MANAGEMENT TESTING AND SCENARIOS FOR THE CALIFORNIA CURRENT

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Appendix MS2013-01. Sensitivity of the California Current ecosystem to climate change and ocean acidification. Isaac Kaplan, Shallin Busch

Appendix MS2013-02. Population responses of Snake River spring/summer Chinook salmon to freshwater and marine climate changes. Lisa Crozier and Rich Zabel.

Appendix MS2013-03. Ocean conditions and selected management options on the population dynamics of Wenatchee River spring Chinook salmon. Jeff Jorgensen

Appendix MS2013-04. Application of the Northern California Current ECOTRAN model to pelagic ecosystem scenarios for the 2013 California Current Integrated Ecosystem Assessment. James Ruzicka

Appendix MS2013-05. Assessing the risk of ocean acidification in the California Current to two key fishery species, Dungeness crab (*Cancer magister)* and pink shrimp (*Pandalus jordani).* Emma Hodgson, Tim Essington, Isaac Kaplan

Appendix MS2013-06. Scenarios for shipping on the US West Coast. Isaac Kaplan, Jessica Redfern, Elizabeth Petras

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INTRODUCTION

In preliminary engagement with managers and other experts as part of the 2012 IEA (Levin, Wells, et al. 2013), we developed narrative scenarios that acted as links between drivers and pressures on the California Current Ecosystem, for instance between increased global seafood demand and local fishing pressure. These were "scenarios for drivers", essentially "what if" stories about alternate paths that drivers and pressures may take in the future. Scenarios included drivers related to human population growth, climate change, demand for conservation, energy, and evolution of status quo management and responses to it (Table 1). Narrative scenarios detailed potential effects on pressures considered in this IEA: urban and agricultural freshwater use, energy infrastructure, fishing, pollution, and shipping. For the 2012 IEA, we accompanied these scenarios with seven quantitative models that forecast impacts of some of these pressures on the ecosystem. The focus of our quantitative modeling in 2012 was primarily on fisheries, with one exception that focused on renewable ocean energy development.

Table MS1. *Schematic of narrative scenarios and potential impacts on five types of pressures on the California Current ecosystem (Levin and Wells 2013).*

	Pressure				
Scenario	Freshwater use, urban and agricultural	Energy Infrastructure	Fishing	Land-based pollution	Shipping
Human Population Growth	↑	↑	↑	↑	↑
Climate Change	↑	↑	↔	↔	↔
Conservation Demands	↓	↓	↓	↓	↓
Energy Crunch	↔	↑	↓	↔	↑
Status Quo	↔	↔	↔	↔	↔

For the 2013 IEA we develop modeling to consider the implications of climate change and ocean acidification, and begin considering trends and tradeoffs associated with shipping. We first focus on climate change, and its effects on the ecosystem and fisheries. In the context of salmon management, we evaluate the utility of strategies that have the potential to offset some of the effects of climate change. We consider the relative vulnerability of life stages of two major fishery species, Dungeness crab and pink shrimp, to ocean acidification. We also track how recent climate variation has altered productivity of key fisheries such as Pacific hake.

We broaden the scope of the IEA to include shipping by developing a series of narratives for shipping, based on conversations with individuals with expertise in the transportation sector. We also apply models that consider the spatial overlap of ships and whales, to identify tradeoffs and unintended consequences of clean air regulations and new shipping routes.

CLIMATE CHANGE AND OCEAN ACIDIFICATION

In the 2012 California Current IEA, preliminary engagement with managers identified climate change and ocean acidification (or more broadly, global change) as potential major drivers of the marine ecosystem. These conversations and narratives included qualitative predictions regarding impacts on salmonid survival and distribution, shifts in migrations and distribution of pelagic or midwater species such as hake or sardine, and increased mortality of shelled, calcifying organisms susceptible to acidified water (Figure **MS1**). Policy responses discussed were limited but included altering harvest, stream restoration, and community-based management. For the most part, quantitative modeling of climate change and ocean acidification was absent from the 2012 IEA, though in the 2011 IEA (Levin & Schwing 2011), Ainsworth et al. and Kaplan et al. presented quantitative ecosystem models simulating effects of global change.

For the 2013 California Current IEA, we have developed three quantitative modeling analyses that address impacts of climate and climate change on salmon and the continental shelf food web. We also present a risk assessment for two calcifying species, Dungeness crab (*Cancer magister*) and pink shrimp (*Pandalus jordani*), which may be particularly vulnerable to ocean acidification. Below, we summarize results from the four analyses, and present lessons learned from this effort. Appendices include an overview of the recent literature regarding climate change and ocean acidification (**Appendix MS2013-01**) in the California Current. Full articles or reports for the modeling analyses are found in the appendices.

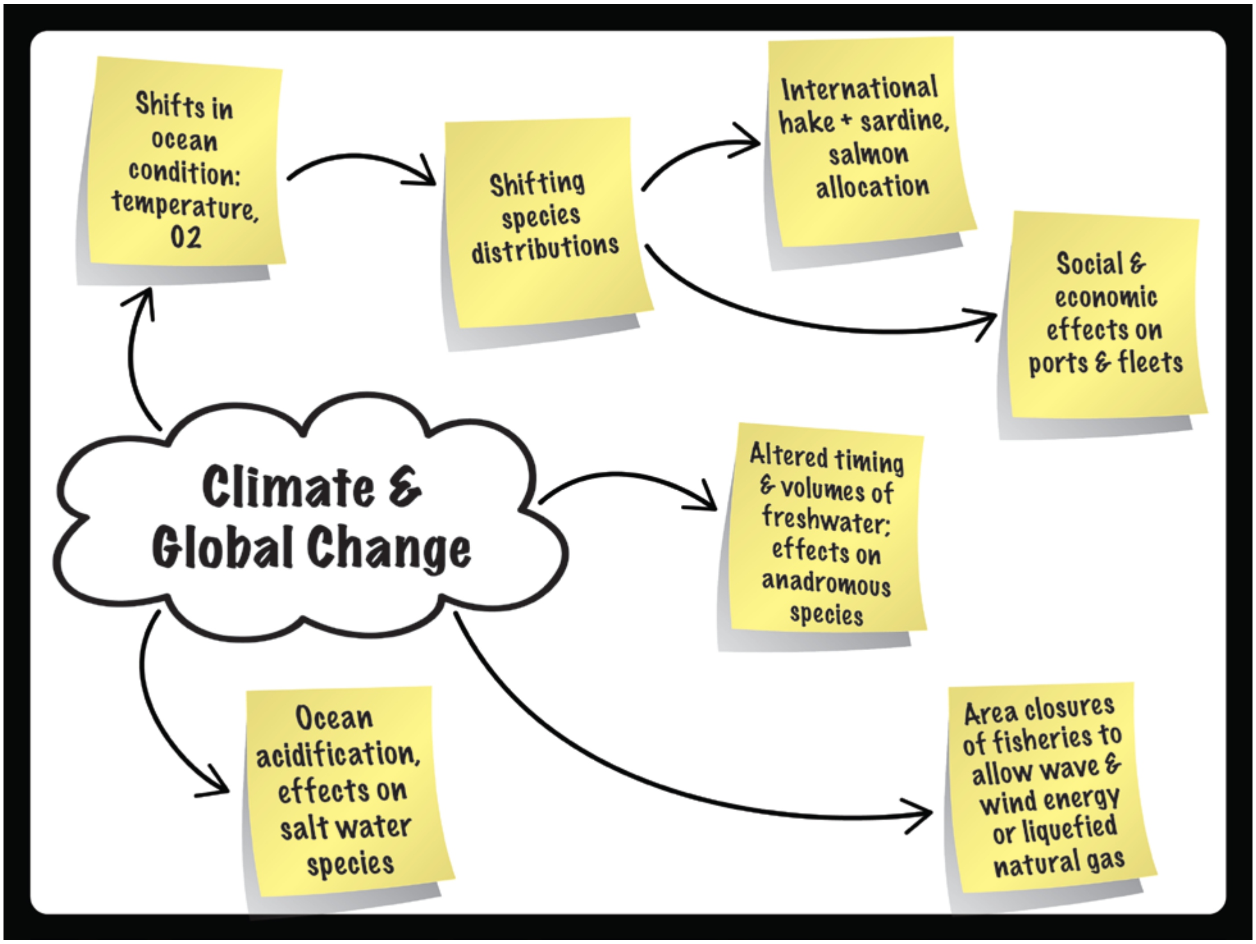

Figure MS1. Climate and Global Change scenario, with pressures (yellow notes) identified in narratives and by experts for the 2012 California Current IEA.

GENERAL APPROACH FOR CLIMATE CHANGE ANALYSES

King et al. (2011), Stock et al. (2011), and Hollowed et al. (2013) note the difficulty in inferring local patterns from coarse scale global circulation models, and they point to the need for downscaled, finer resolution oceanographic modeling to predict climate change impacts. Downscaled oceanographic models of the California Current, forced by coarser scale global models and scenarios for CO2 emissions, are in progress but not yet available to predict a full suite of ocean conditions such as temperature, upwelling, nutrients, and pH. King et al. (2011) provide conceptual diagrams illustrating the potential for climate change to lead to warmer surface waters; increased upwelling-favorable winds; a deepening thermocline; and increased coastal stratification. These authors presented logical consequences of climate change for different fish species, but were not able to make quantitative predictions (see summary, **Appendix MS2013-01**).

Punt and colleagues (2013) acknowledge this lack of quantitative predictions of climate change impacts, in the context of simulation testing fishery management strategies. Given the uncertainties related to precisely forecasting species responses to climate, these authors argue for a more general consideration of how the ecological system may change in the future, and whether management strategies are robust to this change. The three analyses below regarding climate change (**Appendices MS2013 02-04**) illustrate recent inter-annual and inter-decadal shifts in the food web and ocean conditions, and can inform how climate-driven shifts in productivity may alter fisheries and the ecosystem. In particular, a critical question for decision makers is whether potential management actions can buffer or offset changes in productivity or species survival that may stem from climate change.

Two of our analyses on climate change (**Appendices MS2013 02-03**) focus on ocean conditions for salmon. Ocean conditions have a large influence on salmon population dynamics (e.g., Koslow et al. 2002; Scheuerell and Williams 2005; Wells et al. 2008; Burke et al. 2013), and predicting future impacts of climate change on salmon populations requires forecasting ocean conditions and consideration of the implications for abundance and persistence of populations. These ocean conditions are a function of both regional and basin-scale processes (e.g., Mantua et al. 1997; Peterson et al. 2012). For instance, Jorgensen et al. (2013) and Crozier et al. (2013), respectively, have identified coastal upwelling and the Pacific Decadal Oscillation (PDO) as important determinants of ocean survival for Chinook salmon (*Oncorhynchus tshawytscha*) populations in the US Pacific Northwest (**Figure MS2**). In particular, the PDO generally indicated a period of cool, productive conditions for salmon from 1961-1976, and unfavorable warmer years from 1977-1997. Wells et al. (2008) found that Chinook salmon in the Smith River, California benefited from cool ocean temperatures and strong upwelling, wind stress, and a strong California Current.

In lieu of downscaled climate-ocean models for salmon, Crozier and Zabel (**Appendix MS 2**) and Jorgensen (**Appendix MS2013-03**) consider a range of ocean condition scenarios, and evaluate to what extent potential management options can compensate for poor ocean conditions for Chinook salmon. Ocean conditions are based on Monte Carlo resampling of years from the cool, productive phase of the PDO (1961-1976) and the phase with poorer conditions for most salmon stocks (1977-1997). Both models use a similar stochastic, age-structured salmon life cycle modeling framework developed originally by Zabel et al. (2006). Crozier and Zabel (**Appendix MS2013-02**) combine this scenario-based approach for the ocean with downscaled global circulation models applied to the fresh water, similar to other modeling efforts in rivers and streams (Battin et al. 2007; Crozier et al. 2008; Beechie et al. 2012).

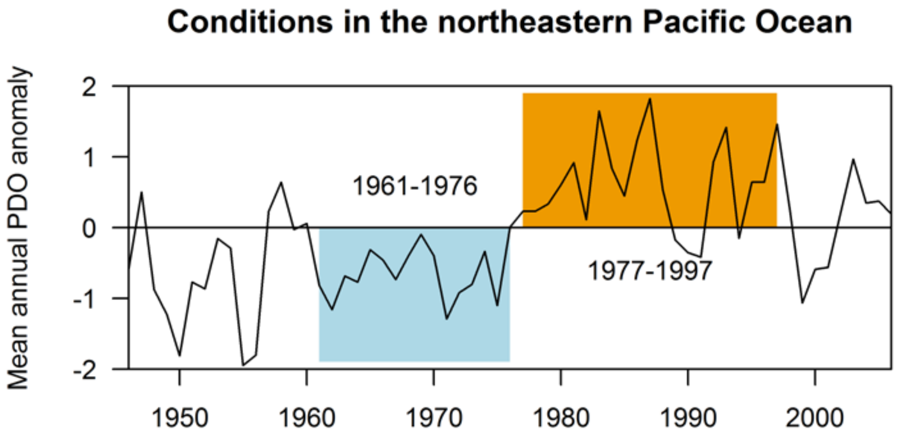

Figure MS2: Ocean conditions as measured by Pacific Decadal Oscillation anomalies in recent years, with relative periods of favorable (cooler ocean surface waters, 1961-1976; blue) and unfavorable (warmer ocean surface waters, 1977-1997; orange) conditions for Pacific salmon survival in the ocean used to develop scenarios of future ocean conditions.

SUMMARY OF INDIVIDUAL CLIMATE CHANGE ANALYSES

Crozier and Zabel (Appendix MS2013-02) employed a life cycle model to evaluate the impact of climate change on three populations of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). These three populations spawn and rear in tributaries of the Salmon River, and are listed as threatened under the Endangered Species Act. The authors used downscaled temperature and stream flow projections for the 2040s from 10 global circulation models (GCMs) and 2 emissions scenarios to characterize freshwater climate changes. They conducted a sensitivity analysis of ocean conditions by systematically varying periods of relatively favorable and unfavorable climate regimes from the historical record. Scenarios for ocean conditions consisted of alternative percentages of years when ocean conditions during early ocean entry by salmon were considered favorable (negative mean annual Pacific Decadal Oscillation [PDO] values) and unfavorable (positive PDO values) for survival, as discussed above and illustrated in Figure **MS2**.

Crozier and Zabel found that Chinook salmon populations differed in their sensitivity to freshwater change, with responses ranging from neutral to negative. In all three populations, spawner abundance declined in a relatively linear manner as the percentage of unfavorable ocean regimes increased (**Figure MS3**). However, there was a dramatic increase in extinction risk if ocean regimes shifted from 60% to 80% unfavorable. Because the 60% scenario produced very similar levels of risk and abundance as our historical scenario, this suggests these populations are already near a tipping point. Any decline in ocean conditions thus poses a very serious risk. However, the management scenarios considered (based on recent improved survival through the Columbia and Snake

Rivers), increased median population abundance 1.6-2.2 times across all climate scenarios and all populations. The maximum extinction risk dropped from 62% to 19%. Most importantly, management actions leading to higher survival through the hydrosystem (dams) successfully mitigated for the increased extinction risk due to climate conditions in all three populations. Abundance still declined from baseline under the worst ocean scenarios in two populations. Whether this recent improved survival can be sustained is not clear. But these results suggest a significant opportunity for recovery in these threatened populations.

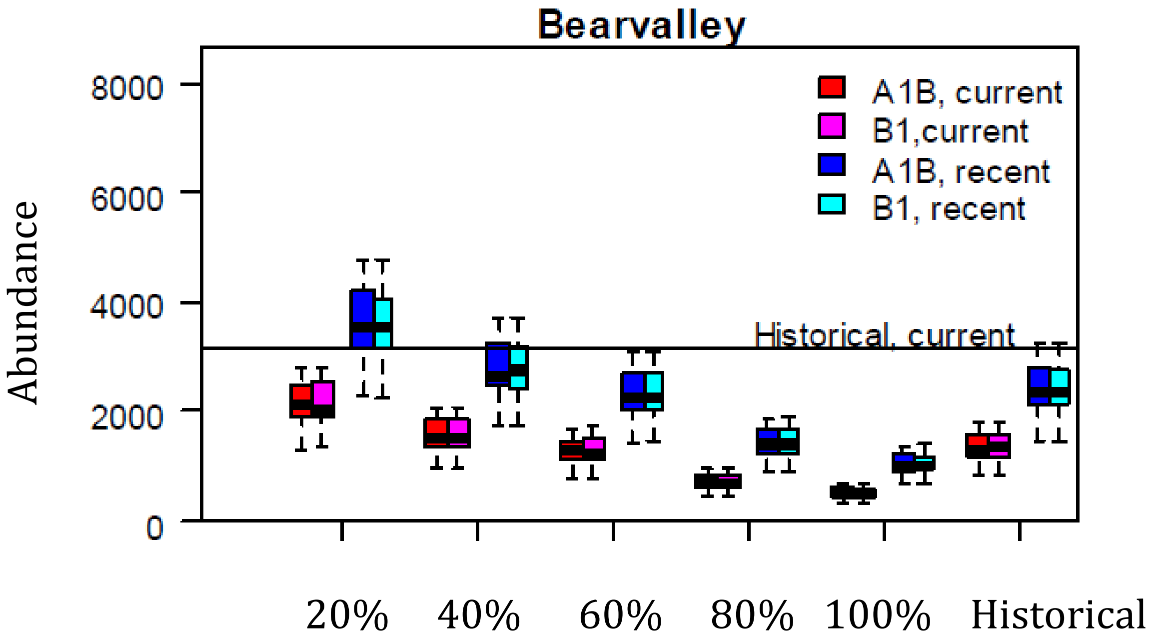

Figure MS3. *Median spawner abundance of Bear Valley Creek (Salmon River) Chinook salmon, as a function of freshwater climate scenarios (A1B or B1), hydrosystem survival ("Current", or improved survival rates labelled "recent"), and ocean conditions. Ocean conditions are characterized in terms of the percent of years with consistently positive PDO, and are compared with the actual historical time series ("Historic"). The baseline scenario used the historical freshwater and ocean conditions and the "current" hydrosystem management, and is shown by the horizontal line. The boxes show the range across all global climate models (GCMs) for a given scenario (line shows the median GCM, the boxes show the interquartile range, and the whiskers show the full range of all GCMs).*

Jorgensen (Appendix MS2013-03) applied scenarios for climate and management actions, focusing on responses of Wenatchee River spring Chinook salmon, a population listed as endangered under the Endangered Species Act. Predictions of population responses are available from a stochastic salmon life cycle model, similar to that used by Crozier and Zabel (**Appendix MS2**). Jorgensen (Appendix MS2013-03) combined scenarios of simulated future ocean conditions with estimated effects of management actions that affected the freshwater (prespawning adults, and rearing juvenile fish), mainstem (smolt migration through the Federal hydropower system), and estuary (avian predation). Similar to **Appendix MS2013-02**, scenarios for ocean conditions consisted of alternative percentages of years when ocean conditions were generally favorable for West Coast salmon (negative mean annual Pacific Decadal Oscillation [PDO] values) and unfavorable (positive PDO values) (**Figure MS2**). Compared to a benchmark scenario, in the Wenatchee River median spawners and carrying capacity declined with worsened ocean conditions. When management actions were applied individually, freshwater survival increases had the best ability to mitigate for poor ocean conditions, while mainstem hydropower dam and estuary survival improvements had a more moderate ability to mitigate for poor ocean conditions (**TableMS2**). Collectively, freshwater, mainstem, and estuary management actions offset the effects of some moderate declines in ocean condition, but not the poorest ocean conditions considered in these scenarios.

Table MS2: *Estimated impacts of management actions on the number of Wenatchee River basin wild spring Chinook salmon spawners using a life cycle model that incorporated scenarios of simulated future ocean conditions. FCRPS survival is downstream smolt survival through the dams.* $N_{100, 50\%}$ *is 50th percentile of spawner abundance at time t = 100 years, taken across runs.* $Pr(QE)_{100}$ *is probability of quasi-extinction for simulations that ran t = 100 years. The geometric mean of the number of wild spawners for the five year period 2005-2009 was 576 spawners.*

Ocean conditions	Avian predation	FCRPS survival	Freshwater survival	$N_{100, 50\%}$	$Pr(QE)_{100}$
Historical	Current	Current	Current	860	0.001
20% bad	Current	Current	Current	822	0.002
40% bad	Current	Current	Current	737	0.005
60% bad	Current	Current	Current	632	0.001
80% bad	Current	Current	Current	549	0.009
100% bad	Current	Current	Current	493	0.008
Historical	Current	Current	+10%	1111	0
20% bad	Current	Current	+10%	1049	0
40% bad	Current	Current	+10%	901	0
60% bad	Current	Current	+10%	859	0
80% bad	Current	Current	+10%	668	0.001
100% bad	Current	Current	+10%	606	0.001
Historical	-50% reduced	+10%	Current	1004	0
20% bad	-50% reduced	+10%	Current	976	0
40% bad	-50% reduced	+10%	Current	826	0.001
60% bad	-50% reduced	+10%	Current	734	0
80% bad	-50% reduced	+10%	Current	642	0.003
100% bad	-50% reduced	+10%	Current	541	0.004
Historical	-50% reduced	+10%	+10%	1226	0
20% bad	-50% reduced	+10%	+10%	1254	0
40% bad	-50% reduced	+10%	+10%	1055	0
60% bad	-50% reduced	+10%	+10%	970	0
80% bad	-50% reduced	+10%	+10%	811	0
100% bad	-50% reduced	+10%	+10%	700	0.001

Ruzicka (**Appendix MS2013-04**) developed an end-to-end model (Steele & Ruzicka 2011; Ruzicka et al. 2012) to estimate the ecosystem-level and functional group responses to inter-annual variability in food web structure. The NCC ECOTRAN model maps the flow of production through the food web from lower trophic-level producers to upper trophic-level consumers and fisheries. The model domain covers the Oregon and Washington continental shelf ecosystem during the summer. NCC ECOTRAN was driven by inter-annual changes over the past decade in phytoplankton production and biomass, copepod community composition and biomass, the biomass of large jellyfishes, and changes in the forage fish community. Ten parameterizations of the model, one per year for 1998 through 2007, were developed in **Appendix MS2013-04**. For this region, the inter-annual variability in the abundance of these species was likely driven by basin-scale patterns such as the PDO and El Niño, but also by local patterns involving upwelling timing and influx of cold, fresh water from the north (Venrick et al. 2003; Peterson et al. 2006).

Generally, there was correspondence between years of high phytoplankton biomass and production rates up the food web. This was largely driven by the extreme years of the time-series: the low production El Niño year of 1998 and the high phytoplankton production years of 2002, 2006, and 2007 (**Figure MS4**). Aside from these extreme years, the response of the trophic groups and fisheries depended not on mean abundance of the groups manipulated in the scenarios but on abundance of particular lower trophic level groups, and trophic interactions.

This simple scenario modeling exercise demonstrated the short-term effects of observed community changes within the plankton and forage fish community upon higher trophic levels and upon production of fished species. Primary production and food web structural variability over the past decade suggest that pelagic fishery production, a measure of energy flow to the target species, generally varied 50% - 200% about the decadal mean. Variability was higher among fisheries that target forage species. Energy flow to Pacific hake, a major fishery target species, has varied from 40% below to 50% above the decadal mean (**Figure MS4**). Energy flow to gear types that targeted hake and sablefish performed best during years of higher euphausiid production (2006-2007), with roughly 30-50% increases during these years. Though we cannot at present predict what future levels of productivity will be under climate change, this period from 1998-2008 provides a range of annual production rates that could be used in the future to bracket what may occur under climate change.

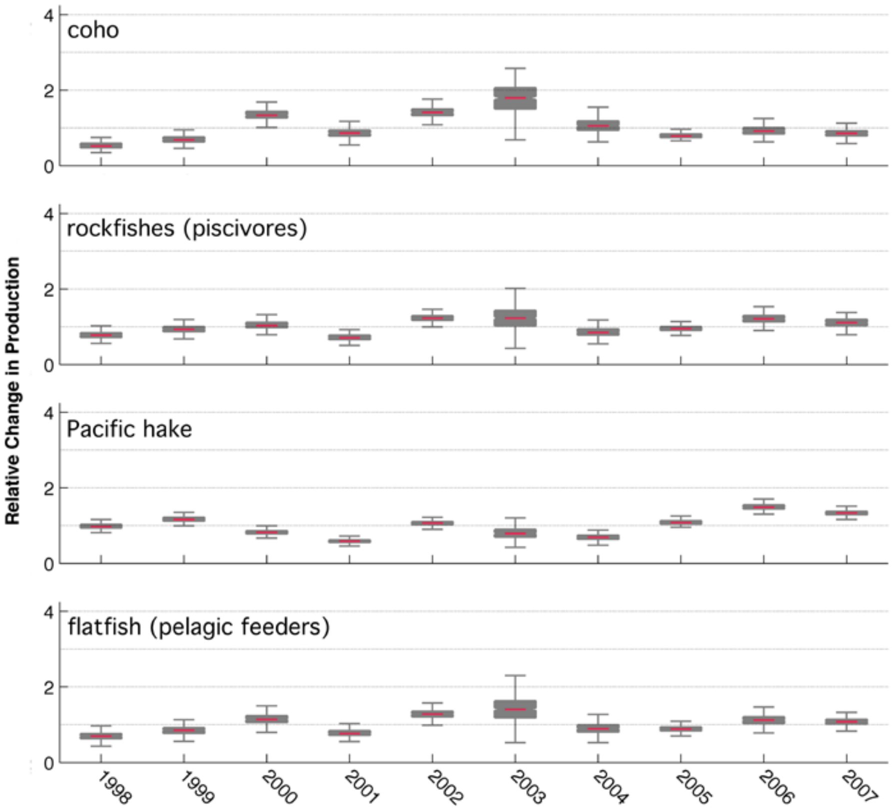

Figure MS4. *Scenarios showing effects of interannual variability among bottom- and mid-trophic level groups (phytoplankton, copepods, jellyfish, and forage fish) upon the production rates of select fish groups. Boxplots show distributions of changes in production rates relative to the inter-annual mean (ratio of scenario production rate to inter-annual mean, or 'base' model production rate). Boxplots show distributions of scenarios applied to 445 random, thermodynamically balanced model parameter configurations. A value of 1 on the y-axis represents no change from the inter-annual mean.*

SUMMARY OF OCEAN ACIDIFICATION STUDY

Hodgson et al. (**Appendix MS2013-05**) developed an ecological risk analysis of ocean acidification impacts on two species in the California Current: Dungeness crab, *Cancer magister*, and pink shrimp, *Pandalus jordani*. These species support US West Coast fisheries that were worth $174 million and $32 million in 2012, respectively. The California Current is particularly susceptible to ocean acidification, as low levels of carbonate saturation already exist within the near-shore environment (**see Appendix MS2013-01**). For each life stage of these species, Hodgson and colleagues define two components of risk: sensitivity and exposure. Sensitivity was determined from a literature review that examined the response of Dungeness crab and Pink shrimp, or related species, to acidification, typically measured in experimental conditions. Exposure is the overlap of species' distributions with pH predicted for the year 2050 (Gruber et al. 2012). The methods build on ecological risk analyses in the 2012 IEA (Levin, Wells, et al. 2013), but with a focus on these two shelled species, and these more precise predictions of future pH .

Though ocean climate change analyses such as that by Crozier and Zabel (**Appendix MS2013-02**) and Jorgensen (**Appendix MS2013-03**) necessarily relied on a scenarios approach to crudely bracket future ocean conditions, the analysis by Gruber and colleagues offers a downscaled prediction for coastal ocean acidity (but not climate shifts related to temperature or other factors), and can be applied in the risk analysis of ocean acidification (**Appendix MS2013-05**).

Hodgson et al. (**Appendix MS2013-05**) found that juvenile stages of these two species are most at risk, specifically larvae for pink shrimp and settled megalops for Dungeness crab (**Figure MS5**). Shrimp larvae are the most at risk because they are both highly sensitive and experience high levels of exposure. Within their distribution, 81.3% of their habitat at 100 m depth is predicted to be exposed to water more acidic than pH 7.7 by year 2050. (Laboratory and field studies suggest impacts on some marine species at values below, or more acidic than, pH 7.7). Hodgson and colleagues' sensitivity metric is derived from experiments on a related species, *Pandalus borealis*, that indicate impacts on development but not survival (Bechmann et al. 2011, Arnberg et al. 2012). Experimental results suggest that Dungeness crab settled megalops are only moderately sensitive to low pH, but they also have a high exposure, with 59% of waters they inhabit predicted to be more acidic than pH 7.7 by year 2050. Combining high exposure and moderate sensitivity suggests a relatively high final risk score.

All life history stages of both species are likely to experience a high degree of exposure to acidic waters (more acidic than pH 7.7 in year 2050) in >10% of their distributions. Of the eight life history stages of two species examined, six are predicted to be exposed to water more acidic than pH 7.7 in 59-89% of their distribution. This is largely due to the temporal and spatial distributions of adults and eggs of species, which are found along the bottom where pH is the lowest.

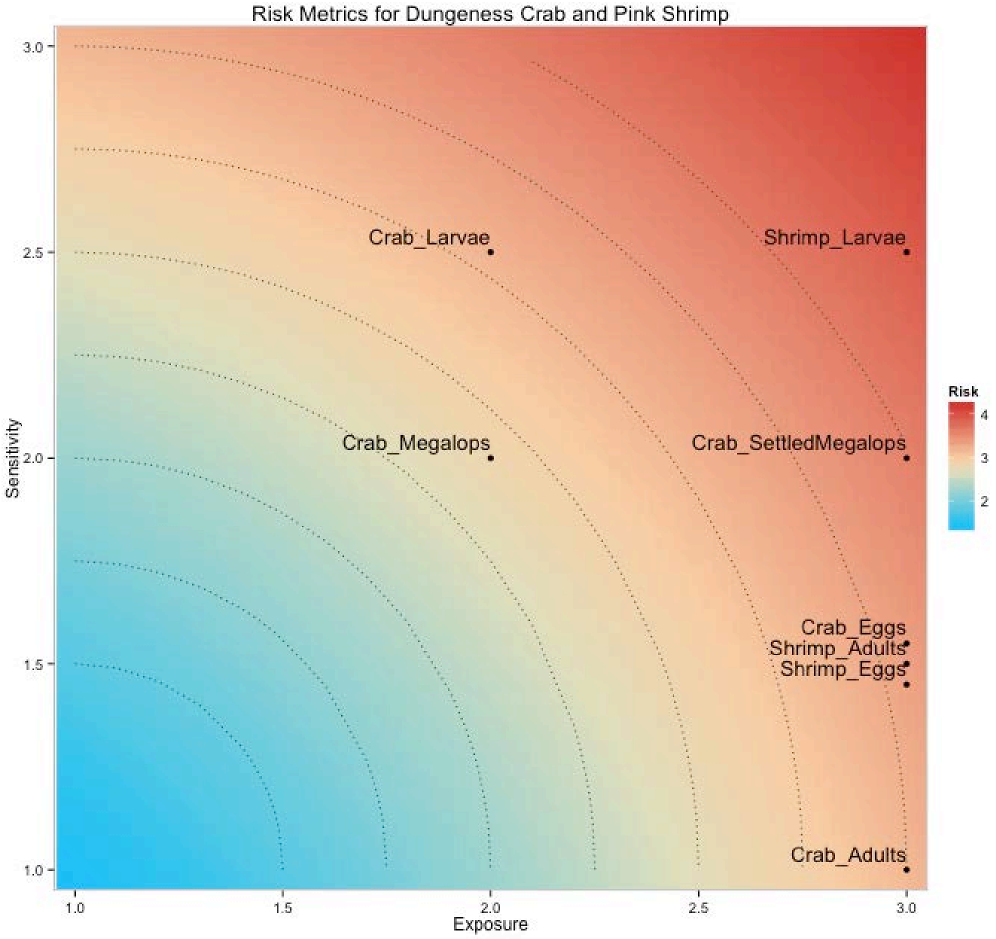

Figure MS5*. Risk plot demonstrating risk scores for each species and life history stage. Sensitivity values come from the literature and exposure values are specifically related to exposure to pH below 7.7.*

SUMMARY OF SHIPPING STUDIES

To lay the groundwork for future quantitative models that may include shipping, we conducted a series of conversations with eight individuals familiar with the shipping industry (**Appendix MS2013-06**). The goal was to understand recent and potential future trends in US West Coast shipping sectors over the next 5-30 years. These conversations outlined five trends, which are simple scenarios that are relevant to understanding or predicting shipping routes, speeds, or volumes, and may be relevant in predicting effects of shipping on various components of the ecosystem.

The first trend involved reduced ship speeds (super slow steaming). Container ships, bulk freighters, and tankers were all reported to have adopted this practice in recent years, for instance reducing ship speeds from maximum (e.g. 25 knots) to most efficient (e.g. 17 knots) speeds, with the exact speed varying by ship and engine type. Scenario 1 envisioned continuation of super slow steaming into the future. Potentially these lower speeds would reduce the probability of lethal shipstrikes on marine mammals.

The second trend, in container and tanker ships, was a large increase in ship size over the last decade, in an effort by shipping firms to maximize economies of scale. Scenario 2 envisioned a continuation of this trend toward fewer, larger vessels that would likely favor the use of the largest ports, such as LA/Long Beach. Shipping impacts on the ecosystem would likely be concentrated on these ports.

The Panama Canal is being expanded, with a new set of locks and capacity for larger ships slated for 2015. Goods manufactured in Asia and transported in containers could bypass the US West Coast and instead travel via the canal directly to markets on the East and Gulf Coasts. The most extreme outcome would be a scenario with a 50% decline in container ship traffic to West Coast ports. Impacts from shipping on the marine environment, or conflicts with other marine sectors, would likely decline near major container ship ports such as LA/Long Beach, San Francisco/Oakland, Tacoma, and Seattle.

The fourth trend involved altered spatial patterns of shipping due to new clean fuel requirements. In 2008, California began requiring the use of low sulfur fuel (clean fuel) in large vessels traveling within 24 nautical miles of the coast. The initial rules resulted in shifts in ship travel patterns: many ships moved farther offshore, in order to avoid the cleaner fuel requirement. However, by 2015, the International Maritime Organization will require clean fuel use out to 200 nautical miles, which could eliminate the advantage of these routes that were slightly offshore of 24 nautical miles. In such a scenario, a change in shipping routes would lead to changes in the overlap with habitat use by particular whale species. For instance, Redfern et al. (2013) found that humpback whales in Southern California occur in nearshore areas, while fin whales occur farther offshore.

The fifth trend involved continued development of new sources of oil, natural gas, and coal throughout the US and Canada, accompanied by increases in tanker and bulk freight cargos from ports in Oregon, Washington, and the Vancouver Canada area. This scenario envisioned continued increases in tanker and bulk freight shipping from Pacific Northwest ports, with increased potential for impacts concentrated in this region.

Future quantitative modeling of shipping, such as potential extensions of the work of Redfern et al. **(Appendix MS2013-07)**, may use these scenarios to consider how global forces translate into impacts on the local ecosystem.

Figure MS6. *Container ships. Photo: NOAA*

In **Appendix MS2013-07** and Redfern et al. (2013), the authors focus on spatial overlap between whales and shipping, and the potential for ships striking whales. As discussed in the narrative scenarios (**Appendix MS2013-06**), the California Air Resources Board recently implemented the Ocean-Going Vessel Fuel Rule. The fuel rule required large, commercial ships to use cleaner-burning fuels when traveling close to the mainland coast. Before implementation of the rule, a majority of ships traveled through the traffic separation scheme adopted by the International Maritime Organization in the Santa Barbara Channel. Following implementation, a higher proportion of ships began traveling south of the northern Channel Islands. The authors assessed the risk of ships striking humpback (*Megaptera novaeangliae*), blue (*Balaenoptera musculus*), and fin (*B. physalus*) whales in alternative shipping routes derived from patterns of shipping traffic observed before and after implementation of the fuel rule.

Redfern and colleagues (**Appendix MS2013-07** and Redfern et al. (2013)) developed models predicting habitat use by whales, and assumed ship-strike risk for the alternative shipping routes was proportional to the number of whales predicted by the models to occur within each route. The route with the lowest risk for humpback whales had the highest risk for fin whales and vice versa. Risk to both species may be ameliorated by creating a new route south of the northern Channel Islands and spreading traffic between this new route and the existing route in the Santa Barbara Channel. Creating a longer route may reduce the overlap between shipping and other uses by concentrating shipping traffic. Blue whales are distributed more evenly across the study area than humpback and fin whales; thus, risk to blue whales could not be ameliorated by concentrating shipping traffic in any of the routes we considered. Reducing ship-strike risk for blue whales may be necessary because the assessment of the potential number of strikes suggests that they are likely to exceed allowable levels of anthropogenic impacts established under U.S. laws.

SYNTHESIS: LESSONS LEARNED

IDENTIFY SCOPE FOR MANAGEMENT ADAPTATION TO CLIMATE CHANGE

Analyses related to climate change (**Appendices MS2013 02-04**) illustrate the potential for decision makers to mitigate the impacts of declining ocean conditions. Impacts of climate on salmon stocks could be mitigated by selected management practices focused on freshwater tributary, mainstem hydropower, and estuary survival (**Appendices MS2013 02-03)**. Chinook salmon life cycle modeling for the Wenatchee and Snake Rivers illustrated that improvements to fish survival rates in the rivers and estuary could compensate for moderate declines in ocean productivity. Offsetting poor ocean conditions would involve dam operations, policies related to barge transport of salmon, habitat restoration in spawning and rearing reaches, and reduced avian predation. For the Wenatchee and Salmon River populations, life cycle models suggested that stock status could be maintained or improved, despite scenarios for generally poor ocean climate. In addition to reducing extinction rates, these management policies prevented declines in abundance for some stocks when faced with a slightly higher frequency of poor ocean conditions (<60-80%) than in recent decades. Prior to these analyses, we did not anticipate that small improvements in freshwater survival could substantially buffer against moderate declines in ocean condition and survival. However, the analyses also show that some salmon populations remain at risk even with the freshwater management interventions.

Food web modeling of the Northern California Current food web (**Appendix MS2013-04**) did not explicitly test new management actions, but instead estimated four-fold interannual variability in energy flow to key fisheries species. If climate change alters these energy flows, for instance increasing years when less production is routed to species such as Pacific hake, fishery managers may need to respond by adjusting both harvests of forage fish and high trophic level species. Future work should explore the types of management actions that may be required.

RECENT DECADES ILLUSTRATE IMPACTS OF CLIMATE

Modeling of Salmon River and Wenatchee River Chinook salmon and of the Northern California Current food web (**Appendices MS2013 02-04**) illustrate the highly variable nature of local oceanography and productivity. This was driven both by large scale climate patterns (PDO, ENSO), but also by local patterns such as upwelling timing in the Northern California Current and influx of cold, fresh water from the north (**Appendix MS2013-04**). As suggested by Punt et al. (2013), in lieu of forecasts of ocean conditions, we can consider how to devise management that is robust to recent extremes in low productivity, or extended periods of poor ocean conditions. We can use observations of outcomes during extreme conditions to understand how the ecosystem and various ecosystem components are impacted and respond to these conditions. Using models, including single-species and ecosystem models, parameterized and fitted to available data for periods with more extreme ocean conditions, we can project outcomes that may occur if these conditions persist for longer periods than have occurred to date.

CONSIDER GLOBAL DRIVERS, REGULATIONS, AND ECONOMIC TRENDS

Our narratives and analysis of shipping (**Appendices MS2013 06-07**) illustrate the extent to which the local ecosystem is influenced by global economic trends and international agreements. In particular, requirements for clean fuel and energy efficiency were expected to influence shipping pressure in California Current; clean fuel requirements at the state level have already altered ship-strike risk for marine mammals (**Appendix MS2013-07**). Global trends in fuel prices and container ship sizes and routes, for example, are also likely to alter risk of impacts such as fuel spills, ship-strikes, and ballast-water invasions. In the 2012 IEA (Levin, Wells, et al. 2013) we considered scenarios related to global population growth, seafood demand, and energy needs, focusing primarily on impacts on fisheries. However, such global trends are also relevant to protected species and to sectors beyond just fisheries. Predicting these trends is outside the scope of the IEA, but as with impacts of climate change on the ecosystem, it is useful to at least explore the impacts of particular scenarios to understand how economic changes can ripple through the ecosystem.

SCENARIOS: BOTH A STEPPING STONE, AND A LONG TERM TOOL

A useful approach to advance the ability to model impacts of climate change is the use of scenarios to bracket potential climate conditions; for example, scenarios that are based on extremes of recent ocean productivity. This illustrates trophic effects that could ripple through the food web (**Appendix MS2013-04**) and the extent to which decision makers can adapt to potential shifts (**Appendix MS2013 02-03**). We hope that the scenario approach can give way to coupling ecosystem models to downscaled atmosphere-ocean models.

The model by Gruber et al. (2012) projects coastal ocean acidification, and Hodgson et al. (**Appendix MS2013-05**) illustrate how this can be used to infer risk for species of interest. This fine-scale model differs from other global models operating on geometries as coarse as 1° latitude x 1° longitude (Dunne et al. 2012, 2013). However, the downscaled model of Gruber and colleagues is forced with a constant climate, i.e., there is no trend in atmospheric forcing except for CO2. One advantage of this model's relatively fine spatial resolution is that it can capture currents and upwelling within our region. This is particularly useful for understanding the spatial overlap of a threat (acidification) with nearshore fishery species, in this case state-managed Dungeness crab and pink shrimp fisheries that together are valued at more than $200 million annually.

In contrast to our climate change modeling, for which scenarios may be a stopgap approach, consideration of trends and future impacts of shipping may involve the scenario approach as a permanent, long term tool. Individuals with expertise in shipping (**Appendix MS2013-06**) emphasized that it is very difficult to make 5+ year forecasts of rapidly changing business practices and economic conditions for the transportation sector. We expect that future efforts to forecast complex human responses to economics will necessitate forward projections based on hypothetical scenarios, with retrospective analyses of recent data to identify trends (e.g. time series of pressures such as shipping volume reported in the IEA).

MANAGEMENT SCENARIOS AND TESTING CAN INFORM INDICATOR SELECTION AND RISK ASSESSMENT

The analyses here suggest that this IEA should include ongoing time series of certain key indicator species or biological groups. Ruzicka's (**Appendix MS2014-04**) analysis suggests that major changes in the Northern California continental shelf food web stem from altered abundances of forage fish and jellyfish. Analyses in the 2012 IEA (Levin, Wells, et al. 2013) also indicated that forage fish abundance strongly affects other components of the food web (Kaplan et al. 2013). Forage fish are sampled annually by several research groups, and time series are now included in the IEA. Jellyfish are more challenging to sample, and are not included in the 2012 IEA (Levin, Wells, et al. 2013), though the authors noted that "other indicators warrant more examination in the future, including the biomasses of jellyfish."

Our narratives and conversations suggest that the IEA should continue to include two distinct types of metrics related to shipping: both the number of ships, and the volume or amount of cargo. Respondents familiar with the container ship and tanker sectors noted large increases in ship size over the last decade, in an effort to maximize economies of scale and reduce cost per unit of cargo. Thus, we may expect diverging trends between indicators of vessel counts and cargo volume. Predicting impacts of shipping on different marine resources might require tracking different indicators of shipping activity. For instance, risk of mammal ship-strikes or likelihood of oil spills may depend on ship transits, while the potential scale of oil spills may depend on liquid cargo and fuel volumes.

Schematic diagrams portraying the IEA process (Levin et al. 2009) separate Risk Assessment from Management Testing and Scenarios, perhaps artificially. In previous California Current IEAs, Management Testing and Scenarios dealt primarily with forward projections or forecasts, while Risk Assessment focused more on spatial overlap between existing threats and particular habitats or species. Here we have begun to blend these two efforts. The risk of ocean acidification to Dungeness crab and pink shrimp (**Appendix MS2013-05**) and the risk of ship-strikes of marine mammals (**Appendix MS2013-07**) illustrate the value of combining ecological risk assessment (Hobday et al. 2011; Samhouri & Levin 2012) with scenario-based projections of climate, acidification, or shipping. A key contribution of Hodgson et al. (**Appendix MS2013-05**) is to demonstrate that impacts of ocean acidification needs to be considered in a spatial risk framework, based on maps of projected pH and species' habitat usage, and not simply from laboratory studies or meta-analyses.

EXPAND BEYOND FISHERIES TO MULTI-SECTOR MANAGEMENT AND CONSERVATION

While the focus of modeling analyses in 2012 was mainly on fishery management and impacts of fisheries, for the 2013 IEA we present analyses relevant to non-fishing drivers such as climate change and acidification. Even the single-species salmon models (**Appendices MS2013 02-03**) include detailed consideration and statistical relationships between climate or ocean conditions and ecological responses. We provide an introduction to issues related to shipping, a key non-fishing sector that may have a variety of impacts on, and risks to, the California Current. Fisheries landings and revenue are crucial metrics for the California Current, and we expect fisheries management actions to be included in Management Testing and Scenarios for future IEAs, but, we anticipate a broader, more comprehensive, approach going forward.

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