2575	0.07
		Greenstriped	17378	0.48
		Halfbanded		0.00
		Rosethorn		0.00
		Stripetail	16127	0.45
SHR	Shallow large rockfish		60215	
		Brown	1445	0.03
		Copper	3287	0.07
		Greenblotched		0.00
		Greenspotted	3110	0.07
		Redstriped		0.00
		Flag		0.00
		Black	30363	0.69
		Blue	5447	0.12
		Kelp Greenling	624	0.01
FMM	Pacific hake	Pacific Hake	3868390	
FMN	Sablefish	*Sablefish*	270662	
FVD	Large piscivorous flatfish		55909	
		Halibut, Ca	36000	0.64
		Halibut, Pacific	19909	0.36
ARR	Arrowtooth flounder	Arrowtooth	103914	
PET	Petrale sole	Petrale	23724	
FVS	Large demersal predators		96091	
		lingcod (north if noted)	63488	0.66

		lingcod south pop	30875	0.32
		Cabezon	1728	0.02
		bass, giant sea		
FVT	Large pelagic predators		166820	
		Albacore	128125	*0.77*
		yellowfin tuna	16464	*0.10*
		Swordfish	147	*0.00*
		bigeye tuna	21280	*0.13*
		Marlin	804	*0.00*
FPL	Mackerel	Mackerel	211126	
JAC	Jack mackerel	jack mackerel	389000	
FPS	Small planktivorous fish		387388	
		sand lance		
		whitebait smelt	24243	0.06
		Saury	347200	0.90
		Eulachon	15000	0.04
		Pink sea perch	945	0.00
SAR	Sardines	Sardines	659539	
ANC	Anchovies	Anchovies	194635	
HER	Pacific herring	*Herring*	199663	
FVB	Chinook salmon		18000	
SHD	Demersal sharks		2200	
		Sixgills		0.33
		Sleeper		0.33
		Sevengill		*0.33*
SHB	Small demersal sharks		57040	
		spotted ratfish	24464	*0.58*
		brown catshark	9962	*0.24*
		filetail cat shark	7516	*0.18*
DOG	Spiny dogfish	Dogfish	375988	
SHP	Pelagic sharks		13167	
		Blue shark		*0.20*
		White		*0.20*
		Mako		*0.20*
		Thresher		*0.20*
		Brown		*0.20*
		Soupfin		*0.20*
SSK	Skates and rays		121530	
		CA Skate		0.00
		Sandpaper skate		0.07
		bering skate		0.00
		roughtail skate		0.00
		longnose skate	71217	0.80
		Big Skate		0.13
PIN	Pinnipeds		52542	
		Steller Sea Lions	5600	0.10

		N. Elephant Seals	46076	0.82
		Northern Fur Seals	3977	0.07
		Guadalupe Fur Seals	594	0.01
CSL	California sea lions	Ca Sea Lions	50986	
HSL	Harbor seals	Harbor Seals	5909	
REP	Transient orcas		800	
WHB	Baleen whales		686695	
		Humpback	127349	0.19
		Blue	386187	0.56
		Fin	169216	0.25
		Sei	2118	0.00
		Minke	1825	0.00
GRA	Gray whale	Gray whale	293995	
WHT	toothed Whales		32344	
		offshore killer whales	481	0.01
		pygmy sperm	114	0.00
		baird's beaked whale	3277	0.10
		cuvier's beaked whale	6088	0.19
		mesopledont beaked whales	291	0.01
		Sperm	22093	0.68
ORC	Resident orcas	resident orcas	582	
WHS	Dolphins		62901	
		Dalls Porp	2791	0.04
		Harbor Porp	2288	0.04
		short-beaked common dolphin	36716	0.58
		long-beaked common dolphin	12210	0.19
		bottlenose dolphin	278	0.00
		striped dolphin	1410	0.02
		Short-finned Pilot whale	601	0.01
		Risso's dolphin	1562	0.02
		N. Right Whale Dolphin	972	0.02
		Pacific white-sided dolph	4075	0.06
WDG	Sea otters	Sea otter	184	
FVO	Migrating birds		1604	
		Black footed/Laysan albatross	227	0.14
		black-legged kittiwake	38	0.02
		Sooty shearwater and pinkfooted shearwatters (All Shearwaters)	1098	0.68
		Northern fulmar	73	0.05
		Phalaropes	67	0.04
		Black-vented shearwater	65	0.04
		Black storm petrel	36	0.02
SB	Seabirds (pelagic feeders)		1600	
		Cassin's auklet	226	0.14
		Common murre	988	0.62
		Rhinoceros auklet	51	0.03
		Tufted puffin	29	0.02
		Marbeled Murrelet	8	0.01
		Caspian tern	28	0.02

		Brown pelican	89	0.06
		Leach's storm petrel	180	0.11
SP	Seabirds (benthic and pelagic feeders)		729	
		Pigeon guillemot	29	0.04
		Brandt's cormorant	220	0.30
		Pelagic cormorant	80	0.11
		Double-crested cormorant	110	0.15
		Western gull	291	0.40

Appendix A: Sources for Abundance and Life History Parameters

Nutrients and Phytoplankton (Nitrate, Ammonia, Silicate, Large Phytoplankton, Small Phytoplankton, Coccolithophores)

We base initial conditions for nutrients and phytoplankton from extensive sampling by the CalCOFI and GLOBEC programs in 2010-2011 and 1998-2003, respectively. We use data from December, January, and February only, to capture a January 1st model start date, and to avoid relatively high primary production in the autumn, and strong upwelling and nutrient increases in spring.

Though GLOBEC samples are from a decade prior to our model initial conditions, to our knowledge they are the only comprehensive sampling of the Northern California Current upon which to base the model. GLOBEC data for winter are available only on two transects, the Newport Hydrographic line off Newport, Oregon and Coos Bay Oregon (Five Mile Transect). Data were downloaded from the US GLOBEC Data System (http://globec.whoi.edu/jg/dir/globec/nep/ccs/ltop/). Nitrate, ammonia, silicate, and chlorophyll-a are available from rosette bottle samples taken at depth for each survey location. GLOBEC data were applied from the northern model boundary to as far south as Cape Mendocino (Atlantis polygons 1-30). Polygons in this northern region that lacked GLOBEC samples were assigning nutrients and phytoplankton abundance from GLOBEC data in identical depth (z) ranges and the closest proximity. Chlorophyll a concentrations were converted to phytoplankton abundance as detailed below.

CalCOFI rosette bottle samples for nitrate, ammonia, silicate, and chlorophyll-a are available for San Francisco through the US-Mexico border, approximately 29.8°N-37.8°N, corresponding to Atlantis polygons 37-61. Data were downloaded via NOAA ERDDAP (Environmental Research Division's Data Access Program) data server, available at (http://coastwatch.pfeg.noaa.gov/erddap/tabledap/siocalcofiHydroBottle.html). Model initial conditions for polygons north of the CalCOFI sampling region but south of Cape Mendocino were based on the CalCOFI sampling. Similarly, polygons in Mexico were extrapolated from the CalCOFI samples, using the sample region immediately north of Point Conception (to avoid effecs of the Southern California Bight).

Following Brand et al. (2007), we assigned 3/4 of chlorophyll a to Large Phytoplankton (diatoms) and 1/4 into a catch-all smaller phytoplanton group, and assumed a ratio of 3: 1 for Si:N for Large Phytoplankton (diatoms). We assume 30mg C: 1 mg chlorophyll a

(Strickland 1966). The catch-all smaller phytoplankton group was further divided into the Atlantis groups Small Phytoplankton (2/3) and Coccolithophores (1/3), on the basis of global modeling of the ratio of biomass of those two taxa (Gregg and Casey 2007).

Invertebrates

The majority of invertebrate groups are unchanged since Horne et al. (2010). Revisions are noted below, and focus particularly on calcifying (shell-forming) species relevant to ocean acidification, and zooplankton likely to be tightly linked to forage fish dynamics. Diets, consumption rates, and growth rates are taken from Horne et al. (2010) unless noted below.

Large Zooplankton and Mesozooplankton

We estimated biomass of two zooplankton groups from a dataset provided by Bill Peterson (unpublished data, NOAA NWFSC, Newport Oregon) from vertical and bongo plankton tows at stations spanning Washington to California from 1994-2007. The two Atlantis zooplankton groups are Large Zooplankton (ZL, primarily euphausiids and chaetognaths) and Mesozooplankton (ZM, primarily copepods). These data come from tows conducted at over 236 stations along the coast. The tows are vertically integrated, meaning that abundance can be mapped in two dimensions but the vertical distribution of plankton in the water column is not considered. The bottom depth of the ocean at each station was determined using ArcGIS and categorized according to Atlantis bins spanning 0-50, 50-100, 100-200, 200-550, 550-1200 and 1200-2000m. Additionally, species listed in the database were assigned to the appropriate Atlantis plankton group.

The data are reported in biomass as mg/m^3 dry weight carbon. For each tow the sum across all species in each group (ZL or ZM) for the tow was calculated and then the average biomass in carbon across all tows was determined, grouped by depth bin. This provided us with final values of mg/m^3 dry weight carbon of ZL and ZM functional groups for each Atlantis depth bin. These values were then converted to nitrogen using the standard conversion for Atlantis of dividing by 5.7 (based on the Redfield ratio). We applied these coastwide. Therefore, as an example all Atlantis areas with bottom depths from 50-100m have identical initial concentrations of these plankton groups. Future efforts will improve the north-south spatial representation of plankton concentrations, and will incorporate data from CalCOFI.

Pteropods

This functional group represents shelled (Thecosome) pteropods including *Limacina helicina.* This calcifying plankton has been identified as highly susceptible to ocean acidification, with shell dissolution already evident in some portions of the California Current that have seasonally low pH (Bednaršek et al. 2014). For Atlantis, we apply biomass estimates from Bednaršek and colleagues (2012), using as a starting point the global mean density of 4mg c/m^3. We apply this to the entire horizontal model domain and down to a depth of 200m, which suggests 10.5 million metric tons of Pteropods, compared to 39.5 million metric tons of Large Zooplankton and 34 million metric tons of Mesozooplankton. This pteropod estimate may be high, and Bednarsek (NOAA PMEL, pers. comm) has provided a PANGEA database with additional abundance data.

Vertical distributions of pteropods during night versus day follow patterns provided from 2011 cruise data (N. Bednaršek, pers. comm.). Diets are taken from a synthesis by Hunt et al. (2008) and based on discussion in Lalli and Gilmer (1989). Hunt et al. (2008) provided data for *Limacina helicina, Limacina helicina antarctica, and Clio pyramidata*, which suggest 65% of the diet as Mesozooplankton, 8% as Large Phytoplankton, 3% Micro Zooplankton, and 1% other pteropods. Lalli and Gilmer (1989) provide extensive discussion of the filter feeding mucus webs that are likely to capture bacteria and detritus, and so we assume 7% diet composition of each of Pelagic Bacteria, Labile Detritus, and Refractory Detritus.

Market squid

US harvest of market squid has been capped at near 100,000 metric tons, with landings primarily in Southern and Central California. This equates to a rough average of 1 mt/km2 of harvest on the US shelf and slope. We assume 2 mt/km2 of biomass, consistent with Field (2004), applied on the shelf and slope (out to 1200m).

Humboldt squid

Humboldt squid are a species that is present episodically in the California Current, with potentially very high peak biomasses followed by years of absence. We assume 1.1 mt/km2 on the slope (200-1200m), and 0.5 mt/km2 on shelf waters. These spatial distributions reflect higher densities at the slope-shelf break and farther offshore (John C. Field et al. 2013; Zeidberg and Robison 2007). For comparison, Tam et al. (2008) estimated 0.25-0.5 mt/km2 in the Nothern Humboldt Current, a similar upwelling system where the species is also present. There is some evidence of migrations from Mexican or offshore Southern California to northern waters during spring and summer, and a return in the fall (John C. Field et al. 2007; John C. Field et al. 2013), so our initial (January) spatial distribution is for Point Conception and south only.

Squid

Estimates of abundance of non-harvested squid are highly uncertain. For all cephalopods (including market squid), Field (2004) estimated 2 t/km^2 on the continental shelf and slope. For the Atlantis Squid functional group (which excludes market and Humboldt squid) we assume approximately 0.5 t/km^2, applied to the entire model domain shallower than 1200m, for an initial biomass of approximately 110,000 t.

Stony corals (Scleractinia) and Black Corals (Antipatharia)

Data on both Scleractinian (stony corals) and Antipatharian (black corals) were obtained from work by the Five Year Review of Essential Fish Habitat (http://efh-catalog.coas.oregonstate.edu/overview/). Scleractinian coral presence was obtained from model predictions of favorable habitat (Davies and Guinotte 2011). Data on antipatharian corals were obtained from Curt Whitmire (curt.whitmire@noaa.gov), with data consisting of point locations where antipatharian corals were found off the US west coast. These data are part of the work by the Essential Fish Habitat working group, but are not available on the website.

The data sources listed above provide model predictions of Scleractinia presence, and trawl survey data of Antipatharia presence. Since Antipatharian presence is only point locations in surveyed locations, whereas the Scelactinian presence uses habitat modeling to predict presence across the entire region, there is much higher cover by Scleractinian corals in the results.

The data sources provide maps of Antipatharia at a pixels size of 1 km x 1 km, and of Scleractinia at a pixel size of 525 m x 525 m. These maps were re-projected onto the Atlantis polygon geometry and coordinate system. Percent cover was then calculated as the fraction of each Atlantis polygon which contained coral of each type. Since presence in a grid cell does not mean complete cover by coral, if Antipatharian corals were present in 1 km x 1 km cell they were assumed to have 13% cover (Anderson et al. 2011, Bridge et al. 2011), and Scleractinian corals were assumed to have 48% cover (Rogers et al. 1984, Kenyon et al. 2010, Bridge et al. 2011).

Percent cover was then converted to biomass. Using the same values as Ruiz Sebastian and McClanahan (2013), Scleractinians were assumed to be 12.55 mg ww / cm2 and Antipatharians were 5.68 mg ww / cm2 (Table s.9) (Ruiz Sebastián and McClanahan 2013). The values were multiplied by 10 to convert mg/cm2 to g/m2, then divided by 20 to convert to dry weight, and finally divided by 5.7 to convert to g N/m2.

Soft Coral (Subclass Octocorallia)

Similar to stony and black corals, data for soft corals were obtained from work by the Five Year Review of Essential Fish Habitat (http://efh-catalog.coas.oregonstate.edu/overview/) and provided courtesy of Curt Whitmire, NOAA NWFSC-Newport. The data were re-organized to group all species/genus, etc. by order and then the soft coral orders Gorgonacea (sea whips and sea fans), Alcyonacea (soft corals) and Pennatulacea (sea pens) were identified.

For soft corals, only point data (observed coral locations) were available. Using GIS, the points were plotted, re-projected, and then assigned to the Atlantis polygons using ‘Intersect’ and ‘Summary Statistics’ tools in GIS to count the number of points in each

Atlantis polygon. Points from three different orders were then summed so that there is one value of total soft coral points per Atlantis polygon.

Data for this group are perhaps best suited to illustrate the spatial distribution of soft corals. However, converting to biomass is a necessity for the Atlantis model, though analysis of results involving this group should focus on spatial distribution and not biomass. For simplicity, since we do not know the proper weight of a sea fan or sea whip, we assumed that one data point was equivalent to 100 kg wet weight. This was then converted to kg/m2 by dividing by polygon area. We converted from wet to dry weight (divide by 20) and then to nitrogen (divide by 5.7).

Since these data were only for the US coast, soft coral densities from polygons 13-18 (Washington State) were used for Canadian coast polygons 7-12 and 1-6. Soft coral densities from polygons 43-48 (just north or Point Conception, California) were used for Mexican coast polygons 62-67 and 68-73.

Benthic Carnivores (Polychaetes)

The data for polychaetes come from the ABA Consulting (2000). These data were part of a sampling effort to evaluate alternatives routes for an MCI Worldcom/Southern Cross Monterey Bay Cable Landing project. Infaunal sampling involved 95 Smith-McIntyre grabs in Monterey Bay, at depths from 10-200m. ABA Consulting (2000) reports polychaete densities in wet weight g/m2, which we converted to dry weight mg nitrogen/m^2 using our standard conversions. Since the depth intervals for sampling do not exactly match those for Atlantis, the groupings were assumed as:

- ABA report depths: 0-50 m, Atlantis depth bin: 0-50m
- ABA report depths: 60-90 m, Atlantis depth bin: 50-100 m
- ABA report depths: 109-150 m, Atlantis depth bin: 100-200 m
- ABA report depths: 325-45 m, Atlantis depth bin: 200-550 m
- ABA report depths: 700-1200 m, Atlantis depth bin: 550-1200 m

Nearshore urchins

This group is primarily composed of *Strongylocentrotus franciscanus,* the red sea urchin that exists in nearshore kelp beds. 2012 US harvests were 12.25 million pounds or 5600 metric tons. Lacking a reliable biomass estimate, we assume total biomass of four times this amount, distributed in the nearshore (<50m) depth zones coastwide.

Dungeness crab

Precise biomass estimates of Dungeness crab are not available, despite the large economic value of this fishery on the US West Coast. However, US landings data are available from PacFin (http://pacfin.psmfc.org/pacfin_pub/all_species_pub/woc_r307.php), and we use these to inform our model initial conditions. Average landings from 2008-2012 in round weight was 58,416,000 pounds per year, or 2.6 x10^7 kg.

Since this is just landed biomass (and only males can be retained by the fishery), we made the following assumptions to calculate total biomass: 75% of males are caught and that the population has a 50:50 sex ratio. The biomass calculated was then converted to mg dry weight nitrogen, assuming dry weight = 1/20th wet weight, and dry weight/5.7 = nitrogen weight.

Dungeness crab values are represented as densities in mg N/m2. Therefore the total biomass for the US portion of the coast was divided by the area in US waters in which they are found. Dungeness are only found from 0-100 m and north of the Channel Islands. Therefore the total crab area is a sum of boxes from 0-50 and 50-100 m, north of the Channels Islands region and up to the northern extent of Washington State.

The biomass was divided by the total area, and the concentration (22.58 mgN/m2) was applied to all depth bins 0-50 and 50-100 from the northern tip of Vancouver Island (boxes 1,2) to just north of the Channel Islands (boxes 43, 44).

Pandalid shrimp

Similar to Dungeness crab, pandalid shrimp (*Pandalus jordanii*, pink shrimp) support a valuable fishery for which landings but not biomass data are available. Landings data from PacFin (http://pacfin.psmfc.org/pacfin_pub/all_species_pub/woc_r307.php) suggest average annual landings for 2008-2012 of 25,007 mt per year. Since this is just harvested biomass, the biomass was multiplied by 4 to approximate the total population biomass, assuming that annual catch is ¼ of standing stock. The biomass calculated was then converted to mg dry weight nitrogen, using the standard conversion described above.

Pink shrimp are found between bathymetries 90-230m (Hannah 2011), and thus were all assumed to be in the Atlantis polygons extending from the 100-200 m isobaths. The biomass was divided by the total area (for polygons between the 100-200 m isobaths within the US), and the resulting density (0.0405 mgN/m2) was applied to all polygons in this depth range, from the northern tip of Vancouver Island (box 3) to the southern end of California (box 51).

Benthic Herbivorous Grazers; Crangon shrimp; Crabs; Seastars, moonsnails, and whelk

Extensive marine epifauna data sets across large spatial scales are rare in the California Current. One exception is for southern California, where the Southern California Coastal Water Research Project (SCCWRP) has repeated bottom trawl surveys that target and identify epifauna. Trawl survey data from 2003 for southern California were provided by Shelly Moore (SCCWRP). Bottom trawl surveys had a 3.8 cm body mesh and 1.3cm cod end mesh, and so are perhaps best sampling larger epifauna. Sampling speeds were 1 m/s, tow length approximately 525m, and net width approximately 8m [2].

The SCCWRP database contains a list of species found in each trawl conducted in 2003, and the biomass of the species in the trawl. In order to group these species by functional group, the species were assigned to taxonomic categories: Phylum, Class, Order, Family and Common Name. Assignments were done through web search (primarily using WoRMS: www.marinespecies.org) and some were double checked using the Southern California Marine Invertebrate Taxonomists list (http://www.scamit.org/).

The trawls were conducted across bathymetries rather than along bathymetries. A number of trawl stations were immediately eliminated if they were: harbors, marinas, bays or municipal water outfalls. As a result the final trawl depths included were 5-30m; 30-120m; 120-200m; and 200-500m. We assigned trawl depths to Atlantis depth intervals, according to Table 3.

Table 3. SCCWRP trawling depths and assigned Atlantis depth bin

Atlantis Depth Bin (m)	SCCWRP Trawl Data (m)
0-50	5-30
50-100	30-120
100-200	120-200
200-550	200-500
550-1200	200-500 (assumed to be the same)
1200-2400	NA = 0

Of the total biomass in the SCCWRP dataset for regions of use (excluding harbors, bays, marinas and municipal water outfalls), 82% of the data were assigned to an Atlantis functional group. The primary species not included were octopus and squid. Though a few octopus and squid species are common in SCCWRP data, many other octopus and squid species that are known to occur in the California Current are not present in SCCWRP, and we therefore did not use SCCWRP data as representative of these two functional groups.

Species were assigned to functional groups as follows:

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[2] Detailed information regarding the data collection methods can be found at: http://www.sccwrp.org/Documents/BightDocuments/Bight03Documents/Bight03PlanningDocuments.aspx
Document: Field Operations Manual

BG Benthic Herbivorous Grazers

- Sea snails; multiple species
- Sea urchins; non-fishery urchins: *Allocentrotus fragilis, Lytechinus pictus*
- Sand dollars; multiple species
- Nudibranch; multiple species

PWN Shrimp (excluding pink shrimp)

- Crangon
- Ridgeback prawns
- Cleaner shrimp
- Spot prawns

BMD Seastars, moonsnails, whelk

- All sea stars and brittle stars in the data base (~41 species)

BML Crabs

- All crab species, besides Dungeness (37 species) including hermit crabs
- Squat lobster

For each trawl, the biomass was summed across the multiple species in a functional group. Each trawl was then assigned to a depth bin according to Table 3, and the average value of biomass in that depth bin was calculated. This gave values in biomass (Kg wet weight). Biomass was divided by trawl area (4200 m2) and converted to mg/m2 wet weight. Final biomass values are in mg N m^{-2}. These biomass densities per depth bin are applied to polygons outside Southern California, lacking extensive epifaunal sampling in those regions.

Fish

We have updated the majority of fish biomass estimates since Horne et al. (2010). This includes updates to forage fish, several of which are now modeled as single species rather than as an aggregated group. Diets, consumption rates, and growth rates are taken from Horne et al. (2010) unless noted below.

Pacific sardine (*Sardinops sagax*)

Abundance of sardine, 660,000 t, is taken from the 2012 stock assessment (Hill et al. 2012). This estimate is for the entire range of this stock, which matches the Atlantis model domain. Life history parameters and diets follow those in Horne et al. (2010) and Dufault et al. (2009).

Northern anchovy (*Engraulis mordax*)

Eggs surveys conducted by Fissel et al. (2011) found a spawning stock biomass (SSB) for the central subpopulation of anchovy to be 159,370 mt. Extrapolating to a total biomass for the population assuming weights-at-age and numbers-at-age (based on constant natural mortality rates) led to a total of 186,714 mt for the central subpopulation (population from San Francisco, CA to the southern extent of the model in Baja). Since anchovy mature at 2 years of age, calculating total biomass led addition of age 1 fish.

A northern subpopulation of anchovies is found in Oregon and Washington (Pacific Fishery Management Council 2011) , separate from the central subpopulation studied by Fissel et al. (2011). Lacking detailed estimates, we apply a density of 1333 individuals per km^2 (Orsi et al. 2007) to calculate a total biomass for the Northern subpopulation. The total area from San Francisco, CA to the northern extent of the model and out to 2000m is equal to 127,600 km^2, and at 50 grams per individual this leads to a total biomass of 8504 mt in the North. Adding this to the total biomass from the South (186714 mt) leads to 195,000 mt.

Life history and diet information is taken from Horne et al. (2010) and Dufault et al. (2009).

Herring (*Clupea pallasii*)

DFO (DFO 2012) estimated there to be 12,143 tons of herring off the West Coast of Vancouver Island and northern Vancouver Island (DFO Area 27) in 2013. We apply that biomass estimate to the Canadian portion of our model domain.

Herring abundance in the US is more uncertain. Hay and McCarter (1997) summarize estimates of herring abundance for British Columbia, Washington/Oregon, and North and Central California. Those authors suggest maximum densities of 10, 0.8, and 2 t/km^2 for these regions, respectively. One approach would be to apply these rough maximum density estimates to the areas shallower than 200m and from Central California north, which would suggest 46,000 t in US waters, and 149,000 t in the Canadian portion of our model domain, much higher abundance than would be expected from DFO (2012). Instead, for Washington/Oregon we scaled the densities from DFO (2012) by the ratios from Hay and McCarter (1997), 0.8/10, and for North and Central California we similarly scale the Canadian estimate by 2/10. The resulting initial abundances for US waters are 2820 t. For comparison, US fisheries landed 1743 t of herring and 2.5 t of roe in 2012.

Life history and diet information is taken from Horne et al. (2010) and Dufault et al. (2009).

Small Planktivorous Fish

This group includes the forage fish that are not currently major fishery target species: Pacific saury (*Cololabis saira*), smelts (Osmeridae), eulachon (*Thaleichthys pacificus*), and pink sea perch (*Zalembius* rosaceus). To some extent a catch-all group, the species in this group range from offshore, pelagic species such as saury, to species closer to shore such as smelts. Life history parameters are taken from Horne et al. (2010), and diets from Dufault et al. (2009).

Crude biomass estimates are available for these four species. For saury, Smith et al. (1970) estimated 0.31 t/km^2 . Applying this to the pelagic boxes (ranging from the 1200m isobaths to the 200 nm limit) suggests 347,000 tons in the model domain. These pelagic boxes cover 1.12 million square kilometers, and account for 84% of the dynamic model area.

For smelt, Ruzicka and colleagues (2007) estimated 0.00281 t/km2, or 24,000 t in our model domain from the shore to 1200m depth. Ruzicka's estimate is based on analysis of the BPA and GLOBEC trawl survey data, and applies a scalar of 15 to those observations, based on comparison to the sardine stock assessment and a 2008 cruise by the *RV* Miller Freeman (J. Ruzicka, Oregon State University, Newport OR).

For Eulachon, a NOAA Status Review. (Gustafson et al. 2010) suggests 80-90% of eulachon (hooligan) are in British Columbia waters. Estimates of biomass are available from DFO shrimp surveys off the West Coast of Vancouver Island ((D. E. Hay, Harbo, R., et al. 1999; D. Hay and McCarter 2000; D. E. Hay, Harbo, et al. 1999)), which estimate abundance as high as 15,000 mt in 2002. The Status Review also summarizes estimates of eulachon abundance from AFSC Triennial trawl data. Though this trawl survey did not target forage fish, it indicates that ~90% of eulachon were caught in Canadian Vancouver area, with abundances of 1281 mt, 153 mt, and 13,470m, for years 1995, 1998, and 2001 respectively. We use an estimate of 15,000 t as initial conditions for the model.

Pink sea perch are poorly sampled by all gears, yet are among the top 40 species identified in the NWFSC Slope/Shelf trawl survey (Bradburn, Keller, and Horness 2011); we use an estimate of 945 metric tons from swept-area estimates in those trawl survey data.

Life history parameters are primarily from FishBase, and are taken from Horne et al. (2010). Saury account for 90% of the biomass, and therefore life history parameters primarily reflect this species. Diets are taken from Dufault et al (2009), with the addition of five new studies.

Jack Mackerel (*Trachurus symmetricus*).

Demer et al. (in press) and Zwolinski et al. (Zwolinski et al. 2012) have estimated jack mackerel abundances from the Mexican border to Vancouver Island, with acoustic methods and complementary trawl sampling. Demer et al. (in press) suggest 389,000 t of jack mackerel, which we use for the model initial conditions. Zwolinski et al. (2012) estimated 323,000 t for 2010. Note that these differ substantially from the preliminary biomass estimates, used in Horne et al. 2010 and Brand et al. 2007, of 900,000 mt (Stauffer and Charter 1982, MacCall and Stauffer 1983).

Life history parameters and diets are taken from Horne et al. (2010) and Dufault et al. (2009).

Pacific chub mackerel (*Scomber japonicus*)

Pacific chub mackerel abundance of 211,000 t is taken from the 2011 stock assessment (Crone et al. 2011). The assessment covers the stock off Baja California and southern California, which also migrates northward. Life history parameters and diets are taken from Horne et al. (2010) and Dufault et al. (2009), with the addition of three new diet studies.

Shallow Miscellaneous Fish

This group of small nearshore fish is mainly carnivorous, and includes sculpin and lords (Cottidae), midshipmen (*Porichthys notatus)*, white croaker (*Genyonemus lineatus*), white sea bass (*Atractoscion nobilis*), wolf-eel (*Anarrhichthys ocellatus)*, kelpfish (*Chironemus marmoratus*), gobies (Gobiidae), ocean whitefish (*Caulolatilus princeps*), prickleback (*Plectobranchus evides* and *Poroclinus rothrocki)*, mosshead warbonnet (*Chirolophis nugator*), pipefish (*Syngnathidae*), tubesnout (*Aulorhynchus flavidus*), and opaleye (*Girella nigricans*). As for Horne et al. (2010), abundance of these groups is taken from dive surveys by the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) . PISCO data for California include 4888 transects, from 77 sites, studied from 1999-2006. Sampling sites were from approximately 34N -36N latitude. Six Oregon sites were surveyed from 2001-2003, for a total of 169 transects in northern Oregon and 82 transects in southern Oregon. Dive surveys extended to 20m depth, and sampling protocols are available from PISCO[3]. Estimated densities were 0.144, 0.06, and 0.025 g/m^2 wet weight for California, southern Oregon, and northern Oregon. We applied these densities to the nearshore model domain (0-50m) for the areas south of Cape Mendocino, from Cape Mendocino to southern Oregon, and from Northern Oregon to Vancouver Island. The total biomass estimate was 41,900 t.

Myctophids

Recent surveys of these small mesopelagic fish have been conducted by Auth et al. (2006), Brodeur et al. (2003), and Davison et al. (2013). Common species include chubby flashlightfish (*Electrona rissoi)*, California flashlight fish *Protomyctophum crockeri*,

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[3] http://www.piscoweb.org/research/science-by-discipline/ecosystem-monitoring/kelp-forest-monitoring/sampling-protocols

Northern flashlightfish (*Protomyctophum thompsoni)*, blue lanternfish (*Tarletonbeania crenularis*), Pinpoint lampfish *(Nannobrachium regale)*, Northern lampfish (*Stenobrachius leucopsarus),* California headlightfish (*Diaphus theta),* California smoothtongue (*Leuroglossus stilbius*), and North Pacific argentine (*Argentina sialis)*.

Recent field studies suggest that biomass of mytophids and other small mesopelagic fish is at least five times higher than previously reported. This is likely to have substantial impacts on our understanding of the pelagic food web. Previous versions of Atlantis for the California Current relied on studies by Pearcy and Laurs (1966) and Savinykh (1999), which reported densities of 1.4- 3.6 g m^{-2} wet weight. Davison and colleagues (2013) have recently reported 17 g m^{-2} , and ongoing work (J. Koslow, UC San Diego*, pers. comm*) is now suggesting as much as 30 g m^{-2} . Applying the published estimate from Davison et al. (2013) to the Atlantis model domain suggests 22.7 million t.

Ideally, life history parameters would be available for the most common species reported by Auth et al. (2006) and Brodeur et al. (2006). However, to our knowledge parameters such as growth and lifespan are available only for northern lampfish (*Stenobrachius leucopsarus)* and blue lanternfish (*Tarletonbeania crenularis*). The former speices is six times more abundant than the latter (Auth et al. 2006), and we therefore weight life history parameters by this ratio.

As for other pelagic species, the very large area of the pelagic boxes (from the 1200m isobath to the EEZ) contains the bulk (86%) of biomass. We rely on diet and life history information from Horne et al. (2010).

Deep Demersal Fish

This group of seven deep demersal fish consists of slickheads (Alepocephalidae), eelpouts (Zoarcidae), and grenadiers (Macrouridae), which commonly occur in the NWFSC slope/shelf survey. The seven species are California slickhead *Alepocephalus tenebrosus*, twoline eelpout *Bothrocara brunneum*, bigfin eelpout *Lycodes cortezianus,* black eelpout *Lycodes diapterus*, giant grenadiers *Albatrossia pectoralis*, blackbelly eelpout *Lycodes pacificus*, and Pacific grenadiers *Coryphaenoides acrolepis.* Other eelpouts, grenadiers, and slickheads are less commonly sampled in the survey and are omitted here.

Biomass estimate of 118,000 mt is taken from swept area estimates from the 2011 NWFSC slope/shelf survey (Bradburn et al. 2011). Stock assessments are not available for any of these species. We multiply by a factor of 1.36 to scale up US waters (0-1200m) to the entire Atlantis domain (0-1200m). Life history parameters and diets follow Horne et al. (2010) and Dufault et al. (2009), with the addition of two new diet studies.

Shallow Large Rockfish

Species of shallow rockfish include greenspotted rockfish (*Sebastes chlorostictus*), kelp greenling (*Hexagrammos decagrammus),* blue rockfish (*S. mystinus*), and black rockfish (S. melanops). Biomass estimates are available from stock assessments for these species from Dick et al. (2011), Cope and MacCall (2005), Key et al. (2007), Wallace et al. (2007), and Sampson (2007). Total biomass for the functional group was estimated to be 39,500 t, summing the abundance of each of these four species in US waters. Other species such as redstriped rockfish and brown rockfish could fall within this group, but we lack estimates of abundance for them, either from stock assessments or trawl survey data. For Atlantis, we multiply this stock size by 1.36 to scale up from US slope and shelf waters (0-1200m) to abundance in the US, Canada, and Mexico.

Diet data are summarized in Dufault et al. (2009), taken from adult redstripe and blue rockfishes, and juvenile copper and blue rockfish. One new additional study on starry rockfish was included. Life history parameters were summarized by Horne et al. (2010) and Brand et al. (2007).

Spatial distributions of this group are derived from spatial modeling of West Coast Bottom Trawl Survey data for black rockfish, predicted on a 2x2 km grid. These projections were provided by Kotaro Ono (University of Washington) using methodology based on that of Ole Shelton (National Marine Fisheries Service (NMFS) 2013). We extracted model-predicted abundance for black rockfish, and re-projected it onto the Atlantis model domain within GIS. We then used the "Intersect" tool within GIS and summed abundance in each Atlantis polygon. Summed abundance (kg) was converted to densities (kg/km2) by diving by the area of the Atlantis polygon. Since there was no information on Canadian or Mexican spatial rockfish abundances, densities from Washington (boxes 13-18, see **Figure 1**) were used for Canadian areas (boxes 7-12 and 1-6), and densities from just north of Pt Conception (boxes 43-48) were applied to the Mexican area (boxes 62-67 and 68-73. After including Canadian and Mexican regions, we recalculated total biomass (kg) per box, and from that calculated the final spatial input parameter needed for Atlantis, which is the proportion of total stock biomass that is apportioned to each polygon. Similar methods were applied to a suite of 16 species (see below), though using a different spatial modeling effort also described within (National Marine Fisheries Service (NMFS) 2013).

Groundfish Spatial Distributions from Kinlan and Menza (NMFS 2013)

Initial spatial distributions of 16 groundfish species (proportion of stock biomass per box) were taken from spatial modeling by Brian Kinlan and Charles Menza (NOAA NCCOS) following methods presented in an Essential Fish Habitat report (National Marine Fisheries Service (NMFS) 2013). Data are available on http://efh-catalog.coas.oregonstate.edu/synthesis/, but were provided courtesy of Charles Menza and Brian Kinlan. Spatial predictions of abundance were based on observations from the West Coast Bottom Trawl Survey, with a predictive model that included space (geographic position) as well as environmental covariates (depth, rugosity, slope, bathymetric position index, bottom temperature, sea surface temperature, chlorophyll a concentration, signed distance to hard bottom habitats, and a categorical variable to differentiate the study area into three regions). The ‘hurdle’ model developed by these authors separately predicts probability of presence and relative abundance when present; combining these two predictions leads to spatial predictions of abundance on a 1x1 km grid.

For the Atlantis model initial conditions, we selected the 16 species’ spatial distributions that were recommended by reviewers of the model, and by the model authors. These species tend to be well sampled by the West Coast Bottom Trawl survey, and to be less associated with extremely rocky habitat that is difficult to sample with trawl gear. The species include bocaccio, cowcod, Pacific Ocean Perch, widow, yelloweye, darkblotched, blackgill, chilipepper, and canary rockfish, longspine thornyhead, shortspine thornyhead, , lingcod, Pacific hake, Dover sole, Petrale sole, and sablefish.

We extracted model-predicted spatial abundance for these groundfish species, and re-projected it onto the Atlantis model domain within GIS. We then used the “Intersect” tool within GIS and summed abundance in each Atlantis polygon. Summed abundance (kg) was converted to densities (kg/km2) by diving by the area of the Atlantis polygon. For functional groups (which include more than one species), densities per species per polygon were summed to yield a functional group density for each polygon. Since there was no information in this dataset on Canadian or Mexican spatial rockfish abundances, densities from boxes 13-18 were used for 7-12 and 1-6, and from boxes 43-48 for boxes 62-67 and 68-73. The Southern California Bight (Boxes 49-61) is sparsely sampled by West Coast Bottom Trawl Survey. In particular, the large Cowcod Conservation Area lacks trawl sampling. Therefore we also extrapolate groundfish densities from the region immediately north of Point Conception (boxes 43-48) to the Southern California Bight. After including Canadian, Mexican, and Southern California regions, we recalculated total biomass (kg) per box, and from that calculated the final spatial input parameter needed for Atlantis, which is the proportion of total stock biomass that is apportioned to each polygon.

Yelloweye rockfish (*Sebastes ruberrimus*)

Yelloweye rockfish were assessed by Taylor and Wetzel (2011), with an estimated 2200 t in US waters. DFO (2011a) assessed the Canadian stock, estimated to be 780 t. Yelloweye rockfish are rare south of Central California (Love 1991). Life history parameters follow from Horne et al. (2010). Diet studies summarized in Dufault et al. (2009) consist of Steiner (1979) and York (2005), both from the Oregon coast. The modeling of Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Cowcod (*Sebastes levis*)

Dick et al. (2009)estimated southern California biomass of cowcod in the Southern California Bight to be 233 mt. However, the stock is common off Baja California, typically shallower than 200m. We scale up from the Southern California Bight assessment by multiplying by 3.8, the ratio 0-200m model habitat south of Point Conception divided by the area of 0-200m habitat in the Bight. This yields an estimate of 909 metric tons. Life history parameters follow from Horne et al. (2010). Diets are assumed identical to yelloweye rockfish. The modeling of Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Deep Small Rockfish

Species included: longspine thornyhead (*Sebastolobus altivelis*), splitnose rockfish (*Sebastes diploproa*), aurora rockfish (*S. aurora*), and sharpchin rockfish (*S. zacentrus*). Stock assessments are available for all four species, and summing these suggests 160,500 t for a US coast-wide abundance (O. Hamel, Cope, and Matson 2013; Cope et al. 2013; Stephens, A. and Taylor 2013; V.V. Gertseva, Cope, and Pearson 2009). Stock assessment estimates of biomass are not available for Canada or Mexico, though Canadian authors have reported trends in longspine thornyhead survey and catch data. We scale the US estimate of biomass up by 1.36, the ratio of total area (0-1200m) in the entire model divided by area (0-1200m) in the US. The final estimate is 212,000 t for Atlantis initial conditions. The modeling of longspine thornyhead by Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Life history parameters are consistent with Brand et al. 2007 and Horne et al. 2010. Diets were obtained from compiling sharpchin rockfish, longspine thornyhead, and splitnose rockfish (see Dufault et al. 2009 for details).

Deep Large Rockfish

Species included: shortspine thornyhead (*Sebastolobus alascanus*), blackgill rockfish (*S. melanostomus*), and rougheye rockfish (*S. aleutianus*). Similar species for which abundance estimates are not available include bank rockfish (*S. rufus*), and redbanded rockfish (*S. babcocki*). Summing the US stock assessment estimates for shortspine, blackgill, and rougheye suggests 263,000 t, with 244,000 from shortspine (Field and Pearson 2011, Hicks 2013, Taylor and Stephens 2013). Stock assessment estimates of shortspine biomass are not available for Canada or Mexico, though Canadian authors have reported trends in shortspine thornyhead survey and catch data. Based on the relatively low abundance of rougheye rockfish compared to shortspine in the US, we expect a similar pattern in British Columbia. DFO (1999, Stock Status Report A6-15) discuss survey estimates of rougheye off southwestern Vancouver Island of only 64 t, though the authors mention that this may be an underestimate. Scaling up from US abundance to abundance in US, Canada, and Mexico based on area suggests 357,000 t. Life history parameters are taken from Horne et al. (2010). Diets were based rougheye rockfish and shortspine thornyhead (Dufault et al. 2009).

The modeling of longspine thornhead and blackgill rockfish by Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Darkblotched rockfish (*Sebastes crameri*)

Abundance for darkblotched rockfish in US waters is available from the 2013 stock assessment (V.V. Gertseva and J.T. Thorson 2013). The assessment estimated 16,600 t. Life history parameters are taken from Horne et al. (2010) and diets for this species are included in Dufault et al. (2009). No abundance estimate is available for Canadian waters, and the species is rare south of Central California (Love 1996). We estimate total abundance for the model by scaling up the US abundance by 1.24, the ratio of model domain north of Point Conception divided by the US portion north of Point Conception. Final biomass is therefore 20,600 t. The modeling of Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Canary Rockfish (*Sebastes pinniger)*

Canary rockfish were assessed in 2011, with 16,100 t in US waters (J. R. Wallace and Cope 2011). Canadian survey results suggest 7,300-17,100 t off the West Coast of Vancouver Island and Queen Charlotte Sound (COSEWIC 2007); Queen Charlotte Sound is north of our model domain. Summing the US estimate and the lower bound of the Canadian estimate suggests 23,400 t biomass. Canary rockfish are rare south of Central California, and are assumed absent from Mexico. Life history parameters are taken from (Stewart 2007). Adult and juvenile canary rockfish diet studies are summarized in Dufault et al. (2009). The modeling of Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Shallow Small Rockfish

Species of small shallow rockfish include stripetail rockfish (*Sebastes saxicola)*, greenstriped rockfish (*S. elongatus*), and gopher rockfish (*S. carnatus*). Similar common species that are excluded, due to lack of abundance estimates, are rosethorn rockfish (*S. helvomaculatus*), halfbanded rockfish (*S. semicinctus*), and flag rockfish (*S. rubrivinctus*), among others.

Only gopher rockfish has been assessed (Meisha Key et al. 2005), with a US estimate of 2600 t. Greenstriped and stripetail rockfish are most common in the NWSC trawl survey, and swept area estimates for those species suggest abundance of 17,400 t and 16,100t , respectively. Greenstriped and stripetail rockfish are found in US, Mexico, and Canada, but gopher rockfish are primarily found in Central California and farther south. Summing the three abundance estimates above, and multiplying by 1.7 (ratio of 0-200m habitat in the whole model, divided by 0-200m habitat in US waters), yields 61,300 t as an estimate of initial abundance.

Life history parameters were taken from Horne et al. (2010). Diets are summarized in Dufault et al. (2009). Adults diets were taken from York (2005) in Oregon, and juvenile diets from two studies in California (Chess et al. 1988, Reilly et al. 1992).

Spatial distributions of this group are derived from spatial modeling of West Coast Bottom Trawl Survey data for greenstriped rockfish, predicted on a 2x2 km grid. These projections were provided by Ole Shelton and summarized in an Essential Fish Habitat review (National Marine Fisheries Service (NMFS) 2013). Methodology applying these spatial distributions as Atlantis input follows that used above for black rockfish and the 16 groundfish considered by Kinlan and Menza.

Shortbelly Rockfish, *Sebastes jordani*

Shortbelly rockfish are relatively small-bodied, unexploited nearshore fish that serve as forage for birds and mammals. Shortbelly are found within the entire model domain, but are most common off Central California. A biomass estimate of 64,000 t for US waters, and life history parameters for the group come from a recent assessment (John C. Field, Dick, and MacCall 2007).We multiplied by 1.7 (ratio of 0-200m habitat in the whole model, divided by 0-200m habitat in US waters), to yield 109,000 t.

Diets were differentiated between adults and juveniles, and are summarized in Dufault et al. (2009). Adult data came from 190 stomachs (Chess et al. 1988) and juvenile data came from the sources mentioned previously (Chess et al. 1988, Reilly et al. 1992).

Midwater Rockfish

Midwater rockfish include chilipepper rockfish (*Sebastes goodei*), vermilion rockfish (*S. miniatus*), widow rockfish (*S. entomelas*), and yellowtail rockfish (*S. flavidus*). All four species have been considered in US stock assessments. Biomass estimates for these species, respectively, are 33,600, 14,600, 68,200, and 143,384 tons (Field 2007, MacCall 2005, He et al. 2011, Wetzel and Cope 2013). Summing this suggests 260,000 t in US waters.

In British Columbia, Stanley (1999) provided preliminary estimates of widow rockfish. Assuming that fishing mortality was equal to natural mortality, they suggested widow rockfish abundances for British Columbia coastal waters to be 7,000-43,000 t. Lacking full stock assessments for British Columbia or Baja California, we extrapolate from US estimates based on available habitat. These species are primarily found on the continental shelf. In aggregate, the functional group is found throughout the model domain, since it includes both more northerly species such as yellowtail, widow rockfish found throughout US survey range (Bradburn et al. 2011), and chilipepper and vermillion rockfish found in California and southward. Extrapolating based on area <200m in each of the three countries requires multiplying the US estimate by 1.7, yielding 442,000 t. The modeling of chilipepper and widow rockfish by Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Similar to the species in this Midwater Rockfish functional group, Pacific ocean perch (*S. alutus*), and canary rockfish also tend to leave the seafloor and prey upon groups in the water column, but those are modeled as separate functional groups to particular management concerns for those species.

Life history parameters are taken from Horne et al. (2010). Adult midwater rockfish diets as well as those for Pacific Ocean Perch were derived from yellowtail rockfish, widow rockfish, and Pacific ocean perch stomachs. Three additional studies were added to the Dufault et al. (2009) diet summary.

Pacific Ocean Perch (*Sebastes alutus*)

Hamel and Ono (2011)estimated US abundance of Pacific Ocean Perch to be 25,500 tons. Most Pacific Ocean Perch are found north of Cape Mendocino (Bradburn et al. 2011). Schnute and colleagues (2001) note that in the year 2000 there was 563 t of catch in DFO areas 3C and 3D, off the West Coast of Vancouver Island. Considering commercial trawl fishery catch and trawl effort (swept area), those authors calculated biomass ranging from 3,000-7,000 t for year 2000. The same authors report AFSC triennial survey estimates from 2000 of approximately 5,000 t. We assume 5,000 t for Canadian waters in the Atlantis domain, for a total abundance in the Atlantis domain of 30,500 t. The modeling of Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution of this species, apportioning a proportion of total stock biomass to each Atlantis polygon.

Life history parameters and diets follow Horne et al. (2010) and Dufault et al. (2009).

Bocaccio Rockfish (*Sebastes paucispinis*)

Field (2011) estimated US abundance of bocaccio to be 12,500 tons. Stanley and colleagues (2012)estimated 2205 t in British Columbia waters; we assume half of this biomass is in the Canadian portion of the model domain. Scaling up by a factor of 1.3, the ratio of total model area <550m divided by US and Canadian model area <550m, suggests 17,700 t. The modeling of Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Life history parameters follow Horne et al. (2010). As noted by Dufault et al. (2009), there is little diet information for bocaccio, and we use the midwater rockfish group diets as a substitute.

Small Flatfish

Species include Pacific sanddab (*Citharychtys sordidus*), rex sole (*Glyptocephalus zachirus*), slender sole (*Lyopsetta exilis*) , starry flounder (*Platichthys stellatus,* English sole (*Parophrys vetulus*), and deepsea sole (*Embassichthys bathybius*). Ralston (2005)estimated US abundance of starry flounder to be 9,029 mt, and Cope and colleagues (2013) estimated 47,000 mt of English sole and 18,500 mt of rex sole. He et al. (2013) assessed the US sanddab population, estimating 2012 total biomass of 13,500 mt. The remaining two species are well sampled by the NWFSC groundfish trawl survey, and swept area estimates suggest 10,300 mt of slender sole and 9,700 to of Deep Sea sole. Fargo (1999) assessed a British Columbia stock of English sole, but for Hecate Strait, north of our model domain. Summing the US estimates suggests 108,000 t of small flatfish in US waters. In aggregate, these species are common on both the continental slope and shelf, and at all model latitudes. We extrapolate from the US estimate to the entire Atlantis domain by multiplying by 1.36, the ratio of total model area <1200 divided by US area <1200m, to yield 147,000 t.

Note that these are considered data moderate stocks, and uncertainty around the biomass estimates is high. For instance, swept-area based estimates of sanddab from survey data alone are 71,000 mt, and rex sole are 43,600 mt, which are 5.25 and 2.4 higher than the stock assessment estimates. Here we use stock assessment biomass estimates, but note that poor catch records and other assessment input lead to wide uncertainties.

Related species for which biomass estimates are not available include flathead sole (*Hippoglossoides elassodon*), butter sole (*Isopsetta isolepis*), fantail sole (*Xystreurys liolepis*), rock sole (*Lepidopsetta bilineata*), sand sole (*Psettichthys melanostictus*), curlfin sole (*Pleuronichthys decurrens*), spotted turbot (*P. ritteri*), hornyhead turbot (*P. verticalis*), and longfin sanddab (*C. xanthostigma*).

Life history parameters are unchanged from Horne et al. (2010). Flatfish diets were available for multiple species (deepsea sole, rex sole, English sole, and Pacific sanddab), but were not differentiable to adult and juvenile stages (Dufault et al. 2009). We added diet information from Wakefield (1984) to the Dufault et al. (2009) diet synthesis.

Dover Sole (*Microstomus pacificus*)

Dover sole were assessed by Hicks and Wetzel (2011), and that document formed the basis for the biomass estimate of 684,700 t for this group. Fargo (1999) noted 1092 t of catch in 1998 in British Columbia, but did not estimate total biomass. The species is found throughout Canadian, US, and Mexican portions of the California Current (Love 1991). We extrapolate the estimate from Hicks and Wetzel (2011) by 1.36, the ratio of area <1200m in the Atlantis domain divided by area <1200m in the US, to yield 931,000 t. The modeling of Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Over 1500 Dover sole diets were available coast wide, and diets are summarized in Dufault et al. (2009).

Pacific hake (*Merluccius productus*)

Hake were assessed in 2013 (Hicks et al. 2013), with biomass of 3,868,400 t . Life history parameters are maintained as in Horne et al. (2010). Adult and juvenile diets were available from multiple studies coast wide, as summarized in Dufault et al. (2009). The modeling of Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Sablefish (*Anoplopoma fimbria*)

In the US, sablefish were assessed to be 205,700 mt in 2011 (Stewart, Thorson, and Wetzell 2011). Haist et al. (Haist, Kronlund, and Wyeth 2004) estimated 65,000 t in all of British Columbia, only a portion of which would be the Atlantis model domain. Sablefish extend into Mexico (Bradburn et al. 2011), though abundances are higher north of Cape Mendocino. We use 265,000 t as an initial biomass estimate for the Atlantis model domain. The modeling of Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Sablefish diets and life history parameters follow Dufault et al. (2009) and Horne et al. (2010).

Arrowtooth Flounder (*Atheresthes stomias*)

US arrowtooth flounder stock size was estimated to be 85,175 mt in 2007 (Kaplan and Helser 2007). Arrowtooth life history parameters were taken from that document.

Fargo and Starr (2001) considered trends in survey data off the West Coast of Vancouver Island. They report Triennial Trawl Survey data from 1998 with 52,000 t of arrowtooth flounder off the West Coast of Vancouver Island, versus 29,000 to off Washington. However, since these estimates are substantially lower than the estimate for US waters, and arrowtooth are expected to increase in abundance with latitude, we scale the US estimate upward based on area of suitable habitat off Vancouver Island. Kaplan and Helser (2007) illustrate that the majority of biomass is found shoreward of 550m, and we therefore base the scalar (1.22) on the ratio of habitat <550m. Arrowtooth flounder are rare south of San Francisco (Kaplan and Helser 2007), and we assume no biomass in Mexico. The final abundance estimate for the Atlantis model is therefore 102,000 t.

Arrowtooth flounder diet studies have largely been concentrated in the Gulf of Alaska; however, as in Dufault et al. we use them to parameterize diets in the California Current. We added diet data from Plummer et al. (1983) and Brodeur and Livingston (1988) to the original diets synthesis by Dufault et al.

Large Piscivorous Flatfish

Species include Pacific halibut *Hippoglossus stenolepis,* and California Halibut *Paralichthys californicus.*

Stewart et al. (2012) estimated that Pacific halibut, ranging from the Bering Sea to California, had an abundance of 849 million net lbs (headed and gutted) of age 2+ fish. This equates to 1,131 million lbs round weight. Based on 2012 survey catches[4] roughly 2% of abundance is in US waters, and 13.2% in British Columbia, but only 14.2% of total British Columbia catch was from our model domain (Vancouver Island and south) (*pers. comm.*, I. Stewart, IPHC, Seattle,WA). Applying these fractions and summing over the total Atlantis domain suggests 19,900 t within the model.

California halibut (*Paralichthys californicus*) have been recently assessed (Maunder 2011). Summing abundance estimates for Southern and Central California suggests approximately 18,000 mt spawning stock biomass. We assume total stock biomass to be equal to twice this, 36,000 mt.

Life history parameters are retained from Horne et al. (2010). As reported in Dufault et al., diets for halibut are taken from Yang and colleagues (Yang 1994, Yang and Nelson 2000) from the Gulf of Alaska.

Petrale sole (*Eopsetta jordani*)

Haltuch (2013) estimated US petrale sole biomass to be 15,000 t, noting that the bulk of biomass is shallower than 550m. Scaling the biomass from Haltuch (2013) up by 1.58, the ratio of total model area shallower than 550m divided by US habitat shallower than 550m, suggests 24,000 t. Life history parameters in the Atlantis model are retained from Horne et al. (2010). Petrale sole diet data is assumed to be similar to Pacific halibut and arrowtooth flounder, since Wakefield (1984) is the only source of percent-by-weight diet composition data. Note that gape size is incorporated in the Atlantis model, and will drive differentiation of Petrale sole diets from those of larger flatfish. The modeling of Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above,

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[4] http://www.iphc.int/publications/rara/2012/rara2012503_ssa_survey.pdf

informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Large Demersal Predators

This group includes lingcod (*Ophiodon elongatus*) and cabezon (*Scorpaenichthys marmoratus*). Hamel et al. (2009) estimated abundance of lingcod in Oregon and Washington to be 32,222 t, and in California to be 31,266 t. DFO (2011b) estimated 57,00 t of lingcod off northern and southern Vancouver Island. Cope and Key (2009) estimated 1700 t of cabezon in Oregon and California. Life history parameters are as summarized in Horne et al. (2010). Diets in Dufault et al. (2009) were taken from four stomachs collected by Wakefield (1984), and 500 samples from Beaudreau and Essington (2007). Lingcod abundance is low south of Point Conception (Love 1991), and we assume no lingcod in Mexican waters. Total summed biomass is 121,000 for the Atlantis model domain. The modeling of lingcod by Kinlan and Menza (National Marine Fisheries Service (NMFS) 2013), described above, informs the initial spatial distribution, apportioning a proportion of total stock biomass to each Atlantis polygon.

Salmon

Species included: Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*). Biomass for US and Canada is taken from estimates of ocean harvest plus escapement to fresh water (*pers. Comm., E. Ward, NOAA NWFSC, Seattle WA*). We sum the harvest and abundance for salmon runs on the West Coast of Vancouver Island, Southern British Columbia, and all Washington, Oregon, and California stocks, assuming a weight of 8.1kg per fish, yielding 18,000 t.

Salmon biomass and life history parameters were from Brand et al. (2007). Because Chinook salmon contribute 95% of the biomass of this group, only their diets were used to represent this group (Dufault et al. 2009). Diet data from Miller and Brodeur (2007) and Brodeur and Pearcy (1990) were added to the previous diet synthesis by Dufault et al. (2009).

Large Pelagic Predators

This group is meant to represent large pelagic predators, primarily in the offshore boxes extending from the 1200m isobath to 200 miles. Particularly in summer months, these predators also move near shore and into the northern California Current. Species include albacore tuna (*Thunnus alalunga*), yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*), bigeye tuna (*Thunnus obesus).* These species are predators of forage groups such as sardines, anchovies, and squid.

Landings data for the US West coast include fish caught both within and outside the EEZ. Albacore are the major catch, followed by swordfish, with minor amounts of bigeye tuna and yellowfin tuna. For these four species respectively, catches for 2009-2012 ranged from 11,000-14,000, 370-619, 7-50, and 1-45 t.

Quantitative stock assessments are available for these species, but often at spatial scales that are not compatible with the model domain. An albacore stock assessment (International Scientific Committe for Tuna and Tuna-like Species in the North Pacific Ocean 2011) estimated the North-Pacific stock of albacore to be 850,000 t. As an approximation, we assume a local albacore abundance in the model domain of 128,000 t, based on the assumption that the 14,000 t US catch and 6,500 t Canadian catch are being removed at a sustainable rate ($F_{msy} = 0.16$, ISCTTS 2011). Little albacore is caught in Mexico (17-25 t for 2009 and 2010) (International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean 2011).

For species other than albacore, stock assessments at the scale of the Eastern Pacific Ocean are conducted by the Inter American Tropical Tuna Commission. On that scale, Aires da Silva and Maunder (Aires Da Silva and Maunder 2012a; Aires Da Silva and Maunder 2012b) estimated abundances of 357,000 mt of yellowfin tuna, and 340,000 mt of bigeye. The Hinton and Maunder (Hinton and Maunder 2011) striped marlin assessment estimated spawning stock biomass in entire eastern Pacific Ocean, including parts of the California Current and much larger areas to the south. Lacking estimates on the spatial distribution of these stocks, we use a placeholder taken from an Eastern Tropical Pacific Ecopath model (Olson and Watters 2003) for species other than albacore. Densities of these species are applied to the pelagic boxes of the Atlantis domain (1200m to 200 miles). Summing abundance of these species and albacore suggests 167,000 t in the Atlantis model domain.

Life history parameters reflect those of albacore, which comprises 77% of the biomass of this functional group. Parameters are as listed in Horne et al. (2010) and Brand et al. (2007). Albacore diets are summarized in Dufault et al. (2009), but primarily come from small albacore, and were taken from the 1950s-1984. Life history parameters for the other species are from FishBase, and diets are from Olsen and Watters (Olson and Watters 2003).

Skates and Rays

Species in this functional group include longnose skate (*Raja rhina*), big skate (*R. binoculata*), Bering (aka sandpaper) skate (*Bathyraja interrupta*). Gertseva and Schirripa (2007) performed a stock assessment on longnose skate, and estimated 71,200 t. NWFSC trawl survey data from 2011 suggest that total biomass of these three species is about 1.25 times the biomass of longnose skate alone. We therefore scaled this up by a factor of 1.25, to 89,400 t for US waters. Extrapolating by a factor of 1.36 from the area of US habitat, 0-1200m, to total model domain habitat from 0-1200m leads to an estimate of 122,000 t.

Skates for which biomass estimates and species composition are not available, and which are therefore excluded from the model, include deepsea skate (*B. abyssicola*), roughtail skate (*B. trachura*), starry skate (*R. stellulata*), Aleutian skate (*B. aleutica*), , California skate (*R. inornata*), and Pacific electric ray (*Torpedo californica*).

Skate life history parameters in the model are for longnose skate, since this species accounts for 80% of skate abundance in the NWFSC trawl survey. Life history parameters are taken from a stock assessment (Gertseva and Schirripa 2007) and Horne et al. (2010). Longnose, Bering, and big skates diets were taken from Robinson et al. (2007) and Wakefield (1984) and summarized in Dufault et al. (2009). For the revised Atlantis model, we added diets of sandpaper skates (Rinewalt et al. 2007).

Small Demersal Sharks

Species commonly occurring in the NWFSC trawl survey, and included in this functional group, included spotted ratfish (*Hydrolagus colliei*), brown catshark (*Apristurus brunneus*), and filetail cat shark (*Parmaturus xaniurus*). Swept area estimates from the NWFSC trawl survey suggest 24,500, 10,000, and 7,500 t abundances of these species, respectively. Total US abundance sums to 42,000 t. Extrapolating by a factor of 1.36 from the area of US habitat, 0-1200m, to total model domain habitat from 0-1200m leads to an estimate of 57,000 t.

Biomass and life history parameters are from Brand et al. (2007), with weighting of the functional groups based on NWFSC trawl survey data from 2011. Diets for ratfish are available from Wakefield (1984).

Spiny dogfish (*Squalus acanthias*)

Gertseva and Taylor (2011) estimated abundance of spiny dogfish in US waters to be 216,000 t. Gallucci et al. (2011) estimated there to be between 210,063 and 318,841 t in British Columbia. We use as a starting estimate 160,000 t for the Canadian portion of the model. In research surveys, spiny dogfish are rare south of Point Conception (Bradburn et al. 2011). Summing these US and Canadian biomass estimates suggests 377,000 t. Life history parameters remain as in Horne et al. (2010) for this species.

Dogfish diet studies summarized in Dufault et al. (2009) are from Washington (Bonham 1954), Washington and Oregon (Brodeur et al. (1987)), and off Vancouver Island (Tanasichuck et al. 1991).

Large Demersal Sharks

Species include Pacific sleeper shark (*Somniosus pacificus*), bluntnose sixgill shark (*Hexanchus griseus*), and broadnose sevengill shark (*Notorynchus cepedianus*). Life history parameters for this group came from Brand et al. (2007). The life history parameters for the functional group are the simple averages of parameters for the three species. Biomass estimates are highly uncertain. Field (2004) estimated 0.05 t/km2 for all coastal sharks, but that included blue shark, mako, thresher, soupfin, as well these demersal species. Here we assume 0.01 t/km2, which when applied to the model domain out to 1200m depth suggests 2,200 t.

As summarized in Dufault et al, sleeper shark diets made up the majority of this group's diet data, with a small contribution from sixgill shark data. All shark diets in Dufault et al. (2009) were adapted from a review of shark diets worldwide (Cortes 1999). We have added sevengill shark diet information from Ebert (2002).

Pelagic Sharks

Species include tope (aka soupfin) shark (*Galeorhinus galeus*), blue shark (*Prionace glauca*), white shark (*Carcharadon carcharhinus*), mako shark (*Isurus oxyrinchus*), thresher shark (*Alopius vulpinus*), and brown shark (*Apristurus brunneus*).

Biomass estimates within the model domain are highly uncertain. Thresher, mako, and blue sharks are the primary species landed in the US, with catches ranging from 95 – 424 t between 2001-2011. Note that landings may come from outside the EEZ, and in fact longliners, which land some shark catch, are not allowed to fish within California's portion of the EEZ or the model domain. Of these species, only blue shark has been assessed (Kleiber et al. 2009). Those authors used a stock assessment model that included a NE Pacific region, substantially larger than our model domain, with approximately 100,000 t total biomass. As a starting point, we assume that the high catch of 424 mt is taken sustainably, i.e. at a fishing mortality rate equal to stock productivity. Assuming an average stock productivity or intrinsic rate of increase (r) of 0.055 (NOAA Fishery Management Plan 2011) suggests approximately 7700 t biomass in US waters. Scaling up from the US to the entire model domain, from shore to 200 miles, by a factor of 1.7 suggests 13,200 t.

Our biomass estimate equates to 0.010 t km^{-2} .For comparison, this is 2.5x the biomass density of the large shark functional group in Olsen and Watters (Olson and Watters 2003), which focuses more on the open pelagic (and less productive) Eastern Tropical Pacific.

Life history parameters are based on an average of parameters for these seven species. Due to the highly uncertain biomass estimates, we simply weight these species equally. Diets are taken from Dufault et al. (2009), with the addition of thresher shark diets from Preti et al. (2001, 2004, 2008) and blue shark diets from Miller and Brodeur (2007) and Brodeur et al. (1987).

Seabirds: Summary of New Data

Seabird abundance estimates were significantly updated from the previous version of the California Current Atlantis model (Horne et al. 2010). We collated data from colony counts from each state or province for species breeding within the CCLME (see below for methods for migratory species). For each known colony, we used the most recent estimate of the number of breeding birds. Colony data from all of BC, as described in Birds of North America Online, was generally used to represent the West Coast of

Vancouver Island. This may slightly overestimate breeding birds in the Canadian portion of the model, but because the largest bird colonies in BC are on the Scott Islands, which are within our model domain, any overestimation is unlikely to be severe. Washington counts came from the Catalog of Washington Seabird Colonies (Speich and Wahl 1989), updated with some recent surveys (Jenkerson and Pearson 2012). We excluded birds at colonies in Puget Sound. Oregon colony counts came from the Catalog of Oregon Seabirds (Naughton et al. 2007). California colony counts were compiled from multiple sources. Carter et al. (1992) provided a baseline estimate for each known colony during the 1970s to 1990. We updated these counts with more recent data when available (described below). Colony counts for Baja California came from a review by Wolf et al. (2006).

Raw counts were converted to total abundance by a two-step process. When study authors presented their estimates as breeding estimates we used those directly (e.g. Carter et al. 1992). However, when colony data was presented as nest counts, we multiplied by 2 to obtain an estimate of the breeding population. When colony data were presented as raw counts of breeding birds, we multiplied these counts by 1.67 to account for breeding birds not present at the colony during the count. This multiplier was developed for common murre (W. J. Sydeman et al. 1997), however a similar multiplier has been used by Oregon and California seabird catalogs for multiple species (Naughton et al. 2007; Carter et al. 1992).

We converted estimates of the breeding population to total abundance estimates by multiplying each species' abundance by a second conversion factor that accounted for the proportion of the population that had not reached maturity (but had already fledged). These conversion factors were derived by estimating the stable age distributions from age-structured models using estimates of survival rates for juveniles and adults and age at maturity from Birds of North America Online.

Total abundances were then converted to biomass by multiplying by the weight of average individuals by species (most seabirds reach nearly adult size by the time they fledge). Weights of individual species were taken from Hunt et al. (2000), which lists individual weights by species in the subarctic North Pacific.

Life history data for seabirds was unchanged from the previous version of the model, and is described by Horne et al. (2010).

Benthic and Pelagic-feeding Seabirds

Species included: Brandt's cormorant (*Phalacrocorax penicillatus*), pelagic cormorant (*P. pelagicus*), double-crested cormorant (*P. auritus*), western gull (*Larus occidentalis*), glaucous-winged gull (*Larus glaucescens*), and pigeon guillemot (*Cepphus columba*).

Brandt's and double crested cormorants were summarized primarily using aerial surveys (Capitolo et al. 2011; Capitolo et al. 2004). Castle rock counts came from Jacques et al. (2007). Gualala point island had recent counts for Brandt's and pelagic cormorants, western gull, and pigeon guillemot (Garcia-Reyes, Thayer, and Sydeman 2013). Alcatraz island counts for Brandt’s cormorant, western gull, pelagic cormorant, and pigeon guillemot were ground-based surveys (Saenz et al. 2006; Acosta et al. 2010). Colony data from Southeast Farallon Island in 2011 were available for pigeon guillemot, double-crested cormorant, pelagic cormorant, Brandt’s cormorant, and western gull (Warzybok and Bradley 2011). From Point Reyes to Central California, we updated counts of Brandt’s cormorant, pelagic cormorant, and western gull (Eigner et al. 2010). Ano Nuevo island counts for Western gull, pelagic cormorant, Brandt’s cormorant, and pigeon guillemot came from ground surveys (Hester et al. 2014).

Diet information for these species was updated from the previous version of the model. We included three additional diet studies on cormorants (Anderson, Roby, and Collis 2004; Collis et al. 2002; Robertson 1974). Collis et al. (2002) and Robertson et al. (1974) also included diet information for glaucous winged gull. We also added a diet study for glaucous winged gull (Kees Vermeer 1982).

Pelagic-feeding Seabirds

Species included: Cassin’s auklet (*Ptychoramphus aleuticus*), common murre (*Uria aalge)*, marbled murrelet (*Brachyramphus marmoratus*), rhinoceros auklet (*Cerorhinca monocerata*), tufted puffin (*Fratercula cirrhata*), Caspian tern (*Hydroprogne caspia*), Leach’s storm petrel ( ), and brown pelican (*Pelecanus occidentalis*).

More specific abundance estimates were available for Vancouver Island for this group. Abundance estimates for the Vancouver Island model regions come from multiple sources. Triangle Island has large colonies of cassin’s auklets, rhinoceros auklet, and tufted puffin (Bertram, Mackas, and McKinnell 2001; Rodway 1991). Common murre estimates came from Hipfner et al. (2005). Vancouver Island marbled murrelet estimates came from COSEWIC (2012a).

Multiple data sources updated the Carter et al. colony count data from California. At Castle Rock, Jaques et al. (Jaques 2007) had common murre counts and Cunha (Cunha 2010) had rhinoceros auklet and cassin’s auklet counts. Gualala Point Island had more recent common murre counts (Garcia-Reyes, Thayer, and Sydeman 2013)(Garcia-Reyes et al. 2013). Southeast Farallon Island data were available for common murre, rhinoceros auklet, cassin’s auklet, and tufted puffin (Warzybok and Bradley 2011; Thayer and Sydeman 2007). Ano Nuevo island counts for rhinoceros and Cassin’s auklets came from ground surveys (Hester et al. 2014). Marbled murrelet abundances for the entire US model region were taken from Miller et al. (2012).

Diets of pelagic feeding seabirds were updated from the previous version of the California Current Atlantis model (Horne et al. 2010). We added three studies on rhinoceros auklet (Hedd et al. 2006; Bertram and Kaiser 1993; K. Vermeer 1979) and two diet studies on Cassin’s auklet (Kees Vermeer, Fulton, and Sealy 1985; Bertram, Harfenist, and Hedd 2009).

Bird biomass was distributed along the coast according to their relative abundance at known breeding colonies during April to September. From October to March, birds were distributed evenly among all boxes ranging in depth from 0 to 550 m (as roughly indicated in Nur et al. 2011).

Migrating Seabirds

Species included: black-footed albatross (*Phoebastria nigripes*), Laysan albatross (*P. immutabilis*), black-legged kittiwake (*Rissa tridactyla*), sooty shearwater (*P. griseus*), pink-footed shearwater (*Puffinus creatopus*), northern fulmar (*Fulmarus glacialis*), and red and red-necked phalaropes *(Phalaropus fulicarius and P. lobatus).*

Abundance estimates for the migratory seabird group were derived from region-specific density estimates extrapolated to relevant model areas. We used densities from surveys during May to July whenever possible. For regions or species without more specific density estimates, we used densities from the 2008 California Current Ecosystem Survey (total observations/total surveyed area, McClatchie 2009).

Sooty shearwaters make up the largest proportion of the biomass of this group (90%), and their abundance estimates come from the most reliable survey data. In BC, Burger et al. (2003) provided year-round density estimates from the mid-1990s. We extrapolated these density estimates to the area of the model domain in BC waters from 0-200 m. In Washington and Oregon model regions, we used a density estimate from Zamon et al. (2013) for birds north and south of the Columbia river plume (not in the plume), extrapolated to the 0-200m area of the Washington and Oregon domain. For southern Oregon to the Northern boundary of the Cordell Bank National Marine Sanctuary, we used the overall density estimate from the 2008 California Current Ecosystem Survey (McClatchie et al. 2009), multiplied by the area from 0-2000 m depth in that region. Ainley and Hyrenbach (2010) provided a density estimate within the sanctuaries, which we multiplied by their survey area (0-3000m). For California south of the sanctuaries, we used density estimates for 1999-2002 from Mason et al. (2007), applying their region-specific densities to our overlapping model boxes, and summing across boxes. The Baja region lacked density estimates for sooty shearwaters, so we calculated an average density across Southern California from Mason et al. (2007) and applied that density to the Baja region from 0-1200m.

Laysan and black-footed albatross abundance estimates came from extrapolating the CCES densities for most regions in the US. In BC, COSEWIC (2006) estimated 2500 black-footed albatross use Canadian waters. For the sanctuary boxes in Central California, we used Ainley and Hyrenbach (2010) density estimate. In Baja, we used winter breeding colony counts from Wolf et al. (2006). Notably the birds breeding in Baja are not the same birds summering in the northern part of the model domain, which breed in the Hawaiian archipelago.

Phalaropes have been observed in high numbers in the CCLME during northward and southward migrations (McClatchie et al. 2009). Observations recorded during the California Current Ecosystem Survey resulted in a density estimate of 11.3 birds/km2 in the northern survey region (north of San Francisco bay). This estimate represents the northward migration, which typically occurs over a short period in April-May, which corresponded to the timing of the survey. We used densities observed by Mason et al (2007) in May for southern California, and May-June estimates from Ainley and Hyrenbach (2010) for the National Marine Sanctuaries model region. For Baja, we used an average density estimated from Mason's southern California data.

Little is known about the abundance of Black-legged kittiwakes in the CCLME. The CCES observed densities of 0.06 birds/km2 in April-May (McClatchie et al. 2009). This results in a population estimate of roughly 12000 birds in the model domain. This is surely an underestimate, however, because Black-legged kittiwake abundance peaks in winter in the CCLME, and the spring survey likely picked up only the tail end of the northward spring migration. Therefore we use the year-round density from Burger et al. (2003) for the BC region, the Mason et al. (2007) densities for Southern California from a survey occurring in Jan, and an average density calculated from the Mason observations applied to the rest of the model domain from 0-1200 m depth.

Diets for migratory birds were based on sooty shearwaters, with no data for differentiating adult and juvenile diets. We updated diets from the previous version of the model with nearly 400 feeding observations by Gould et al. (2000).

Migratory birds were distributed outside the model domain November thru March. In summer (July-Sept), we distributed bird biomass according to the studies we compiled to estimate total abundance. In the shoulder seasons (April-June and Oct), biomass was evenly distributed across 0-1200m model boxes.

Marine Mammals

Toothed Whales

Species included: pygmy sperm whale (*Kogia breviceps*), sperm whale (*Physeter macrocephalus*), Baird's beaked whale (*Berardius bairdii*), Cuvier's beaked whale (*Ziphius cavirostris*), and five species of mesoplodon beaked whales: Blainville's beaked whale (*Mesopoldon densirostris*), Hector's beaked whale, (*M. hectori*), Stejneger's beaked whale (*M. stejnegeri*), gingko-toothed beaked whale (*M. ginkgodens*), and Hubbs' beaked whale (*M. carlhubbsi*), and offshore orcas (*Orcinus orca*).

Abundance data for the toothed whale group within US waters came from NOAA marine mammal stock assessment reports. We added additional biomass of sperm whales in Canada by assuming the density within the US and Canada is equivalent and scaling up the US biomass estimate accordingly. We did the same in Mexico for pygmy sperm, sperm, Baird's beaked, Cuvier's beaked, and mesoplodon beaked whales.

Large toothed whale biomass was distributed using density estimates for sperm and mesopledont whales within US waters (Elizabeth A. Becker et al. 2012; Becker et al. 2014). We superimposed our model boxes over their density grid to estimate total biomass by model box. These biomass estimates were converted to proportional densities to distribute biomass across all four seasons.

Most life history parameters, body masses, life span estimates, and diets were carried over from Horne et al. (2010). Consumption rates were updated using equations in Barlow (2008).

Resident Orcas (*Orcinus orca*)

The resident orca group consists of northern and southern resident killer whales. Complete census data are available for these populations from Carretta et al. (2012) and Ellis et al. (2011). We attributed all of the southern residents, and half of the northern residents to our model domain in winter. In summer, we assumed all of the southern residents and half of the northern residents left the model for inland waters. While definitive data on resident orca movements is lacking, this pattern follows the qualitative understanding of their seasonal movements.

Life history and diet information was carried over from Horne et al. (2010). Consumption rates were updated using equations in Barlow (2008).

Transient Orca

The west coast transient stock is estimated to be a minimum of 354 individuals, and ranges from southeast Alaska to Point Conception (Allen and Angliss 2010). Life history and diet information as in Horne et al. (2010). Consumption rates were updated using equations in Barlow (2008).

Baleen Whales

Species included: humpback whale (*Megaptera novaeangliae*), blue whale (*Balaenoptera musculus*), fin whale (*B. physalus*), sei whale (*B. borealis*), and minke whale (*B. acutorostrata*).

Baleen whale abundance estimates were obtained from Caretta et al. (2012) for US waters. Additional summer abundance estimates for blue whales in Baja came from Calambokidis and Barlow (2004). Canadian abundance estimates for humpbacks came from DFO (2009) and blue whales came from COSEWIC (2012b). We assumed the fin, sei, and minke whale population estimates for the US account for whales traveling through Canadian and Mexican waters.

Baleen whale seasonal distributions were derived from Becker et al. (2014; 2012), as described for large toothed whales. Baleen whale migrations occur December to April. Ten percent of the group leave from the northern model boxes to represent humpback migrations to Hawaii, and 30 percent of the group migrates south to breeding grounds outside the model domain.

Life history parameters, body masses, life span, and diets were carried over from Horne et al. (2010). Consumption rates were updated using equations in Barlow (2008).

Gray Whale (Eschrichtius robustus)

Abundance estimates for gray whales come from the 2012 Marine Mammal Stock Assessment Report (Caretta et al. 2012) for US waters. Because this population breeds in Baja and the Gulf of California in winter, we assume the population in US waters during the summer survey is representative of the entire West Coast population.

Gray whales were distributed evenly across the model domain within 100m depth during spring and fall quarters. In winter, gray whales migrate to their breeding grounds in Mexico. Seventy percent stay within the model domain, while the remaining 30 percent moves further south to breeding lagoons outside the model domain (Urbán et al. 2003). In summer, all gray whales migrate north to feeding ground outside the model domain.

Life history parameters and diets came from Horne et al. (2010) and Dufault et al.(2009). Consumption rates were updated using equations in Barlow (2008).

Small Cetaceans

Species included: Dall's porpoise (*Phocoenoides dalli*), harbor porpoise (*Phocoena phocoena*), short-beaked common dolphin (*Delphinus delphis*), long-beaked common dolphin (*D. capensis*), bottlenose dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleoalba*), short-finned pilot whale (*Globicephala macrorhynchus*), Risso's dolphin (*Grampus griseus*), northern right whale dolphin (*Lissodelphis borealis*), and Pacific white-sided dolphin (*Lagenorhynchus obliquidens*).

Small cetacean abundance estimates were taken from the Marine Mammal Stock Assessments (Caretta et al. 2012) for all species within US waters. Dall's porpoise, harbor porpoise, and northern right whale dolphin were assumed not to occur within Mexican waters. A Long-beaked common dolphin density of 0.545 /km2 (Carretta, Chivers, and Perryman 2011) was extrapolated to all of Baja California using the area of the model domain in Mexican waters. All other species in the group were assumed to occur with the same density in Mexican waters as in US waters, and extrapolated to the Mexican area under this assumption. Additional biomass was added for Canadian waters for harbor porpoise, Dall's porpoise, and Pacific white-sided dolphin using densities observed in northern BC (cite) and extrapolated to the area of the model offshore of the west coast of Vancouver Island. Northern right whale dolphin and short-finned pilot whale were assumed to occur in the same density in Canadian waters as in US waters.

Biomass was distributed using densities derived from Becker et al. (2014, 2012), combining obeservations of Risso's dolphin, Pacific white sided dolphin, northern right whale dolphin, dall's porpoise, striped dolphin, and short-beaked common dolphin, as described above. We assumed constant spatial distribution across seasons.

Life history information was carried over from Horne et al. (2010). One new diet study was obtained to improve harbor porpoise diets, which found primarily consumption of market squid, anchovy, and sardine (n=18, Toperoff 2002). Consumption rates were updated using equations in Barlow (2008).

California Sea Lion (*Zalophus californianus*)

California sea lion abundance was estimated from pup counts at rookeries in southern California (Caretta et al. 2012) and northern Baja California (Lowry and Maravilla-Chavez 2003). Pups and female sea lions stay near rookeries year round, while males move north. During the non-breeding season (Oct-March), we distributed half the total biomass evenly across model boxes 0-200m depth, and half the biomass to model boxes nearest rookeries (0-200 m depth), proportional to the relative abundance estimated at each rookery. During the breeding season (April-September), 25 percent of the biomass was evenly distributed to account for non-breeding males, with the remainder distributed proportional to pup counts at rookeries within the model domain.

Life history parameters came from Trites and Pauly (1998). We used diet information from a review of marine mammal diets to set California sea lion diet availability parameters (Pauly et al. 1998).

Harbor Seal (*Phoca vitulina*)

Abundance estimates for harbor seals within US waters came from the stock assessment report (Caretta et al. 2012), excluding seals from inland waters in Washington. For the Canadian portion of the model, we added an estimated 15000 individuals. The estimate for all of BC is 105,000, but roughly 65000 of these occur in inland waters (DFO 2010). DFO estimates roughly 2.6 harbor seals per km of shoreline outside the Strait of Georgia, which equates to about 15000 animals for the West Coast of Vancouver Island. For Baja California, we assume the same densities as in Southern California (1.062 individuals per square kilometer), and extrapolate to the model area in Mexican waters 0-200m depth. We distributed harbor seal biomass between regions (i.e. between latitudinal zones in the model domain) according to estimates from Caretta et al. (2012), and then used constant densities for boxes within each region from 0-200 m.

Life history parameters came from Trites and Pauly (1998). Harbor seal diets have been improved from the previous version of the model by additional diet studies (Torok 1994; Roffe and Mate 1984; Gibble 2011). These studies suggest harbor seals primarily consume species in the small nearshore fish group and anchovy.

Other Pinnipeds

Species included: Steller sea lion (*Eumetopias jubatus*), northern elephant seal (*Mirounga angustirostris*), northern fur seal (*Callorhinus ursinus*), and Guadalupe fur seal (*Arctocephalus townsendi*).

Abundances for all pinnipeds in this group in U.S. waters were derived from stock assessments (Carretta et al. 2012, Allen and Angliss 2011). Steller sea lion abundance in BC is described by Olesiuk (2009). We used only the portion of the population occurring at rookeries within our model domain (Scott Islands rookeries). Similarly, we only included the portion of the northern fur seal population that is thought to migrate into the model domain (Allen and Angliss 2012). For Mexico, we added additional Guadalupe fur seals and northern elephant seals from the San Benitos Islands (Esperón-Rodríguez and Gallo-Reynoso 2012; Garcia-Aguilar and Morales-Bojórquez 2005).

Northern elephant seals make up the majority of the biomass of this group. Distribution and migration of biomass reflect this accordingly. We began by distributing biomass evenly across model boxes 0-200 m depth. Two migrations move pinniped biomass outside the model domain each year: a short post-breeding migration during the month of April, and a longer post-molt migration from July to mid-December. These migrations occur to different extents among juveniles and adults, as well as males and females (Boeuf et al. 1996; Robinson et al. 2012). In our model, the migrations affect 20 (first migration) and 60 (second migration) percent of juvenile biomass, and 75 percent (both migrations) of adult biomass, respectively. These proportions reflect the proportion of this pinniped group made up by northern elephant seals, down-weighted to account for Steller sea lions moving south into the model at the same time northern elephant seals move north.

Life history and diet information was carried over from Horne et al. (2010).

Sea otter (*Enhydra lutris*)

Sea otter abundance estimates were combined from assessments of the threatened southern sea otter subspecies (*E. lutris nereis*) in California (Carretta et al. 2012) and the northern sea otter subspecies (*E. lutris kenyoni*) in Washington (WDFW 2010) and the West Coast of Vancouver Island region of British Columbia (Nichol et al. 2005). We distributed sea otter biomass in coastal boxes proportional to their relative abundance off the west coast of Vancouver Island, Washington, and northern California.

Life history and diet information was carried over from Horne et al. (2010).

References

Acosta, Sara, Jaime Jahncke, William Merkle, and Lara Rachowicz. 2010. “Ecological Studies of Seabirds on Alcatraz Island, 2010.” *Final Report to the Golden Gate National Recreation Area National Park Service.(PRBO Conservation Science, Petaluma, CA, 2010)*. http://ww.prbo.org/refs/files/12079_Acostaetal.2010.pdf.

Agostini, Vera N., Robert C. Francis, Anne B. Hollowed, Stephen D. Pierce, Chris Wilson, and Albert N. Hendrix. 2006. “The Relationship between Pacific Hake (Merluccius Productus) Distribution and Poleward Subsurface Flow in the California Current System.” *Canadian Journal of Fisheries and Aquatic Sciences* 63 (12): 2648–59.

Ainley, David G., and K. David Hyrenbach. 2010. “Top-down and Bottom-up Factors Affecting Seabird Population Trends in the California Current System (1985–2006).” *Progress in Oceanography* 84 (3): 242–54.

Aires Da Silva, A., and M. N Maunder. 2012a. *Status of Yellowfin Tuna in the Eastern Pacific Ocean in 2011, and Outlook for the Future*. 13. Stock Assessement Report. Inter American Tropical Tuna Commission. http://www.iattc.org/StockAssessmentReports/StockAssessmentReport13ENG.htm.

———. 2012b. *Status of Bigeye Tuna in the Eastern Pacific Ocean in 2011, and Outlook for the Future*. 13. Stock Assessement Report. Inter American Tropical Tuna Commission. http://www.iattc.org/StockAssessmentReports/StockAssessmentReport13ENG.htm.

Allen, B. M., and R. P. Angliss. 2010. *Killer Whale (Orcinus Orca): West Coast Transient Stock*. Technical Memorandum 223. NOAA NMFS AFSC.

———. 2012. *Steller Sea Lion (Eumetopias Jubatus): Eastern U.S. Stock*. Technical Memorandum 245. NOAA NMFS AFSC.

Anderson, Cynthia D., Daniel D. Roby, and Ken Collis. 2004. “Foraging Patterns of Male and Female Double-Crested Cormorants Nesting in the Columbia River Estuary.” *Canadian Journal of Zoology* 82 (4): 541–54.

Bailey, Kevin M., Robert Colgate Francis, and Payson R. Stevens. 1982. *The Life History and Fishery of Pacific Whiting, Merluccius Productus*. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, US Department of commerce. http://calcofi.ucsd.edu/newhome/publications/CalCOFI_Reports/v23/pdfs/Vol_23_Bailey_etal.pdf.

Barlow, J., M. Kahru, and B. G. Mitchell. 2008. “Cetacean Biomass, Prey Consumption, and Primary Production Requirements in the California Current Ecosystem.” *Marine Ecology Progress Series* 371: 285–95.

Becker, Elizabeth A., Karin A. Forney, David G. Foley, Raymond C. Smith, Thomas J. Moore, and Jay Barlow. 2014. “Predicting Seasonal Density Patterns of California Cetaceans Based on Habitat Models.” http://www.int-res.com/abstracts/esr/v23/n1/p1-22/.

Bednaršek, N., R. A. Feely, J. C. P. Reum, B. Peterson, J. Menkel, S. R. Alin, and B. Hales. 2014. “Limacina Helicina Shell Dissolution as an Indicator of Declining Habitat Suitability Owing to Ocean Acidification in the California Current

Ecosystem." *Proceedings of the Royal Society B: Biological Sciences* 281 (1785): 20140123. doi:10.1098/rspb.2014.0123.

Bednaršek, N., J. Možina, M. Vogt, C. O'Brien, and G. A. Tarling. 2012. "The Global Distribution of Pteropods and Their Contribution to Carbonate and Carbon Biomass in the Modern Ocean." *Earth System Science Data* 4 (1): 167–86. doi:10.5194/essd-4-167-2012.

Bertram, Douglas F., Anne Harfenist, and April Hedd. 2009. "Seabird Nestling Diets Reflect Latitudinal Temperature-Dependent Variation in Availability of Key Zooplankton Prey Populations." *Marine Ecology Progress Series* 393: 199–210.

Bertram, Douglas F., and Gary W. Kaiser. 1993. "Rhinoceros Auklet (Cerorhinca Monocerata) Nestling Diet May Gauge Pacific Sand Lance (Ammodytes Hexapterus) Recruitment." *Canadian Journal of Fisheries and Aquatic Sciences* 50 (9): 1908–15.

Bertram, Douglas F., David L. Mackas, and Stewart M. McKinnell. 2001. "The Seasonal Cycle Revisited: Interannual Variation and Ecosystem Consequences." *Progress in Oceanography* 49 (1): 283–307.

Boeuf, Burney J. Le, Patricia A. Morris, Susanna B. Blackwell, Daniel E. Crocker, and Daniel P. Costa. 1996. "Diving Behavior of Juvenile Northern Elephant Seals." *Canadian Journal of Zoology* 74 (9): 1632–44.

Bradburn, Mark James, Aimee A. Keller, and Beth Helene Horness. 2011. *The 2003 to 2008 US West Coast Bottom Trawl Surveys of Groundfish Resources off Washington, Oregon, and California: Estimates of Distribution, Abundance, Length, and Age Composition*. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center.

Brand, E. J, I. C. Kaplan, C. J Harvey, P.S. Levin, E.A. Fulton, A. J Hermann, and J. C. Field. 2007. "A Spatially Explicit Ecosystem Model of the California Current's Food Web and Oceanography." *NOAA Technical Memorandum* NMFS-NWFSC-84. http://www.nwfsc.noaa.gov/assets/25/6677_12062007_152916_CalCurrentTM84Final.pdf.

BURGER, ALAN E. 2003. "Effects of the Juan de Fuca Eddy and Upwelling on Densities and Distributions of Seabirds off Southwest Vancouver Island, British Columbia." *African Seabird Group Pacific Seabird Group* 31: 113–22.

Calambokidis, John, and Jay Barlow. 2004. "Abundance of Blue and Humpback Whales in the Eastern North Pacific Estimated by Capture-Recapture and Line-Transect Methods." *Marine Mammal Science* 20 (1): 63–85.

Capitolo, Phillip J., Harry R. Carter, Richard J. Young, Gerard J. McChesney, William R. McIver, Richard T. Golightly, and Franklin Gress. 2004. "Changes in Breeding Population Size of Brandt's and Double-Crested Cormorants in California, 1975-2003." https://humboldt-dspace.calstate.edu:9443/handle/2148/930.

Capitolo, Phillip J., Gerard J. McChesney, Jonathan A. Shore, and Crystal A. Bechaver. 2011. "Aerial Photographic Surveys of Brandt's and Double-Crested Cormorant Breeding Colonies in South Central California in June 2010. Unpublished Report for US BLM."

http://www.blm.gov/pgdata/etc/medialib/blm/ca/pdf/coastal_monument.Par.94279.File.dat/Seabird%20Aerial%20Monitoring%20Final%20Report_2010.pdf.

Carretta, James V., Susan J. Chivers, and Wayne L. Perryman. 2011. "Abundance of the Long-Beaked Common Dolphin (Delphinus Capensis) in California and Western Baja California Waters Estimated from a 2009 Ship-Based Line-Transect Survey." *Bulletin, Southern California Academy of Sciences* 110 (3): 152–64.

Carter, Harry R., Gerard J. McChesney, Deborah L. Jaques, Craig S. Strong, Michael W. Parker, Jean E. Takekawa, Deborah L. Jory, and Darrell L. Whitworth. 1992. "Breeding Populations of Seabirds in California, 1989-1991. Volume I-Population Estimates." http://aquaticcommons.org/11254/.

Checkley, D. M, and J. A Barth. 2009. "Patterns and Processes in the California Current System." *Progress in Oceanography* 83 (1-4): 49–64.

Collis, Ken, Daniel D. Roby, David P. Craig, Stephanie Adamany, Jessica Y. Adkins, and Donald E. Lyons. 2002. "Colony Size and Diet Composition of Piscivorous Waterbirds on the Lower Columbia River: Implications for Losses of Juvenile Salmonids to Avian Predation." *Transactions of the American Fisheries Society* 131 (3): 537–50.

Cope, J.M., Dick Dick E.J., A.D. MacCall, Melissa Monk, B. Soper, and C. Wetzel. 2013. *Data-Moderate Stock Assessments for Brown, China, Copper, Sharpchin, Stripetail, and Yellowtail Rockfishes and English and Rex Soles in 2013*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/.

Cope, J.M., and MacCall, A.D. 2005. *Status of Kelp Greenling (Hexagrammos Decagrammus) in Oregon and California Waters as Assessed in 2005*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

COSEWIC. 2006. *COSEWIC Assessment and Status Report on the Black-Footed Albatross (Phoebastria Nigripes) in Canada.* Committee on the Status of Endangdered Wildlife in Canada.

———. 2007. *COSEWIC Assessment and Status Report on the Canary Rockfish Sebastes Pinniger in Canada*. Committee on the Status of Endangdered Wildlife in Canada. www.sararegistry.gc.ca/status/status_e.cfm.

———. 2012a. *COSEWIC Assessment and Status Report on the Marbled Murelet Brachyramphus Marmoratus in Canada.* Ottawa: Committee on the Status of Endangdered Wildlife in Canada.

———. 2012b. *Status Appraisal Summary on the Blue Whale Balaenoptera Musculus Pacific Population in Canada*. Ottawa: Committee on the Status of Endangdered Wildlife in Canada.

Crone, P.R., K.T. Hill, J.D. McDaniel, and K. Lynn. 2011. *Pacific Mackerel (Scomber Japonicus) Stock Assessment for USA Management in the 2011-2012 Fishing Year*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/wp-content/uploads/2011_CPS_Mackerel_Appendix_B.pdf.

Cunha, Michael J. 2010. "BREEDING STATUS OF CASSIN'S AUKLET (PTYCHORAMPHUS ALEUTICUS) AND RHINOCEROS AUKLET (CERORHINCA MONOCERATA) ON CASTLE ROCK NATIONAL

WILDLIFE REFUGE, DEL NORTE COUNTY, CALIFORNIA.” Humboldt State University. http://humboldt-dspace.calstate.edu/handle/2148/764.

Davison, P. C., D. M. Checkley Jr, J. A. Koslow, and J. Barlow. 2013. “Carbon Export Mediated by Mesopelagic Fishes in the Northeast Pacific Ocean.” *Progress in Oceanography* 116: 14–30.

DFO. 2009. *Recovery Potential Assessment of the Humpback Whale Pacific Population*. 2009/048. Science Advisory Secretariat Science Advisory Report. DFO Canada.

———. 2010. *Population Assessment Pacific Harbour Seal (Phoca Vitulina Richardsi)*. 2009/11. Canadian Science Advisory Secretariat Science Advisory Report. DFO Canada.

———. 2011a. *Stock Assessment for the inside Population of Yelloweye Rockfish (Sebastes Ruberrimus) In British Columbia, Canada for 2010*. 2011/084. Science Advisory Report. Fisheries and Ocean Canada. http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2011/2011_084-eng.html.

———. 2011b. *Lingcod (Ophiodon Elongatus) Stock Assessment and Yield Advice for Outside Stocks in British Columbia*. Science Advisory Report 2011/051. Fisheries and Ocean Canada. http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2011/2011_051-eng.html.

———. 2012. *Stock Assessment Report on Pacific Herring in British Columbia in 2012*. Science Advisory Report 2012/062. Fisheries and Ocean Canada. http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2012/2012_062-eng.html.

Dick, E. J., Stephen Ralston, Don Pearson, and John Wiedenmann. 2009. “Updated Status of Cowcod, Sebastes Levis, in the Southern California Bight.” *Pacific Fishery Management Council, Portland, OR*. http://www.pcouncil.org/wp-content/uploads/cowcod_update_assessment_2009.pdf.

Dick, E.J., Ralston, S., and Pearson, D. 2011. *Status of Greenspotted Rockfish, Sebastes Chlorostictus, in U.S. Waters off California*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Dufault, A.M., K. Marshall, and I.C. Kaplan. 2009. “A Synthesis of Diets and Trophic Overlap of Marine Species in the California Current.” *NOAA Technical Memorandum* NMFS-NWSC-103. http://www.nwfsc.noaa.gov/assets/25/7024_12212009_134730_DietsCalCurrentTM103WebFinal.pdf.

Dunne, J.P., A. Gnanadesikan, J.L. Sarmiento, and R.D. Slater. 2010. “Technical Description of the Prototype Version (v0) of Tracers of Phytoplankton with Allometric Zooplankton (TOPAZ) Ocean Biogeochemical Model as Used in the Princeton IFMIP Model.” *Biogeosciences* 7: 3593.

Eigner, Lisa E., Gerard J. McChesney, Sandra J. Rhoades, Mary W. Davis, Jonathan A. Shore, Crystal A. Bechaver, Peter J. Kappes, and Richard T. Golightly. 2010. *Restoration of Common Murre Colonies in Central California: Annual Report 2009*. Humboldt State University/US Fish and Wildlife Service. https://humboldt-dspace.calstate.edu:9443/handle/2148/826.

Elizabeth A. Becker, Karin A. Forney, Megan C. Ferguson, Jay Barlow, and Jessica V. Redfern. 2012. *Predictive Modeling of Cetacean Densities in the California Current Ecosystem Based on Summer/fall Ship Surveys in 1991-2008*. 499. Technical Memorandum. NOAA NMFS SWFSC.

Ellis, G.M., J.R. Towers, and J.K.B. Ford. 2011. *Northern Resident Killer Whales of British Columbia: Photo-Identification Catalogue and Population Status to 2010*. Canadian Technical Report of Fisheries and Aquatic Sciences 2942. DFO Canada.

Esperón-Rodríguez, Manuel, and Juan Pablo Gallo-Reynoso. 2012. "Analysis of the Re-Colonization of San Benito Archipelago by Guadalupe Fur Seals (Arctocephalus Townsendi)." *Latin American Journal of Aquatic Research* 40 (1): 213–23.

Essington, Timothy E., and Éva E. Plagányi. 2014. "Pitfalls and Guidelines for 'recycling' Models for Ecosystem-Based Fisheries Management: Evaluating Model Suitability for Forage Fish Fisheries." *ICES Journal of Marine Science: Journal Du Conseil* 71 (1): 118–27.

Fabry, V. J., B. A. Seibel, R. A. Feely, and J. C. Orr. 2008. "Impacts of Ocean Acidification on Marine Fauna and Ecosystem Processes." *ICES Journal of Marine Science* 65 (3): 414–32. doi:10.1093/icesjms/fsn048.

Fargo, J. 1999. *Flatfish Stock Assessments for the West Coast of Canada for 1999 and Recommended Yield Options for 2000*. Canadian Stock Assessment Secretariat 1999/199. Research Document. Fisheries and Ocean Canada.

Fargo, J., and P.J. Starr. 2001. *Turbot Stock Assessment for 2001 and Recommendations for Management in 2002*. Research Document 2001/150. Fisheries and Ocean Canada. http://www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/2001/2001_150-eng.htm.

Feely, R. A. 2004. "Impact of Anthropogenic CO2 on the CaCO3 System in the Oceans." *Science* 305 (5682): 362–66. doi:10.1126/science.1097329.

Felix-Uraga, R., V. Gomez-Munoz, C. Quiñónez-Velázquez, F. Neri Melo-Barrera, and W. García-Franco. 2004. "On the Existence of Pacific Sardine Groups off the West Coast of Baja California and Southern California." *California Cooperative Oceanic Fisheries Investigations Report* 45: 146.

Fennel, Katja, John Wilkin, Michael Previdi, and Raymond Najjar. 2008. "Denitrification Effects on Air-Sea CO2 Flux in the Coastal Ocean: Simulations for the Northwest North Atlantic." *Geophysical Research Letters* 35 (24). doi:10.1029/2008GL036147.

Field, J. C., R. C. Francis, and K. Aydin. 2006. "Top-down Modeling and Bottom-up Dynamics: Linking a Fisheries-Based Ecosystem Model with Climate Hypotheses in the Northern California Current." *Progress in Oceanography* 68 (2-4): 238–70.

Field, J.C. 2011. *Status of Bocaccio, Sebastes Paucispinis, in the Conception, Monterey and Eureka INPFC Areas as Evaluated for 2011*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Field, John C., Ken Baltz, A. Jason Phillips, and William A. Walker. 2007. "Range Expansion and Trophic Interactions of the Jumbo Squid, Dosidicus Gigas, in the California Current." *California Cooperative Oceanic Fisheries Investigations Report* 48: 131.

Field, John C., Edward J. Dick, and Alec D. MacCall. 2007. *Stock Assessment Model for the Shortbelly Rockfish, Sebastes Jordani, in the California Current*. Portland, Oregon: Pacific Fishery Management Council.

Field, John C., Carl Elliger, Ken Baltz, Graham E. Gillespie, William F. Gilly, R. I. Ruiz-Cooley, Devon Pearse, Julia S. Stewart, William Matsubu, and William A.

Walker. 2013. “Foraging Ecology and Movement Patterns of Jumbo Squid (Dosidicus Gigas) in the California Current System.” *Deep Sea Research Part II: Topical Studies in Oceanography* 95: 37–51.

Fissel, Benjamin E., N. Lo, and S. Herrick Jr. 2011. “Daily Egg Production, Spawning Biomass and Recruitment for the Central Subpopulation of Northern Anchovy 1981–2009.” *Calif. Coop. Ocean. Fish. Invest. Rep* 52: 116–35.

Garcia-Aguilar, Maria de la Concepcion, and Enrique Morales-Bojórquez. 2005. “Estimating the Haul-out Population Size of a Colony of Northern Elephant Seals Mirounga Angustirostris in Mexico, Based on Mark-Recapture Data.” *Marine Ecology. Progress Series* 297: 297–302.

Garcia-Reyes, M., JULIE A. Thayer, and WILLIAM J. Sydeman. 2013. “Citizen Science Studies of Gualala Point Island Seabird Populations and Productivity 2007-2012: Historical, Regional and Environmental Comparisons”. Farallon Institute, Petaluma, CA.

Gertseva, V., and I. G. Taylor. 2011. “Status of the Spiny Dogfish Shark Resource off the Continental US Pacific Coast in 2011.” *Pacific Fishery Management Council, Portland, OR*.

Gertseva, V.V., J.M. Cope, and D.E. Pearson. 2009. *Status of the U.S. Splitnose Rockfish (Sebastes Diploproa) Resource in 2009.* Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Gertseva, Vladlena V., and Michael J. Schirripa. 2007. “Status of the Longnose Skate (Raja Rhina) off the Continental US Pacific Coast in 2007.” *Pacific Fishery Management Council, Portland, OR*. ftp://php.ptagis.org/pub/Briefing%20Books/BB_CDs/BB_CD_0607/0607/Groundfish_Assessments_E6/LongnoseSkate_AssessmentReport.pdf.

Gibble, Corinne Michele. 2011. *Food Habits of Harbor Seals (Phoca Vitulina Richardii) in San Francisco Bay, California*. San Jose State University. http://gradworks.umi.com/15/00/1500623.html.

Gould, Patrick, Peggy Ostrom, and William Walker. 2000. “Foods, Trophic Relationships, and Migration of Sooty and Short-Tailed Shearwaters Associated with Squid and Large-Mesh Driftnet Fisheries in the North Pacific Ocean.” *Waterbirds*, 165–86.

Gregg, Watson W., and Nancy W. Casey. 2007. “Modeling Coccolithophores in the Global Oceans.” *Deep Sea Research Part II: Topical Studies in Oceanography* 54 (5): 447–77.

Guinotte, John M., and Andrew J. Davies. 2013. “Predicted Deep-Sea Coral Habitat Suitability for the US West Coast.” Accessed June 17. http://www.marine-conservation.org/media/filer_public/2013/03/21/guinotte_davies_2012_small.pdf.

Gustafson, Richard G., Michael Jonathan Ford, D. Teel, and Jonathan Scott Drake. 2010. *Status Review of Eulachon(Thaleichthys Pacificus) in Washington, Oregon, and California*.

Haidvogel, DB, H. Arango, WP Budgell, BD Cornuelle, E. Curchitser, E. Di Lorenzo, K. Fennel, et al. 2008. “Ocean Forecasting in Terrain-Following Coordinates: Formulation and Skill Assessment of the Regional Ocean Modeling System.” *Journal of Computational Physics* 227 (7): 3595–3624.

Haist, Vivian, A. R. Kronlund, and M. R. Wyeth. 2004. *Sablefish (Anoplopoma Fimbria) in British Columbia, Canada: Stock Assessment for 2003 and Advice to Managers for 2004*. Research Document 2004/055. Fisheries and Oceans. http://www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/2004/2004_055-eng.htm.

Hall-Spencer, Jason M., Riccardo Rodolfo-Metalpa, Sophie Martin, Emma Ransome, Maoz Fine, Suzanne M. Turner, Sonia J. Rowley, Dario Tedesco, and Maria-Cristina Buia. 2008. “Volcanic Carbon Dioxide Vents Show Ecosystem Effects of Ocean Acidification.” *Nature* 454 (7200): 96–99. doi:10.1038/nature07051.

Hamel, O., J. Cope, and S. Matson. 2013. *Stock Assessment of Aurora Rockfish in 2013*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Hamel, Owen S., and Kotaro Ono. 2011. “Stock Assessment of Pacific Ocean Perch in Waters off of the US West Coast in 2011.” *Pacific Fishery Management Council, Portland, OR*. http://www.pcouncil.org/wp-content/uploads/Pacific_Ocean_Perch_2011_Assessment.pdf.

Hamel, Owen S., Suresh A. Sethi, and Thomas F. Wadsworth. 2009. “Status and Future Prospects for Lingcod in Waters off Washington, Oregon, and California as Assessed in 2009.” *Status of the Pacific Coast Groundfish Fishery through*. http://www.pcouncil.org/wp-content/uploads/Lingcod_Assessment_2009_Final_SAFE_version.pdf.

Hannah, Robert W. 2011. “Variation in the Distribution of Ocean Shrimp (Pandalus Jordani) Recruits: Links with Coastal Upwelling and Climate Change.” *Fisheries Oceanography* 20 (4): 305–13.

Hay, D. E., Harbo, R., Southey, J.E., Clarke, J.E., Parker, G., and McCarter, P.G. 1999. *Catch Composition of British Columbia Shrimp Trawls and Preliminary Estimation of Bycatch with Emphasis on Eulachons*. 99/26. Canadian Stock Assessment Secretariat Research Document. Ottawa, Canada: Fisheries and Oceans Canada, Biological Sciences Branch.

Hay, D. E., and P. B. McCarter. 1997. “Continental Shelf Area and Distribution, Abundance, and Habitat of Herring in the North Pacific.” *Forage Fishes in Marine Ecosystems. American Fisheries Society, Anchorage, Alaska*, 559–72.

Hay, D., and P. B. McCarter. 2000. *Status of the Eulachon Thaleichthys Pacificus in Canada*. Canadian Stock Assessment Secretariat. http://www.dfompo.gc.ca/csas/csas/DocREC/2000/PDF/2000_145e.pdf.

Hay, D.E., R. Harbo, J. Boutillier, E. Wylie, L. Convey, and P.B. McCarter. 1999. *Assessment of by-Catch in the 1997 and 1998 Shrimp Trawl Fisheries in British Columbia, with Emphasis on Eulachons*. Research Document 1999/179. Fisheries and Ocean Canada. http://www.dfo-mpo.gc.ca/csas-sccs/Publications/ResDocs-DocRech/1999/1999_179-eng.htm.

He, Xi, D. Pearson, J.C. Field, Lindsey Lefebvre, and M. Key. 2013. *Status of the U.S. Pacific Sanddab Resource in 2013*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Hedd, April, Douglas F. Bertram, John L. Ryder, and Ian L. Jones. 2006. “Effects of Interdecadal Climate Variability on Marine Trophic Interactions: Rhinoceros Auklets and Their Fish Prey.” *Marine Ecology Progress Series* 309: 263–78.

Hester, Michelle, Ryan Carle, Jessie Beck, David Calleri, and Oikonos-Ecosystem Knowledge. 2014. “Año Nuevo State Park Seabird Conservation and Habitat Restoration: Report 2009-2012.” Accessed May 28. http://www.coastsidestateparks.org/pdfs/Final_ANSP_Seabird%20Conservation%20and%20Habitat%20Restoration_Oikonos_050113_reduced.pdf.

Hicks, A., N. Taylor, C. Grandin, I.G. Taylor, and S.P. Cox. 2013. *Status of the Pacific Hake (whiting) Stock in U.S. and Canadian Waters in 2013*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Hicks, A., and J. Wetzel. 2011. *The Status of Dover Sole (Microstomus Pacificus) Along the U.S. West Coast in 2011*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Hinton, M. F., and M. N. Maunder. 2011. *Status and Trends of Striped Marlin in the Northeast Pacific Ocean in 2009*. Stock Assessent Report 11. http://www.iattc.org/StockAssessmentReports/StockAssessmentReportsENG.htm.

Hipfner, J. MARK. 2005. “Population Status of the Common Murre Uria Aalge in British Columbia, Canada.” *Marine Ornithology* 33 (1): 67–69.

Horne, P. J, I. C Kaplan, K. N Marshall, P. S Levin, C. J Harvey, A. J Hermann, and E. A Fulton. 2010. “Design and Parameterization of a Spatially Explicit Ecosystem Model of the Central California Current.” *NOAA Technical Memorandum*, NMFS-NWFSC, NMFS-NWFSC-104: 1–140.

Hunt, B. P. V., E. A. Pakhomov, G. W. Hosie, V. Siegel, Peter Ward, and K. Bernard. 2008. “Pteropods in Southern Ocean Ecosystems.” *Progress in Oceanography* 78 (3): 193–221.

Hunt, George L., Hidehiro Katō, and Stewart M. McKinnell. 2000. *Predation by Marine Birds and Mammals in the Subarctic North Pacific Ocean*. North Pacific Marine Science Organization. https://pices.int/publications/scientific_reports/Report14/Report14.pdf.

International Scientific Committe for Tuna and Tuna-like Species in the North Pacific Ocean. 2011. *Stock Assessment of Albacore Tuna in the North Pacific Ocean in 2011*.

Jaques, D.L. 2007. “Castle Rock National Wildlife Refuge Information Synthesis. Unpublished Report to the USFWS, Humboldt Bay NWR.” http://www.privatelandownernetwork.org/pdfs/castlerockreport.pdf.

Jenkerson, J., and Scott F. Pearson. 2012. *Catalog of Washington Seabird Colonies: Converting the Catalog to a Geodatabase and Adding New Survey Data*. Washington Department of Fish and Wildlife.

Kaplan, Isaac C., Christopher J. Brown, Elizabeth A. Fulton, Iris A. Gray, John C. Field, and Anthony D.M. Smith. 2013. “Impacts of Depleting Forage Species in the California Current.” *Environmental Conservation* 40 (04): 380–93. doi:10.1017/S0376892913000052.

Key, M., A. D MacCall, J. C Field, D. Aseltine-Neilson, and L. Kirk. 2007. *The 2007 Assessment of Blue Rockfish (Sebastes Mystinus) in California*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Key, Meisha, Alec D. MacCall, Traci Bishop, and Bob Leos. 2005. *Stock Assessment of the Gopher Rockfish (Sebastes Carnatus)*. California Department of Fish & Game. http://137.110.142.7/publications/FED/00780.pdf.

Kleiber, Pierre, Shelley Clarke, Keith Bigelow, Hideki Nakano, Murdoch McAllister, and Yukio Takeuchi. 2009. *North Pacific Blue Shark Stock Assessment*. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Pacific Islands Fisheries Science Center. http://www.nmfs.hawaii.edu/library/pubs/tech/NOAA_Tech_Memo_PIFSC_17.pdf.

Kroeker, Kristy J., Rebecca L. Kordas, Ryan Crim, Iris E. Hendriks, Laura Ramajo, Gerald S. Singh, Carlos M. Duarte, and Jean-Pierre Gattuso. 2013. “Impacts of Ocean Acidification on Marine Organisms: Quantifying Sensitivities and Interaction with Warming.” *Global Change Biology*. http://onlinelibrary.wiley.com/doi/10.1111/gcb.12179/full.

Kroeker, Kristy J., Rebecca L. Kordas, Ryan N. Crim, and Gerald G. Singh. 2010. “Meta-Analysis Reveals Negative yet Variable Effects of Ocean Acidification on Marine Organisms.” *Ecology Letters* 13 (11): 1419–34. doi:10.1111/j.1461-0248.2010.01518.x.

Lalli, Carol M., and Ronald W. Gilmer. 1989. *Pelagic Snails: The Biology of Holoplanktonic Gastropod Mollusks*. Stanford University Press.

Leonard, J., and P. Watson. 2011. “Description of the Input-Output Model for Pacific Coast Fisheries (IOPAC).” *NOAA Technical Memorandum* NMFS-NWFSC-111: 1–64.

Love, Milton S. 1991. *Probably More than You Want to Know about the Fishes of the Pacific Coast*. Really Big Press Santa Barbara, California.

Lowry, MARK S., and OCTAVIO Maravilla-Chavez. 2003. “Recent Abundance of California Sea Lions in Western Baja California, Mexico and the United States.” In *Proceedings of the Sixth California Islands Symposium, Ventura, California*, 485–97. http://www.iws.org/CISProceedings/6th_CIS_Proceedings/Lowry_and_Maravilla-Chavez.pdf.

Mason, John W., Gerard J. McChesney, William R. McIver, Harry R. Carter, John Y. Takekawa, Richard T. Golightly, Joshua T. Ackerman, et al. 2007. *At-Sea Distribution and Abundance of Seabirds off Southern California: A 20-Year Comparison*. Vol. 33. Cooper Ornithological Society. http://sora.unm.edu/sites/default/files/journals/sab/sab_033.pdf.

Maunder, M. 2011. *California Halibut Stock Assessment*. California Department of Fish and Wildlife Report. Sacramento, CA: California Department of Fish and Wildlife. http://www.dfg.ca.gov/marine/sfmp/halibut-assessment.asp.

McClain, Craig R., Lonny Lundsten, Micki Ream, James Barry, and Andrew DeVogelaere. 2009. “Endemicity, Biogeography, Composition, and Community Structure On a Northeast Pacific Seamount.” Edited by Sean Rands. *PLoS ONE* 4 (1): e4141. doi:10.1371/journal.pone.0004141.

McClatchie, S. 2009. *Report on the NMFS California Current Ecossytem Survey (CCES) (April and July-August 2008)*. Technical Memorandum. NOAA NMFS SWFSC.

Miller, Sherri L., Martin G. Raphael, Gary A. Falxa, Craig Strong, Jim Baldwin, Thomas Bloxton, Beth M. Galleher, Monique Lance, Deanna Lynch, and Scott F. Pearson. 2012. “Recent Population Decline of the Marbled Murrelet in the Pacific Northwest.” *The Condor* 114 (4): 771–81.

National Marine Fisheries Service (NMFS). 2013. *Groundfish Essential Fish Habitat Synthesis: A Report to the Pacific Fishery Management Council*. Seattle, WA: NOAA NMFS Northwest Fisheries Science Center.

Naughton, M. B., D. S. Pitkin, R. W. Lowe, K. J. So, and C. S. Strong. 2007. *Catalog of Oregon Seabird Colonies. US Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS*. BTP-R1009-2007, Washington, DC.

Nichol, L. M., J.C. Watson, G.M. Ellis, and J.K.B. Ford. 2005. *An Assessment of Abundance and Growth of the Sea Otter Population (Enhydra Lutris) in British Columbia*. 2005/094. Canadian Science Advisory Secretariat Science Research Document. DFO Canada.

NOAA Regional Ecosystem Delineation Workgroup. 2004. *Report on the Delineation of Regional Ecosystems*. http://www.nmfs.noaa.gov/pr/sars/improvement/pdfs/ecosystem_delineation.pdf.

Nur, Nadav, Jaime Jahncke, Mark P. Herzog, Julie Howar, K. David Hyrenbach, Jeannette E. Zamon, David G. Ainley, John A. Wiens, Ken Morgan, and Lisa T. Ballance. 2011. “Where the Wild Things Are: Predicting Hotspots of Seabird Aggregations in the California Current System.” *Ecological Applications* 21 (6): 2241–57.

Olson, Robert J., and George M. Watters. 2003. “A Model of the Pelagic Ecossystem in the Eastern Tropical Pacific Ocean.” *Inter-American Tropical Tuna Commission Bulletin* 22 (3): 135–218.

Orsi, Joseph A., J. A. Harding, S. S. Pool, R. D. Brodeur, L. J. Haldorson, James M. Murphy, J. H. Moss, et al. 2007. “Epipelagic Fish Assemblages Associated with Juvenile Pacific Salmon in Neritic Waters of the California Current and the Alaska Current.” In *American Fisheries Society Symposium*, 57:105. American Fisheries Society. http://www.richardbeamish.com/uploads/1/6/0/0/16007202/orsietal.-2007-afs_symposum5750-150.pdf.

Pacific Fishery Management Council. 2011. *Coastal Pelagic Species Fishery Management Plan as Amended Through Amendment 13*. Portland, Oregon. http://www.pcouncil.org/coastal-pelagic-species/fishery-management-plan-and-amendments/.

Pauly, Daniel, A. W. Trites, Emily Capuli, and Villy Christensen. 1998. “Diet Composition and Trophic Levels of Marine Mammals.” *ICES Journal of Marine Science: Journal Du Conseil* 55 (3): 467–81.

Peter F. Olesiuk. 2009. *Abundance of Steller Sea Lions (Enumetopias Jubatus) in British Columbia*. 2008/063. Canadian Science Advisory Secretariat Science Research Document. Nanaimo: DFO Canada.

Ralston, Stephen. 2005. *An Assessment of Starry Flounder off California, Oregon, and Washington*. NOAA Fisheries, Southwest Fisheries Science Center. http://swfsc.noaa.gov/publications/FED/00827.pdf.

Robertson, Ian. 1974. “The Food of Nesting Double-Crested and Pelagic Cormorants at Mandarte Island, British Columbia, with Notes on Feeding Ecology.” *Condor*, 346–48.

Robinson, Patrick W., Daniel P. Costa, Daniel E. Crocker, Juan Pablo Gallo-Reynoso, Cory D. Champagne, Melinda A. Fowler, Chandra Goetsch, et al. 2012. “Foraging Behavior and Success of a Mesopelagic Predator in the Northeast Pacific Ocean: Insights from a Data-Rich Species, the Northern Elephant Seal.” *PloS One* 7 (5): e36728.

Rodway, M.S. 1991. “Status and Conservation of Breeding Seabirds in British Columbia.” *International Council for Bird Preservation Technical Publication* 11: 43–102.

Roffe, Thomas J., and Bruce R. Mate. 1984. “Abundances and Feeding Habits of Pinnipeds in the Rogue River, Oregon.” *The Journal of Wildlife Management*, 1262–74.

Ruzicka, James J., Richard D. Brodeur, and Thomas C. Wainwright. 2007. “Seasonal Food Web Models for the Oregon Inner-Shelf Ecosystem: Investigating the Role of Large Jellyfish.”

Saenz, BENJAMIN L., JULIE A. Thayer, WILLIAM J. Sydeman, and DAPHNE A. Hatch. 2006. “An Urban Success Story: Breeding Seabirds on Alcatraz Island, California, 1990–2002.” *Marine Ornithology* 34 (1): 43–49.

Sampson, D. 2007. *The Status of Black Rockfish off Oregon and California in 2007*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Schnute, Jon. 2001. *Pacific Ocean Perch Assessment for the West Coast of Canada in 2001*. Vol. 2001/138. Canadian Science Advisory Secretariat Research Document, Canadian. Canadian Science Advisory Secretariat.

Smith, A. D. M., C. J. Brown, C. M. Bulman, E. A. Fulton, P. Johnson, I. C. Kaplan, H. Lozano-Montes, et al. 2011. “Impacts of Fishing Low-Trophic Level Species on Marine Ecosystems.” *Science* 333 (July): 1147–50. doi:10.1126/science.1209395.

Smith, Paul E., Elbert Halvor Ahlstrom, and Harold D. Casey. 1970. *The Saury as a Latent Resource of the California Current*. California Marine Research Committee.

Speich, S.M., and T.R. Wahl. 1989. “Catalog of Washington Seabird Colonies”. U.S. Fish and Wildlife Service Biological Reports.

Stanley, R. 1999. *Shelf Rockfish Assessment for 1998 and Recommended Yield Options for 1999*. 1999/53. Canadian Stock Assessment Secretariat. Fisheries and Oceans Canada.

Stanley, R., M. K McAllister, and P. Starr. 2012. *Updated Stock Assessment for Bocaccio (Sebastes Paucispinis) in British Columbia Waters for 2012*. 2012/109. Research Document. Fisheries and Ocean Canada. http://www.dfo-mpo.gc.ca/csas-sccs/Publications/ResDocs-DocRech/2012/2012_109-eng.html.

Stephens, A., and I.G. Taylor. 2013. *Stock Assessment and Status of Longspine Thornyhead (Sebastolobus Altivelis) off California, Oregon and Washington in 2013*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Stewart, I., J. Thorson, and C. Wetzell. 2011. *Status of the U.S. Sablefish Resource in 2011*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Strickland, JDH. 1966. "Measuring the Production of Marine Phytoplankton." *Fisheries Research Board of Canada*, no. Bulletin No. 122.

Sydeman, W. J., H. R. Carter, J. E. Takekawa, and N. Nur. 1997. "Common Murre Uria Aalge Population Trends at the South Farallon Islands, California, 1985-1995." *Unpublished Report, Point Reyes Bird Observatory, Stinson Beach, California*.

Sydeman, William J., Marcel Losekoot, Jarrod A. Santora, Sarah Ann Thompson, Trisha Distler, Anna Weinstein, Melanie A. Smith, Nathan Walker, Alaska Audubon, and Ken H. Morgan. 2013. "Hotspots of Seabird Abundance in the California Current: Implications for Important Bird Areas." Accessed June 17. http://fl.audubon.org/sites/default/files/documents/report_audubon_marine_ibas_011813.pdf.

Taylor, I.G., and Wetzel, C. 2011. *Status of the U.S. Yelloweye Rockfish Resource in 2011*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Thayer, J. A., and W. J. Sydeman. 2007. "Spatio-Temporal Variability in Prey Harvest and Reproductive Ecology of a Piscivorous Seabird, Cerorhinca Monocerata, in an Upwelling System." *Marine Ecology Progress Series* 329: 253–65.

Toperoff, Amanda Kate. 2002. "Examination of Diet of Harbor Porpoise (Phocoena Phocoena) from Central California Using Stomach Content and Stable Isotope Analysis from Multiple Tissues." http://scholarworks.sjsu.edu/cgi/viewcontent.cgi?article=3333&context=etd_theses.

Torok, Michael L. 1994. "Movements, Daily Activity Patterns, Dive Behavior, and Food Habits of Harbor Seals (Phoca Vitulina Richardsi) in San Francisco Bay, California". California State University, Stanislaus.

Trites, Andrew W., and Daniel Pauly. 1998. "Estimating Mean Body Masses of Marine Mammals from Maximum Body Lengths." *Canadian Journal of Zoology* 76 (5): 886–96.

Urbán, J. R., L. Rojas_Bracho, H. Pérez-Cortéz, A. Gómez-Gallardo, S.L. Swartz, S. Ludwig, and R.L. Brownell Jr. 2003. "A Review of Gray Whales on Their Winter Grounds in Mexican Waters." *J. Cetacean Res. Manage* 5 (3): 281–95.

US-GLOBEC (U.S. Global Ocean Ecosystems Dynamics). 1992. *Report on Climate Change and the California Current Ecosystem*. 7. Davis, CA USA: US-GLOBEC. http://www.usglobec.org/reports.php.

V.V. Gertseva, and J.T. Thorson. 2013. *Status of the Darkblotched Rockfish Resource off the Continental U.S. Pacific Coast in 2013*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/by-species/.

Vermeer, K. 1979. "NESTING REQUIREMENTS, FOOD AND BREEDING DISTRIBUTION OF RHINOCEROS AUKLETS, CERORHINCA-MONOCERATA, AND TUFTED PUFFINS, LUNDA-CIRRHATA." *Ardea* 67 (3-4): 101–10.

Vermeer, Kees. 1982. “Comparison of the Diet of the Glaucous-Winged Gull on the East and West Coasts of Vancouver Island.” *The Murrelet*, 80–85.

Vermeer, Kees, John D. Fulton, and Spencer G. Sealy. 1985. “Differential Use of Zooplankton Prey by Ancient Murrelets and Cassin’s Auklets in the Queen Charlotte Islands.” *Journal of Plankton Research* 7 (4): 443–59.

Wallace, F., Yuk Wing Cheng, and T. S Tsou. 2007. *Status of the Black Rockfish Resource North of Cape Falcon, Oregon to the U.S.-Canadian Border in 2006*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Wallace, J.R., and J.M. Cope. 2011. *Status Update of the U.S. Canary Rockfish Resource in 2011*. Portland, Oregon: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Warzybok, P. M., and R. W. Bradley. 2011. “Status of Seabirds on Southeast Farallon Island during the 2011 Breeding Season.” *Unpublished Report to the US Fish and Wildlife Service. PRBO Conservation Science, Petaluma, CA PRBO Contribution*, no. 1769. http://vvvvvv.prbo.org/cms/docs/marine/SEFI_seabirds/2011_Seabird_Status_SEFI_Report.pdf.

WDFW. 2010. *Washington State Stock of Northern Sea Otter: Stock Assessment Review*. Washington Department of Fish and Wildlife.

Wolf, S., B. Keitt, A. Aguirre-Muñoz, B. Tershy, E. Palacios, and D. Croll. 2006. “Transboundary Seabird Conservation in an Important North American Marine Ecoregion.” *Environmental Conservation* 33 (04): 294–305.

Wolf, S., B. Keitt, A. Aguirre-MuñOz, B. Tershy, E. Palacios, and D. Croll. 2006. “Transboundary Seabird Conservation in an Important North American Marine Ecoregion.” *Environmental Conservation* 33 (04): 294. doi:10.1017/S0376892906003353.

Zamon, Jeannette E., Elizabeth M. Phillips, and Troy J. Guy. 2013. “Marine Bird Aggregations Associated with the Tidally-Driven Plume and Plume Fronts of the Columbia River.” *Deep Sea Research Part II: Topical Studies in Oceanography*. http://www.sciencedirect.com/science/article/pii/S096706451300129X.

Zeidberg, Louis D., and Bruce H. Robison. 2007. “Invasive Range Expansion by the Humboldt Squid, Dosidicus Gigas, in the Eastern North Pacific.” *Proceedings of the National Academy of Sciences* 104 (31): 12948–50. doi:10.1073/pnas.0702043104.

Zwolinski, Juan P., David A. Demer, Kyle A. Byers, George R. Cutter, Josiah S. Renfree, Thomas S. Sessions, and Beverly J. Macewicz. 2012. “Distributions and Abundances of Pacific Sardine (Sardinops Sagax) and Other Pelagic Fishes in the California Current Ecosystem during Spring 2006, 2008, and 2010, Estimated from Acoustic–trawl Surveys.” *Fishery Bulletin* 110 (1): 110–22.