

VI. IMPLICATIONS FOR SPECIES, POPULATIONS, & COMMUNITIES

The growth and success of an individual species in a changing ocean depends on many environmental factors.⁹⁵¹ Moderate increases in temperature increase metabolic rates, which ultimately determine life history traits, population growth, and ecosystem processes.⁹⁵² For increases in global average temperature exceeding 2.7 to 4.5°F (1.5 to 2.5°C) and in concomitant atmospheric CO₂ concentrations, there are projected to be major changes in ecosystem structure and function, species' ecological interactions and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services, e.g. water and food supply.⁹⁵³ Based on a search of the scientific and grey literature, the following implications of climate change for species, populations, and communities in the NPLCC region have been identified:

1. Shifts in species range and distribution
2. Altered phenology and development
3. Shifts in community composition, competition, and survival
4. Altered interaction with non-native and invasive species

The following structure will be used to present information on the implications of climate change for the NPLCC region's species, populations, and communities.:

- **Observed Trends** – observed changes for the Gulf of Alaska Large Marine Ecosystem (LME) and the California Current Ecosystem (CCE). A few sections also include information on changes observed globally.
- **Future Projections** – projected direction and/or magnitude of change for the Gulf of Alaska LME and the CCE. A few sections also include information on global future projections.
- **Information Gaps** – information and research needs identified by reviewers and literature searches.

Chapter VII discusses implications for key fish, wildlife, plants, plankton, and shellfish in the NPLCC region.

⁹⁵¹ *Hauri et al. (2009, p. 66)

⁹⁵² *Hoegh-Guldberg and Bruno. (2010, p. 1525)

⁹⁵³ *IPCC. *Climate Change 2007: Synthesis Report*. (2007c, p. 48)

1. SHIFTS IN SPECIES RANGE AND DISTRIBUTION

Observed Trends

Global

The distribution of fish and planktonic species are predominantly determined by climatic variables, and there is recent evidence that marine species are moving poleward, and that timing of plankton blooms is shifting (Figure 20).⁹⁵⁴ Similar patterns have been observed in invertebrates and plant communities.⁹⁵⁵

Gulf of Alaska LME and California Current Ecosystem

Since 2003, jumbo squid have been frequently reported in beach strandings, commercial and recreational fisheries, and resource surveys along the West Coast and through southeast Alaska.⁹⁵⁶ During the 1997–98 El Niño event, jumbo squid were observed in substantial numbers off California, as well as in coastal waters off of Oregon and Washington states.⁹⁵⁷ In situ video observations taken from remotely operated vehicle (ROV) surveys from the Monterey Bay region show that jumbo squid continue to be present and sporadically abundant since the 1997–98 El Niño, particularly between 2003 and 2006.⁹⁵⁸

On the Quileute and Hoh reservations (WA), a study by Papiez (2009) reports that some potential range shifts have already been observed in avian and marine species:⁹⁵⁹

- The loggerhead turtle (*Caretta caretta*) was indicated as a new, unusual sighting by Quileute fishermen and other local people.⁹⁶⁰
- The leatherback turtle (*Dermochelys coriacea*) has been sighted during El Niño years, which is very rare and unusual according to local ecological knowledge (LEK) and traditional ecological knowledge (TEK) (see Box 17).⁹⁶¹

TEK indicates that these new species were not present during the time of their Quileute and Hoh ancestors.⁹⁶²

- According to many interviews with elders, LEK, tribal fishermen, and natural resource staff, the brown pelicans are a new arrival to the coast.⁹⁶³ The consensus arrival time was around the mid-

⁹⁵⁴ *Janetos et al. (2008, p. 164). The authors cite Hay et al. (2005) and Roessig et al. (2004) for information on climatic variables and distribution, and Beaugrand et al. (2002), Hays et al. (2005), and Richardson and Schoeman (2004) for information on poleward movements and the timing of plankton blooms.

⁹⁵⁵ *Janetos et al. (2008, p. 164). The authors cite Beaugrand et al. (2002) and Sagarin et al. (1999) for this information.

⁹⁵⁶ Field et al. (2007, p. 132). The authors cite Cosgrove (2005), Brodeur et al. (2006), and Wing (2006) for this information.

⁹⁵⁷ Field et al. (2007, p. 132). The authors cite Percy (2002) for this information.

⁹⁵⁸ Field et al. (2007, p. 132)

⁹⁵⁹ Papiez. *Climate Change Implications for the Quileute and Hoh Tribes (pdf)*. (2009, p. 13)

⁹⁶⁰ *Papiez. (2009, p. 15). The author cites Moon (2008), J. Schumack (2008), and Williams (2008) as the Quileute fishermen interviewed. The author cites Dickerson (2008) and G. Johnson (2008) as the local people interviewed.

⁹⁶¹ *Papiez. (2009, p. 15). The author cites G. Johnson (2008) as the LEK interviewee and Moon (2008) and Ratcliff (2008) as the TEK interviewees.

⁹⁶² *Papiez. (2009, p. 17)

⁹⁶³ *Papiez. (2009, p. 13). The author cites Jackson (2008), Matson (2008), Morganroth III (2008) as the elders interviewed. The author cites Dickerson (2008), B. Johnson (2008), G. Johnson (2008), and Payne (2008) as the

1980s.⁹⁶⁴ Now, the brown pelican has begun to stay longer on the coast.⁹⁶⁵ They are now arriving during the second or third week in June and departing the last week in October.⁹⁶⁶

The sunfish or common mola (*Mola mola*) were frequently referred to as a new arrival to the coast by Quileute and Hoh fishermen.⁹⁶⁷ Sunfish were first seen during strong El Niño years, but have now been present during the cooler La Niña cycle.⁹⁶⁸

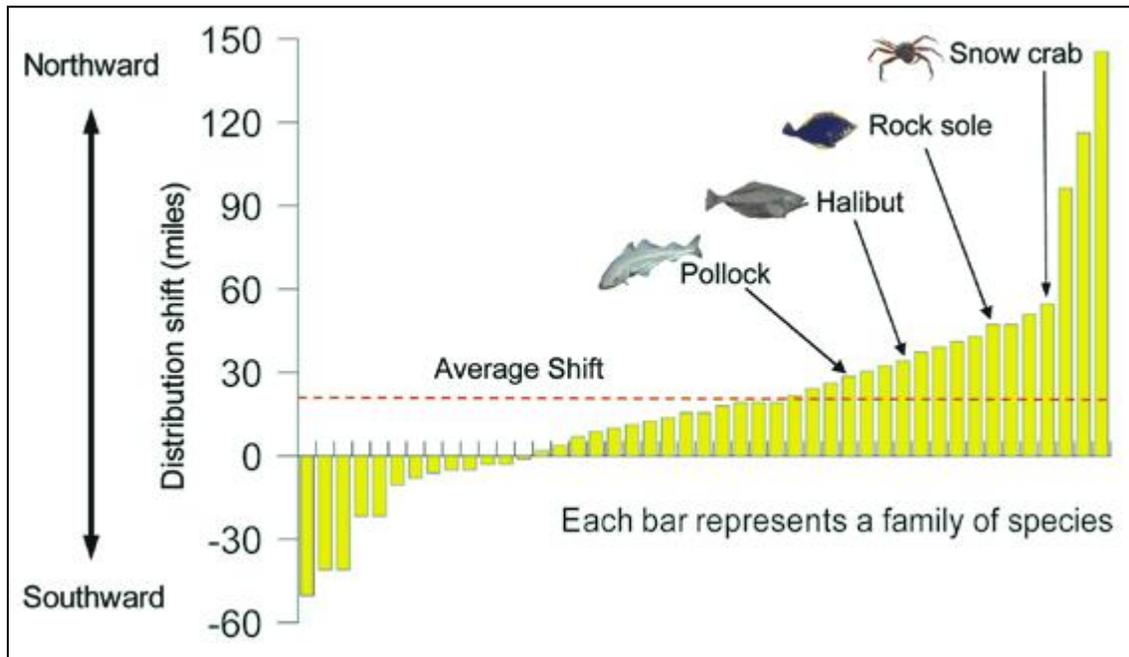


Figure 20. Marine Species Shifting Northward: As air and water temperatures rise, marine species are moving northward, affecting fisheries, ecosystems, and coastal communities that depend on the food source. On average, by 2006, the center of the range for the examined species moved nineteen miles north of their 1982 locations. *Source: Karl, Melillo, and Peterson. (2009, p. 144).*

LEK interviewees. The author cites Moon (2008), Ratcliff (2008), and J. Schumack (2008) as the tribal fishermen interviewed. The author cites Geyer (2008) and Northcut (2008) as the natural resource staff interviewed.

⁹⁶⁴ *Papiez. (2009, p. 13). The author cites interviews with Moon (2008), Morganroth III (2008), and Payne (2008) for this information.

⁹⁶⁵ *Papiez. (2009, p. 13)

⁹⁶⁶ *Papiez. (2009, p. 13). The author cites interviews with Geyer (2008), Moon (2008), Morganroth III (2008), and Penn Jr. (2008) for this information.

⁹⁶⁷ *Papiez. (2009, p. 16). The author cites Black III (2008), Moon (2008), Morganroth III (2008), Ratcliff (2008), Sampson (2008), and Williams (2008) as the Quileute and Hoh fishermen interviewed.

⁹⁶⁸ *Papiez. (2009, p. 16)

Box 17. Indigenous science, and traditional and local ecological knowledge.

Traditional knowledge (also known as indigenous science), as a way of knowing, is similar to Western science in that it is based on an accumulation of observations, but it is different from Western science in some fundamental ways. Interest in traditional ecological knowledge (TEK) has grown in recent years, partly due to a recognition that such knowledge can contribute to the conservation of biodiversity, rare species, protected areas, ecological processes, and to sustainable resource use in general. Cajete provides a working definition of indigenous science and TEK:

Indigenous science is that body of traditional environmental and cultural knowledge that is unique to a group of people and that has served to sustain those people through generations of living within a distinct bioregion. This is founded on a body of practical environmental knowledge learned and transformed through generations through a form of environmental and cultural education unique to them. Indigenous science may also be termed “traditional environmental knowledge” (TEK), since a large proportion of this knowledge served to sustain Indigenous communities and ensure their survival within the environmental contexts in which they were situated.

Local ecological knowledge (LEK), on the other hand, is knowledge based on a shorter timescale than TEK. Both Native and non-Native inhabitants of an area may hold LEK. Their residence and occupations may bring them into close proximity with the environment. Natural resources staff and land managers, particularly those who have studied the area for longer periods of time, often hold LEK.

Many of the prescriptions of traditional knowledge and practice are generally consistent with adaptive management as an integrated method for resource and ecosystem management. It is adaptive because it acknowledges that environmental conditions will always change, requiring societies to respond by adjusting and evolving. In fact, some scholars caution against overemphasizing the differences between Western science and traditional knowledge. However, others argue TEK and Western science cannot be integrated and cannot be bridged. For more information on climate change adaptation planning for natural systems, please see *Section VIII. Sources: Papież (2009); Berkes, Colding, and Folke (2000); Wall (2009).*

Future Projections

Global

Information needed.

Gulf of Alaska LME and California Current

Climate change may have a large impact on the distribution of maximum catch potential – a proxy for potential fisheries productivity – by 2055.⁹⁶⁹ Redistribution of catch potential is driven by projected shifts in species’ distribution ranges and by the change in total primary production within the species’ exploited range.⁹⁷⁰ Ocean warming and the retreat of sea ice⁹⁷⁰ in high-latitude regions opens up new habitat for lower

⁹⁶⁹ *Cheung et al. *Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change.* (2010, p. 31)

⁹⁷⁰ *Cheung et al. *Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change.* (2010, p. 31). The authors cite Sarmiento et al. (2004) and Cheung et al. (2008a) for this information.

latitude species and thus may result in a net increase in catch potential.⁹⁷¹ In subtropical and temperate regions, cold-water species are replaced by warm-water species, rendering the trend in catch potential changes in these regions generally weaker than in tropical, high-latitude and polar regions.⁹⁷²

Based on an empirical model published by Cheung et al. (2008), Cheung et al. (2010) project:

- Both increases and decreases in the ten-year average maximum catch potential in 2055, relative to 2005, in the NPLCC region (A1B scenario; Figure 21).⁹⁷³
- In general, decreases of five to thirty-one percent are projected for the coastal waters, with the exception of southeast Alaska, which ranges from small decreases (<6%) to >100% increases.⁹⁷⁴
- In offshore areas, increases of >100% are projected for the northern and southeastern Gulf of Alaska, while decreases of five to thirty-one percent interspersed with increases of up to thirty percent are projected farther south.⁹⁷⁵

In the CCE, generally warmer ocean conditions will cause a northward shift in the distribution of most species, and possibly the creation of reproductive populations in new regions.⁹⁷⁶ Existing faunal boundaries (i.e., zones of rapid changes in species composition, e.g. the waters between Cape Blanco, OR and Cape Mendocino, CA) are likely to remain as strong boundaries, but their resiliency to shifts in ocean conditions due to global climate change is not known.⁹⁷⁷

Information Gaps

Information is needed on observed changes in the Gulf of Alaska LME as well as in other areas of the California Current Ecosystem. More specific future projections are needed throughout the NPLCC region, e.g. for particular species and communities.

⁹⁷¹ *Cheung et al. (2010, p. 31)

⁹⁷² *Cheung et al. (2010, p. 31)

⁹⁷³ Cheung et al. (2010, Fig. 1, p. 28)

⁹⁷⁴ Cheung et al. (2010, Fig. 1, p. 28)

⁹⁷⁵ Cheung et al. (2010, Fig. 1, p. 28)

⁹⁷⁶ *Peterson, W. & Schwing, F. (2008, p. 55)

⁹⁷⁷ *Peterson, W. & Schwing, F. (2008, p. 55)

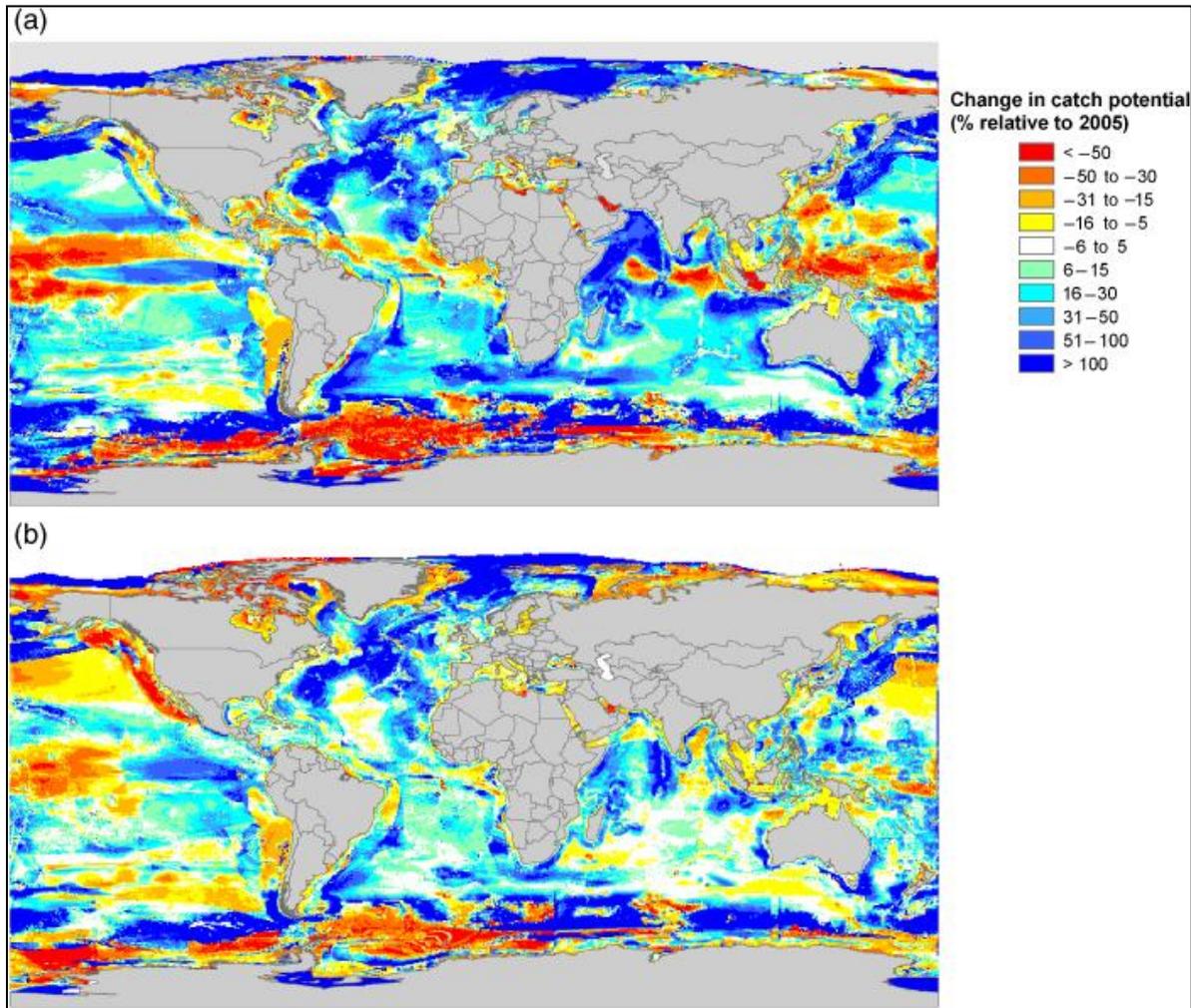


Figure 21. Change in maximum catch potential (10-year average) from 2005 to 2055 in each 30' x 30' cell under climate change scenarios: (a) Special Report on Emission Scenarios A1B and (b) stabilization at 2000 level.
Source: Cheung et al. (2010, Fig. 1, p. 28).

2. ALTERED PHENOLOGY AND DEVELOPMENT

Observed Trends

Global

In a meta-analysis of the effects of ocean acidification on marine organisms, Kroeker et al. (2010) conclude that ocean acidification had a significant negative effect on survival, calcification, growth and reproduction in marine organisms, but no significant effect on photosynthesis.⁹⁷⁸ Results for survival are found in the next section, results for calcification are found in Chapter VII Section 4 (Shellfish), and results for photosynthesis are found in Chapter 4 Section 2 (Altered ocean productivity). Results for growth and developmental stages are reported here:

- **Growth:** The effect of ocean acidification on growth varied between calcifying organisms and non-calcifying organisms as well as amongst taxonomic groups.⁹⁷⁹ Ocean acidification had a significant negative mean effect on the growth of calcifiers, but a significant effect on non-calcifiers was not detected.⁹⁸⁰ Within calcifiers, ocean acidification had a significant negative mean effect on calcifying algae and corals, and a non-significant negative mean effect on coccolithophores, molluscs and echinoderms.⁹⁸¹ There was a significant positive mean effect on fish and fleshy algae, and a non-significant positive effect on crustaceans.⁹⁸²
- **Developmental Stages:** No differences were detected amongst developmental stages in any of the response variables besides survival.⁹⁸³ However, significant differences were detected amongst developmental stages within specific taxonomic groups (molluscs, echinoderms and crustaceans).⁹⁸⁴ For molluscs, there was a larger negative effect for larvae than adults regarding survival.⁹⁸⁵ For echinoderms, there was a larger negative effect for juveniles than larvae in growth responses.⁹⁸⁶ For crustaceans, there was a larger negative effect for adults than juveniles in survival.⁹⁸⁷

Gulf of Alaska LME

Information needed.

⁹⁷⁸ *Kroeker et al. *Meta-analysis reveals negative yet variable effects on ocean acidification on marine organisms.* (2010, p. 1424). The authors refer the reader to Fig. 1 in the cited report.

⁹⁷⁹ *Kroeker et al. (2010, p. 1424). The authors refer the reader to Fig. 2 & 3 in the cited report and provide statistics for results for growth ($Q_M = 14.5$, d.f. = 1, $P = 0.004$) and taxonomic groups ($Q_M = 56.09$, d.f. = 7, $P < 0.001$).

⁹⁸⁰ *Kroeker et al. (2010, p. 1424-1425)

⁹⁸¹ *Kroeker et al. (2010, p. 1425)

⁹⁸² *Kroeker et al. (2010, p. 1425)

⁹⁸³ *Kroeker et al. (2010, p. 1425). The authors refer the reader to Fig. 4 in the cited report.

⁹⁸⁴ *Kroeker et al. (2010, p. 1425). The authors refer the reader to Fig. 6 in the cited report.

⁹⁸⁵ *Kroeker et al. (2010, p. 1425). The authors refer the reader to Fig. 6 in the cited report and provide statistics for this result: $Q_M = 2.92$, d.f. = 2, $P = 0.05$.

⁹⁸⁶ *Kroeker et al. (2010, p. 1425). The authors refer the reader to Fig. 6 in the cited report and provide statistics for this result: $Q_M = 8.03$, d.f. = 1, $P = 0.05$.

⁹⁸⁷ *Kroeker et al. (2010, p. 1425). The authors refer the reader to Fig. 6 in the cited report and provide statistics for this result: $Q_M = 0.36$, d.f. = 1, $P = 0.01$.

California Current Ecosystem

In the Pacific Northwest the summer of 2005 was characterized by a three-month delay to the start of the upwelling season resulting in a lack of significant plankton production until August (rather than the usual April-May time period).⁹⁸⁸ Delayed lower trophic level production was accompanied by:

- A failure of many rockfish species to recruit,
- Low survival of coho and Chinook salmon,
- Complete nesting failure by the sea bird, Cassin's Auklet,
- Widespread deaths of other seabirds such as common murre and sooty shearwaters,⁹⁸⁹ and
- Organisms such as whiting, sardines, shearwaters, and blue and humpback whales that migrate within the CC to take advantage of feeding opportunities associated with the seasonal cycle of production, encountered poor feeding conditions upon their arrival in spring 2005.⁹⁹⁰

Thus fish, birds and mammals that relied upon plankton production occurring at the normal time experienced massive recruitment failure.⁹⁹¹ Similar mismatches have occurred in recent years in which upwelling began early (as in 2006 and 2007) but was interrupted at a critical time (May-June).⁹⁹² The summer of 2006 had some of the strongest upwelling winds on record yet many species again experienced recruitment failure, in part because there was a one-month period of no winds (mid-May to mid-June) that occurred at the time when many bird and fish species are recruiting:⁹⁹³

- Marine organisms that had come to exploit expected production peaks found little food.⁹⁹⁴ The organisms which seem to be the most affected by delayed upwelling include juvenile salmon that were just entering the coastal ocean in April/May, whiting that were migrating northward, seabirds which are nesting at that time and all other animals that migrate to the northern California Current in summer to feed.⁹⁹⁵
- Both salmon and seabirds experienced increased mortality in 2006 and 2007, attributed to poor ocean conditions over a relatively short period in late spring.⁹⁹⁶

As summarized by Somero (2010), Kuo and Sanford (2009) recently reported that populations of the whelk *Nucella canaliculata* from intertidal sites along the Eastern Pacific coastline from central Oregon to central California differed significantly in upper lethal temperature.⁹⁹⁷ This patterning of thermal tolerance is a clear illustration of how heat stress varies across latitude as a consequence of interactions between temperature *per se* and the timing of the tidal cycle.⁹⁹⁸ The most heat-tolerant populations came

⁹⁸⁸ *Peterson, W. & Schwing, F. (2008, p. 45)

⁹⁸⁹ *Peterson, W. & Schwing, F. (2008, p. 54)

⁹⁹⁰ *Peterson, W. & Schwing, F. (2008, p. 54). The authors cite Sydeman et al. (2006), Mackas et al. (2006), Schwing et al. (2006), and Kosro et al. (2006) for information on these trends.

⁹⁹¹ *Peterson, W. & Schwing, F. (2008, p. 45)

⁹⁹² *Peterson, W. & Schwing, F. (2008, p. 45)

⁹⁹³ *Peterson, W. & Schwing, F. (2008, p. 45)

⁹⁹⁴ *Peterson, W. & Schwing, F. (2008, p. 54)

⁹⁹⁵ *Peterson, W. & Schwing, F. (2008, p. 54)

⁹⁹⁶ *Peterson, W. & Schwing, F. (2008, p. 54)

⁹⁹⁷ *Somero. *The physiology of climate change: how potentials for acclimatization and genetic adaptation will determine 'winners' and 'losers'*. (2010, p. 914). The authors refer the reader to Fig. 2 in the cited report.

⁹⁹⁸ *Somero. (2010, p. 914). The authors cite Helmuth et al. (2002), Helmuth et al. (2006), and Helmuth (2009) for this information.

from sites in central Oregon (Fogarty Creek, Strawberry Hill and Cape Arago) where midday low tides in summer expose the snails to more extreme heat stress than is encountered by populations in northern and central California sites, where summer low tides occur during cooler periods of the day.⁹⁹⁹

Future Projections

Global

Reduced developmental times may result in phenological (i.e. timing of biological events such as breeding) mismatches between developing larval organisms and the availability of suitable food, similar to phenological mismatches reported for terrestrial systems.¹⁰⁰⁰

Gulf of Alaska LME

The North Pacific Ocean is a sentinel region for the biological impacts of ocean acidification.¹⁰⁰¹ As described in Chapter III Section 1 (Ocean acidification) of this report, it will be one of the first regions affected by decreasing ocean pH because the depth below which the water is undersaturated in calcium carbonate (the “calcium carbonate saturation horizon”) is relatively shallow and the saturation horizon is projected to reach the surface during this century.¹⁰⁰² At that point, a wide range of North Pacific species will be exposed to seawater undersaturated with respect to calcium carbonate and may be unable, or have difficulty, forming the carbonate structures needed for their shells or other body components.¹⁰⁰³ For example, cold-water scleractinian corals build their skeletons from the more soluble form of calcium carbonate known as aragonite.¹⁰⁰⁴ As the world’s oceans become less saturated over time, corals are expected to build weaker skeletons (a process similar to osteoporosis in humans) and/or experience slower growth rates.¹⁰⁰⁵ A study by Guinotte et al. (2006) projects:

- Of 410 locations where deep ocean waters were saturated with aragonite in pre-industrial times, seventy percent are projected to be in undersaturated waters by 2099,¹⁰⁰⁶ as the aragonite saturation horizon (the depth boundary between waters saturated and undersaturated with aragonite) moves shallower over time.¹⁰⁰⁷
- Although the impacts of undersaturated waters are still being determined, the upward migration of the aragonite saturation horizon has the potential to alter the global distribution of deep-sea scleractinian corals and the organisms that depend on them.¹⁰⁰⁸

⁹⁹⁹ *Somero. (2010, p. 914)

¹⁰⁰⁰ *Hoegh-Guldberg and Bruno. (2010, p. 1525). The authors cite Durant et al. (2007) for information on developmental times and phenological mismatches between larval organisms and food availability. The authors cite Walther et al. (2002) for information on terrestrial systems.

¹⁰⁰¹ *Sigler, M.; Napp, J.; Hollowed, A. (2008, p. 71)

¹⁰⁰² *Sigler, M.; Napp, J.; Hollowed, A. (2008, p. 71-72). See, for example, Feely et al. (2004) and Orr et al. (2005).

¹⁰⁰³ *Sigler, M.; Napp, J.; Hollowed, A. (2008, p. 72)

¹⁰⁰⁴ *Guinotte et al. *Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals?* (2006, p. 142)

¹⁰⁰⁵ *Guinotte et al. (2006, p. 142-143)

¹⁰⁰⁶ *Guinotte et al. (2006, p. 141)

¹⁰⁰⁷ *Guinotte et al. (2006, p. 142)

¹⁰⁰⁸ *Guinotte et al. (2006, p. 146)

California Current Ecosystem

Animals (such as whiting, sardines, shearwaters, leatherback turtles, and blue whales) that migrate both to and within the CCE to take advantage of feeding opportunities associated with the seasonal cycle of production, and time their spawning, breeding or nesting with peaks in the seasonal cycles of production, may have to make adjustments in the timing of such activities.¹⁰⁰⁹

Information Gaps

Information on observed changes in the Gulf of Alaska LME is needed, as well as information on future projections for a wider range of species and communities. Additional information on the California Current Ecosystem is needed, as results from a single study are presented here. Additional information on observed changes and future projections in phenology and development are also needed, as results for from single studies are presented here.

¹⁰⁰⁹ *Peterson, W. & Schwing, F. (2008, p. 53)

3. SHIFTS IN COMMUNITY COMPOSITION, COMPETITION, & SURVIVAL

Observed Trends

Global

A meta-analysis of the effects of ocean acidification on marine organisms concluded a comparison could not be made between the effect of ocean acidification on survival between calcifiers and non-calcifiers because the experiments were dominated by those examining the responses of calcifiers.¹⁰¹⁰ Additionally, the researchers could not detect a difference amongst taxonomic groups.¹⁰¹¹ However, the effect of ocean acidification on survival varied amongst developmental stages.¹⁰¹² The effect size for larvae was the most negative, but this effect was not significant.¹⁰¹³

Ward and Lafferty (2004) conducted an analysis that revealed that disease for some groups of marine species is increasing while others are not.¹⁰¹⁴ Turtles, corals, mammals, urchins, and mollusks all showed increasing trends of disease, while none were detected for seagrasses, decapods, or sharks/rays.¹⁰¹⁵ The effects of increasing temperature on disease are complex, and can increase or decrease disease depending on the pathogen.¹⁰¹⁶

Gulf of Alaska LME

Two alternate stable states have been observed repeatedly in Pacific and Atlantic Subarctic/boreal continental shelf ecosystems; switches between “crustacean/small pelagic fish” communities and “groundfish” communities have been observed in the Gulf of Alaska and elsewhere:¹⁰¹⁷

- A study by Litzow (2006) investigating climate regime shifts and community reorganization in the Gulf of Alaska reports that following the 1976/1977 PDO regime shift (to a positive state), catch per unit effort data for representative taxa showed either rapid decline (capelin, pink shrimp) or rapid increase (arrowtooth flounder, Pacific cod, jellyfish).¹⁰¹⁸
- Survey catch composition strongly responded to local climate at lags of two and four years (using non-linear regression).¹⁰¹⁹
- Consistent with the view that the 1998/1999 climate regime shift did not represent a reversion to a negative PDO state, the analysis failed to detect the 1998/1999 regime shift in local climate, or in survey or commercial catches.¹⁰²⁰

¹⁰¹⁰ *Kroeker et al. (2010, p. 1424). The authors refer the reader to Fig. 2 in the cited report.

¹⁰¹¹ *Kroeker et al. (2010, p. 1424). The authors refer the reader to Fig. 3 in the cited report and provide statistics for this result: $Q_m = 7.81$, d.f. = 2, $P = 0.015$.

¹⁰¹² *Kroeker et al. (2010, p. 1424). The authors refer the reader to Fig. 4 in the cited report and provide statistics for this result: $\text{LnRR} = -1.24$, 95% bias-corrected confidence interval val = -3.4 to 0.01.

¹⁰¹³ *Kroeker et al. (2010, p. 1424)

¹⁰¹⁴ *Janetos et al. (2008, p. 168). Janetos et al. are summarizing the work of Ward and Lafferty (2004).

¹⁰¹⁵ *Janetos et al. (2008, p. 168)

¹⁰¹⁶ *Janetos et al. (2008, p. 168). The authors cite Ward and Lafferty (2004) for this information.

¹⁰¹⁷ *Litzow. *Climate regime shifts and community reorganization in the Gulf of Alaska: how do recent shifts compare with 1976/1977*. (2006, p. 1395). The author cites Anderson and Piatt (1999) for information on the Gulf of Alaska.

¹⁰¹⁸ *Litzow. (2006, p. 1390)

¹⁰¹⁹ *Litzow. (2006, p. 1386)

Switches between the two states are apparently modulated by the relative strength of demersal and pelagic secondary production, and the strength of top-down ecosystem control.¹⁰²¹

California Current Ecosystem

Between 1998 and 2002, after an intense 1997 El Niño and a prolonged La Niña (summer 1998-2002), species composition of pelagic nekton shifted from a community dominated by southern predatory species (mackerels and hake) to one dominated by northern species (smelts, squid and salmonids).¹⁰²²

Near Tatoosh Island (WA), Wootton, Pfister and Forester (2008) observed complex interactions between species under acidified ocean conditions.¹⁰²³ As described in Chapter III Section 1 (Ocean acidification), the model includes all variables that are currently suggested to have a large impact on ocean pH.¹⁰²⁴ Of these, only atmospheric CO₂ exhibits a consistent change that can explain the persistent decline in pH.¹⁰²⁵

The abundance and mean size of the dominant species in the system, the California mussel (*Mytilus californianus*), declined with declining pH, as did the blue mussel (*Mytilus trossulus*) and the goose barnacle (*Pollicipes polymerus*).¹⁰²⁶ In contrast, the abundance of acorn barnacles (*Balanus glandula*, *Semibalanus cariosus*) and fleshy algae (*Halosaccion glandiforme*, *ephemeral algae*, *filamentous red algae*, and *foliose red algae*) increased with declining pH.¹⁰²⁷ Prior evidence suggests the acorn barnacles, noncalcareous fleshy algae, and calcareous coralline algae (*Corallina vancouveriensis*) are strongly impacted by competition with the dominant calcareous sessile species, whose performance declined with lower pH, as well as by reduced predation and grazing by consumers with calcareous shells, which might also be impacted by lower pH.¹⁰²⁸

Along the central Oregon coast in a rocky intertidal area, Sanford (2002) studied rates of seastar density and predation on mussels and found they were reduced during cold-water upwelling events.¹⁰²⁹ The sensitivity of starfish predation to small changes in water temperature was surprising because it occurred in the middle of the seastar's thermal tolerance range.¹⁰³⁰ Seastars maintain diversity on the lower reef by feeding on the competitively dominant mussel, thereby preventing the dominant mussel from overgrowing and smothering less competitive sessile organisms.¹⁰³¹

¹⁰²⁰ *Litzow. (2006, p. 1386)

¹⁰²¹ *Litzow. (2006, p. 1395). The author cites Hunt et al. (2002) and Choi et al. (2004) for information on secondary production, and Worm and Myerst (2003) and Frank et al. (2005) for information on top-down ecosystem control.

¹⁰²² *ISAB. (2007, p. 69). The authors cite Emmett and Brodeur (2000) and Brodeur et al. (2005) for this information.

¹⁰²³ Wootton, Pfister and Forester. (2008)

¹⁰²⁴ *Wootton et al. (2008, p. 18851). The authors cite Solomon et al. (2007), Dore et al. (2003), Pelejero et al. (2005), and Feely et al. (2008) for this information.

¹⁰²⁵ *Wootton, Pfister and Forester. (2008, p. 18851)

¹⁰²⁶ Wootton, Pfister and Forester. (2008)

¹⁰²⁷ *Wootton, Pfister and Forester. (2008, p. 18849)

¹⁰²⁸ *Wootton, Pfister and Forester. (2008, p. 18851)

¹⁰²⁹ Sanford. *Community responses to climate change: links between temperature and keystone predation in a rocky intertidal system*. (2002)

¹⁰³⁰ *Sanford. (2002, p. 183)

¹⁰³¹ *Sanford. (2002, p. 175)

In Bodega Harbor (CA), the dominance of invasive species has approximately doubled over the last forty years, as sea temperatures have increased.¹⁰³² A study by Sorte, Williams and Zerebecki (2010) concluded that introduced species of sessile (permanently attached to a surface) invertebrates were more tolerant of higher temperatures than native species: three of four non-native species were likely to become more abundant as a critical temperature threshold was reached, while a native species declined in abundance, in part due to high mortality.¹⁰³³ The researchers suggest that the effects of climate change on communities can occur via both direct impacts on the diversity and abundance of native species and indirect effects due to increased dominance of introduced species.¹⁰³⁴

Climate change has been implicated in recent variation in the prevalence and severity of disease outbreaks within marine ecosystems.¹⁰³⁵ These influences are likely to be a consequence of several factors, including the expansion of pathogen ranges in response to warming, changes to host susceptibility as a result of increasing environmental stress, and the expansion of potential vectors.¹⁰³⁶ Two recent studies explore the links between climate and disease in the California Current Ecosystem:

- In a study by Rogers-Bennett et al. (2010), red abalone with Rickettsiales-like-prokaryote also exposed to warm water developed the disease Withering Syndrome and did not produce any mature gametes (reproductive cells, e.g. sperm and eggs).¹⁰³⁷ Normal sperm and egg production was found in red abalone testing positive for Rickettsiales-like-prokaryote in cool water.¹⁰³⁸
 - *Note: Rickettsiales-like-prokaryote, or RLP, is the agent of Withering Syndrome, which is a disease of the digestive tract that inhibits production of digestive enzymes, leading to muscle atrophy, starvation, and death in abalone. Vibrio tubiashii is a pathogen of larval bivalve mollusks, causing both toxigenic (i.e. producing a toxin or toxic effect) and invasive disease.*¹⁰³⁹
- During 2006 and 2007, Elston et al. (2008) report that losses of larval and juvenile bivalves were linked to *V. tubiashii* blooms in the coastal environment of western North America.¹⁰⁴⁰ Losses were associated with the apparent mixing of unusually warm surface seawater and intermittently upwelled cooler, nutrient- and *Vibrio* spp.- enriched seawater.¹⁰⁴¹

¹⁰³² *Sorte, Williams and Zerebecki. *Ocean warming increases threat of invasive species in a marine fouling community*. (2010, p. 2203)

¹⁰³³ *Sorte, Williams and Zerebecki. (2010, p. 2200-2201)

¹⁰³⁴ *Sorte, Williams and Zerebecki. (2010, p. 2198)

¹⁰³⁵ *Hoegh-Guldberg and Bruno. (2010, p. 1527). The authors cite Harvell et al. (2009) for this information.

¹⁰³⁶ *Hoegh-Guldberg and Bruno. (2010, p. 1527)

¹⁰³⁷ *Rogers-Bennett et al. *Response of red abalone production to warm water, starvation, and disease stressors: implications of ocean warming*. (2010, p. 599)

¹⁰³⁸ *Rogers-Bennett et al. (2010, p. 599)

¹⁰³⁹ *Hasegawa et al. *The extracellular metalloprotease of Vibrio tubiashii is a major virulence factor for Pacific oyster (Crassostrea gigas) larvae*. (2008, p. 4101)

¹⁰⁴⁰ *Elston et al. *Re-emergence of Vibrio tubiashii in bivalve shellfish aquaculture: severity, environmental drivers, geographic extent and management*. (2008, p. 119)

¹⁰⁴¹ *Elston et al. (2008, p. 119)

Future Projections

Global

One of the inevitable outcomes of differing tolerances for changes in the environment among marine organisms is the development of novel assemblages of organisms in the near future.¹⁰⁴² Such communities will have no past or contemporary counterparts and consequently are likely to present serious challenges to marine resource managers and policy makers.¹⁰⁴³

With regard to competition among species, the winners under low oxygen conditions seem to be smaller specimens that outcompete larger ones due to their advantageous body-mass-oxygen-consumption ratio.¹⁰⁴⁴ The decline of fish stocks due to an extending hypoxia could enhance pCO₂ in the upper water layers and thus make organisms more vulnerable to hypoxia, resulting in a self-sustaining negative loop.¹⁰⁴⁵

According to the IPCC AR4, there is *medium confidence* that approximately twenty to thirty percent of species assessed so far are *likely* to be at increased risk of extinction if increases in global average warming exceed 2.7 to 4.5°F (1.5 to 2.5°C; relative to 1980-1999).¹⁰⁴⁶ As global average temperature increase exceeds about 3.5°C, model projections suggest significant extinctions (40 to 70% of species assessed) around the globe.¹⁰⁴⁷

Results from Kroeker et al.'s (2010) meta-analysis suggest the effects of ocean acidification will be negative for most calcifying organisms, but that variation in life history characteristics will prove some organisms more resilient than others.¹⁰⁴⁸ For example, the echinoderm *Echinus esculentus* larvae had high mortality under ocean acidification, while the echinoderm *Strongylocentrotus droebachiensis* larvae showed increased developmental success.¹⁰⁴⁹

Gulf of Alaska LME

Transition back to a crustacean/small pelagic fish state is an unlikely result in the Gulf of Alaska, because dominant taxa in this state, such as capelin and pandalid shrimp, are associated with cold temperatures.¹⁰⁵⁰ A more likely possibility is a transition to a community containing more temperate/warm-water species.¹⁰⁵¹

With regard to species survival, in coastal basins and fjords whose basin waters are rejuvenated with periodic replacement from the ocean, declining oxygen levels in the subarctic Pacific could lead to serious hypoxia resulting in widespread mortality of benthic species.¹⁰⁵²

¹⁰⁴² *Hoegh-Guldberg and Bruno. (2010, p. 1526). The authors cite Williams and Jackson (2007) for information on past and contemporary counterparts in novel assemblages.

¹⁰⁴³ *Hoegh-Guldberg and Bruno. (2010, p. 1526-1527)

¹⁰⁴⁴ *Ekau et al. (2010, p. 1690). The authors cite Burlerson et al. (2001) for this information.

¹⁰⁴⁵ *Ekau et al. (2010, p. 1691)

¹⁰⁴⁶ *IPCC. *Climate Change 2007: Synthesis Report*. (2007c, p. 54)

¹⁰⁴⁷ *IPCC. *Climate Change 2007: Synthesis Report*. (2007c, p. 54)

¹⁰⁴⁸ *Kroeker et al. (2010, p. 1427)

¹⁰⁴⁹ *Kroeker et al. (2010, p. 1429-1430). The authors cite Dupont and Thorndyke (2009) for this information.

¹⁰⁵⁰ *Litzow. (2006, p. 1395). The author cites Rose (2005) and Wieland (2005) for this information.

¹⁰⁵¹ *Litzow. (2006, p. 1395)

¹⁰⁵² *Whitney, Freeland and Robert. (2007, p. 191)

California Current Ecosystem

Over time, the trends described for the marine community near Tatoosh Island (WA) may result in significant changes to the composition of the coastal environment: in the study, fleshy macroalgae and seagrasses became dominant.¹⁰⁵³ This result supports earlier predictions that calcifiers (particularly corals and crustose coralline algae) harmed by ocean acidification and environmental damage may give way to more aquatic vegetation and herbivores, creating future marine ecosystems that are significantly different from today's.¹⁰⁵⁴

Along the central Oregon coast in a rocky intertidal area, sustained increases in cold-water upwelling may allow the dominant mussel to move down the shore, which may dramatically decrease the diversity of species occupying low zone rock surfaces.¹⁰⁵⁵ Other impacts may mitigate (e.g. ocean acidification, harvesting) or exacerbate (e.g. reduced harvest) the effect.¹⁰⁵⁶

Information Gaps

Information is needed on observed changes and future projections for both the Gulf of Alaska LME and California Current Ecosystem, as results from one or two studies for each ecosystem are presented here. Kroeker et al. (2010) state their results do not support the hypothesis that more soluble forms of CaCO₃ will be more sensitive to ocean acidification, and the resilience of crustaceans and coralline algae requires further experimentation to understand the mechanisms for their responses.¹⁰⁵⁷

¹⁰⁵³ *Cooley, Kite-Powell and Doney. *Ocean acidification's potential to alter global marine ecosystem services*. (2009, p. 173).

¹⁰⁵⁴ *Cooley, Kite-Powell and Doney. (2009, p. 173). The authors cite Anthony et al. (2008) for information on harm to calcifiers and Hoegh-Guldberg et al. (2007) for information on the transition to aquatic vegetation and herbivores.

¹⁰⁵⁵ *Sanford. (2002, p. 189-190). The author cites Paine (1966, 1969, 1974) regarding decreases to the diversity of species occupying low zone rock surfaces.

¹⁰⁵⁶ Comment from reviewer, June 2011.

¹⁰⁵⁷ *Kroeker et al. (2010, p. 1429)

4. ALTERED INTERACTION WITH NON-NATIVE & INVASIVE SPECIES

Over the past several hundred years, the movement of ships and other transport vehicles around the globe has enabled the spread of a large number of marine species.¹⁰⁵⁸ Successful establishment, however, depends on conditions at the destination matching the tolerance range of invading organisms.¹⁰⁵⁹

Both invasive species and climate change are major ecosystems stressors.¹⁰⁶⁰ Climate change will have direct and second order impacts that facilitate the introduction, establishment, and/or spread of invasive species.¹⁰⁶¹ Climate change may enhance environmental conditions for some species in some locations with the following consequences:

- New species are now able to survive in new or existing locations,
- Known invasive species expand their range into new territories, and
- Species that currently are not considered invasive may become invasive and cause significant impacts.¹⁰⁶²

Climate change impacts, such as warming temperatures and changes in CO₂ concentrations, are likely to increase opportunities for invasive species because of their adaptability to disturbance and to a broader range of biogeographic conditions and environmental controls.¹⁰⁶³ Recent accelerated warming of high-latitude environments has increased the chances that species being transported from lower latitudes are able to establish themselves and spread.¹⁰⁶⁴ Warmer air and water temperatures may also facilitate movement of species along previously inaccessible pathways of spread, both natural and human-made.¹⁰⁶⁵

Further, a rising number of species are expanding

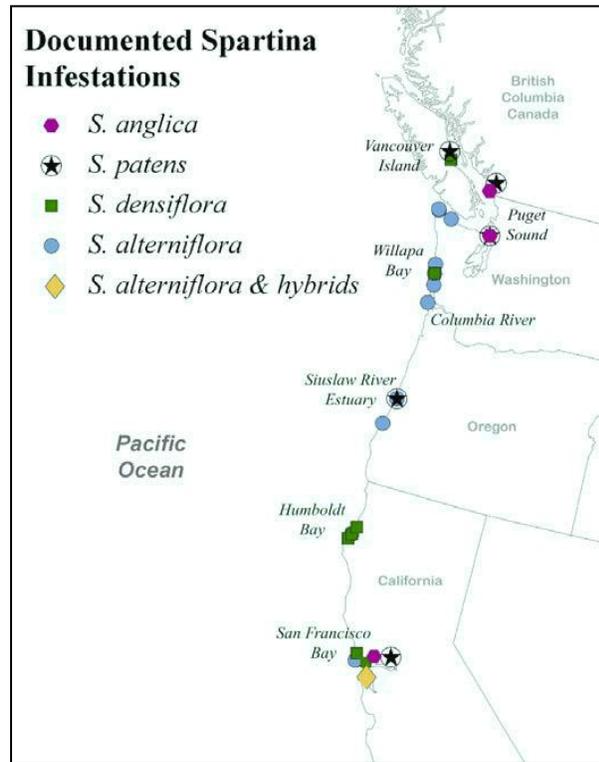


Figure 22. Distribution of non-native *Spartina* species on the Pacific Coast of North America. (courtesy of Portland State University, 2009).

Source: (Boe, et al. 2010, Fig. 1, p. 9)

¹⁰⁵⁸ *Hoegh-Guldberg and Bruno. (2010, p. 1527)

¹⁰⁵⁹ *Hoegh-Guldberg and Bruno. (2010, p. 1527)

¹⁰⁶⁰ *U. S. EPA. (2008b, p. 4-1)

¹⁰⁶¹ *Burgiel and Muir. *Invasive species, climate change and ecosystem-based adaptation: Addressing multiple drivers of global change.* (2010, p. 5)

¹⁰⁶² *U.S. EPA. *Effects of Climate Change on Aquatic Invasive Species and Implications for Management and Research [EPA/600/R-08/014].* (2008, p. 2-14)

¹⁰⁶³ *Burgiel and Muir. (2010, p. 4)

¹⁰⁶⁴ *Hoegh-Guldberg and Bruno. (2010, p. 1527). The authors cite Stachowicz et al. (2002) for this information.

¹⁰⁶⁵ *Burgiel and Muir. (2010, p. 4)

their ranges, often with large-scale impacts on ecosystems at the destination.¹⁰⁶⁶ The impacts of those invasive species may be more severe as they increase both in numbers and extent, and as they compete for diminishing resources such as water.¹⁰⁶⁷

Invasive species can compromise the ability of intact ecosystems to sequester carbon which helps offset greenhouse gas emissions.¹⁰⁶⁸ Thus, invasive species can increase the vulnerability of ecosystems to other climate-related stressors and also reduce their potential to sequester greenhouse gases.¹⁰⁶⁹

*Note: Given the multitude of invasive and non-native species in the NPLCC region and the need for a more in-depth discussion of which species are of most significant concern due to climate change, this chapter compiles information on the three species most often cited by interviewees and reviewers. They are: cordgrass (*Spartina* spp), Japanese eelgrass (*Zostera japonica*), and New Zealand mudsnail (*Potamopyrgus antipodarum*). The focus groups planned for 2011 and 2012 will guide which invasive and non-native species are described in the final report.*



Figure 23. Two blades of *Zostera japonica* (Japanese eelgrass) are pictured with one blade of *Z. marina* (common eelgrass). Source: Washington State University Extension. <http://www.beachwatchers.wsu.edu/ezydweb/seagrasses/Zosterajaponica3.htm> (accessed 4.13.2011).

Observed Trends

Global

Information needed. This section will most likely compile available global trends for the invasive and non-native species identified for the NPLCC region.

Gulf of Alaska LME

Information needed. The focus groups planned for 2011 and 2012 will guide which invasive and non-native species are described in the final report.

California Current Ecosystem

Commonly known as cordgrass, *Spartina* spp (*Spartina anglica*, *S. patens*, *S. densiflora*, *S. alterniflora*, hybrids) is a non-native estuarine grass that is widely considered a noxious weed (e.g., Figure 22).¹⁰⁷⁰ The

¹⁰⁶⁶ *Hoegh-Guldberg and Bruno. (2010, p. 1527)

¹⁰⁶⁷ *Burgiel and Muir. (2010, p. 4)

¹⁰⁶⁸ *Burgiel and Muir. (2010, p. 8)

¹⁰⁶⁹ *Burgiel and Muir. (2010, p. 5)

¹⁰⁷⁰ *Tulalip Tribes. *The Tulalip Spartina Control Project: 1998 Annual Report (website)*. (2002). *Spartina foliosa* is the only native *Spartina* species on the North American Pacific coast (see Boe et al. 2010. pp. 12 for this information)

impacts of *Spartina* species include: conversion of mudflats to monoculture stands, loss of habitat to waterbirds and fish, accretion of sediments, and modification of drainage patterns.¹⁰⁷¹ For example:

- Intertidal areas in Washington dominated by *Spartina* have exhibited large declines in the abundance of shorebirds and waterfowl.¹⁰⁷²

Native to Japan and the West Pacific, Japanese eelgrass (*Zostera japonica*, Figure 23) was first reported on the West Coast of the U.S. in 1957.¹⁰⁷³ The range of Japanese eelgrass in the Pacific Northwest extends from bays and inlets on Vancouver Island and Cortes Island (about 160 km north of Vancouver) in B.C. south through WA and OR.¹⁰⁷⁴ The species was also reported in Humboldt Bay, CA.¹⁰⁷⁵ In Washington there is debate about the non-native vs. invasive characterization for Japanese eelgrass; a 2007 report by WA Department of Natural Resources describes *Z. japonica* as non-native.¹⁰⁷⁶ Japanese eelgrass can invade areas that are naturally barren of plant growth and hence is a pioneering species, as is the native eelgrass (*Zostera marina*).¹⁰⁷⁷ By moving into barren areas, the invasive alters habitat structure, changing water flow and sediment deposition, making the sediments finer grained and richer in organics.¹⁰⁷⁸ Shafer et al. (2008) tested temperature effects on growth and production of *Z. japonica* in its North American range, and showed southern populations were

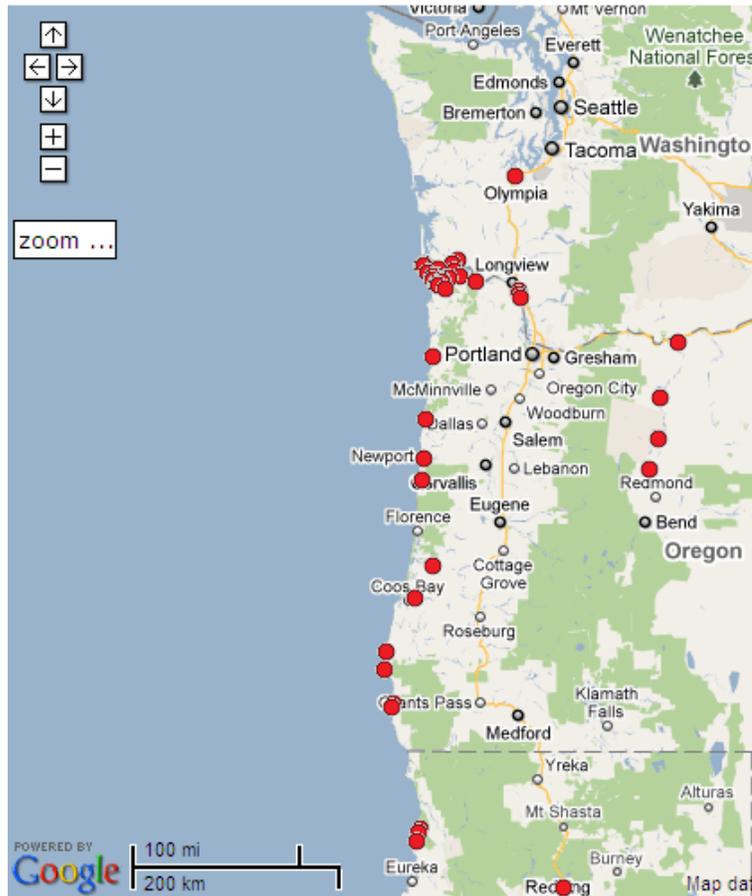


Figure 24. Compilation of confirmed New Zealand mudsnail sighting reports in the United States and Canada from 1987 through 2011, updated daily. For the NPLCC region, one sighting in a waterway in Port Alberni, Vancouver Island, British Columbia is not shown. Source: Benson, A. J. 2011. *New Zealand mudsnail sightings distribution*. Retrieved from newzealandmudsnaildistribution.aspx, 4.14.2011.

¹⁰⁷¹ *Ducks Unlimited Canada. *British Columbia Spartina Eradication Program: 2009 Progress Report (pdf)*. (2009, p. 5)

¹⁰⁷² *Ducks Unlimited Canada. (2009, p. 5)

¹⁰⁷³ *Tallis. *Invasive Species in the Pacific Northwest: Japanese Eelgrass*. (2006, p. 27)

¹⁰⁷⁴ *Tallis. (2006, p. 26)

¹⁰⁷⁵ *Tallis. (2006, p. 26)

¹⁰⁷⁶ Comments from reviewers, January and April 2011; WA DNR. *Eelgrass Stressor-Response Report: 2005-2007 Report*. (2007). See, for example, p. 19.

¹⁰⁷⁷ *Tallis. (2006, p. 26)

¹⁰⁷⁸ *Tallis. (2006, p. 26)

better adapted to high temperatures than northern populations.¹⁰⁷⁹

The New Zealand mud snail (*Potamopyrgus antipodarum*; Figure 24) is a common invasive species in fresh and brackish water ecosystems in Europe, Australia, Japan, and North America.¹⁰⁸⁰ In some invaded habitats, *P. antipodarum* can reach high densities (over 500,000 snails per m²) and dominate the biomass of the benthos, leading to detrimental impacts to native biota and changes in ecosystem dynamics.¹⁰⁸¹ *P. antipodarum* was found recently in thirteen fresh and brackish water systems adjacent to the Pacific coast of North America including a new northern range for *P. antipodarum*: Port Alberni, Vancouver Island, British Columbia, Canada (49.2479°, -124.8395°).¹⁰⁸²

Future Projections

Global

Information needed. This section will most likely compile available global projections for the invasive and non-native species identified for the NPLCC region.

Gulf of Alaska LME and California Current Ecosystem

As sea level rises and marshes and mudflats migrate inland, invasive *Spartina* will have an opportunity to colonize new areas.¹⁰⁸³ While invasive *Spartina* may protect marshes and mudflats from sea level rise, the value of these *Spartina* monocultures for other plants and wildlife would be very low.¹⁰⁸⁴ Unless invasive *Spartina* is eradicated before these large-scale disturbances to marshes take place, a rapid and large scale loss of native marsh may occur.¹⁰⁸⁵ Minimizing other stresses on indigenous marsh species, such as competition from invasive *Spartina*, is critical to increase their ability to cope with climate change.¹⁰⁸⁶

Japanese eelgrass's (*Z. japonica*) response to predicted climatic changes in Puget Sound (WA) and the outer coast of Washington is likely to be either a neutral change or an increase in biomass.¹⁰⁸⁷

Loo et al. (2007) project New Zealand mud snail (*P. antipodarum*) might be distributed in areas many kilometers north of Port Alberni due to its wide range of temperature and salinity tolerance.¹⁰⁸⁸

Information Gaps

Information is needed on the projected distribution of non-native and invasive marine species in the NPLCC region under a changing climate. As stated in the note above, focus groups planned for 2011 and 2012 will help guide which invasive and non-native species are addressed in the final report.

¹⁰⁷⁹ *Mach, Wyllie-Echeverria and Rhode Ward. *Distribution and potential effects of a non-native seagrass in Washington State: Zostera japonica workshop (pdf)*. (2010, p. 24)

¹⁰⁸⁰ *Davidson et al. *Northern range expansion and coastal occurrences of the New Zealand mud snail Potamopyrgus antipodarum (Gray, 1843) in the northeast Pacific*. (2008, p. 349)

¹⁰⁸¹ *Davidson et al. (2008, p. 349)

¹⁰⁸² *Davidson et al. (2008, p. 349)

¹⁰⁸³ *Boe et al. *West Coast Governor's Agreement on Ocean Health Spartina Eradication Action Coordination Team Work Plan (pdf)*. (2010, p. 14)

¹⁰⁸⁴ *Boe et al. (2010, p. 14)

¹⁰⁸⁵ *Boe et al. (2010, p. 14)

¹⁰⁸⁶ *Boe et al. (2010, p. 14)

¹⁰⁸⁷ *Mach, Wyllie-Echeverria and Rhode Ward. (2010, p. 24)

¹⁰⁸⁸ *Davidson et al. (2008, p. 351)