Climate Change Effects and Adaptation Approaches in Marine and Coastal Ecosystems of the North Pacific Landscape Conservation Cooperative Region

A Compilation of Scientific Literature

Phase 1 Draft Final Report

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EXECUTIVE SUMMARY

This Phase I draft final report provides a first-ever compilation of what is known—and not known—about climate change effects on marine and coastal ecosystems in the geographic extent of the North Pacific Landscape Conservation Cooperative (NPLCC). The U.S. Fish & Wildlife Service funded this report to help inform members of the newly established NPLCC as they assess priorities and begin operations. Production of this report was guided by University of Washington's Climate Impacts Group and information was drawn from more than 250 documents and more than 100 interviews. A final report will be published in 2012 following convening of expert focus groups under Phase II of this project.

Information in this report focuses on the NPLCC region, which extends from Kenai Peninsula in southcentral Alaska to Bodega Bay in northern California west of the Cascade Mountain Range and Coast Mountains. The region contains approximately 38,200 miles (~ 61,500 km)[1] of coastline and is home to iconic salmon and orca, a thriving fish and shellfish industry, and a wide range of habitats essential for the survival of fish, wildlife, birds, and other organisms. Many of these species, habitats, and ecosystems are already experiencing the effects of a changing climate.

Carbon dioxide, temperature, and precipitation

The atmospheric concentration of carbon dioxide (CO_2) is increasing in the earth's atmosphere, leading to increases in temperature, altered precipitation patterns, and consequent effects for biophysical processes, ecosystems, and species.

- **Atmospheric CO_2 concentrations have increased** to ~392 parts per million (ppm)[2] from the pre-industrial value of 278 ppm,[3] higher than any level in the past 650,000 years.[4] By 2100, CO_2 concentrations are projected to exceed ~600 ppm and may exceed 1000 ppm.[5] As CO_2 levels increase, a concomitant decline in ocean pH is projected for the NPLCC region,[6] hampering calcification processes for many calcifying organisms such as pteropods,[7] corals, and mollusks.[8]
- **Annual average temperatures increased** ~1-2°F (~0.6-1°C) from coastal British Columbia to northwestern California over the 20th century[9] and 3.4°F (~1.9°C) in Alaska from 1949 to 2009.[10] By 2100, the range of projected increases in the NPLCC region varies from 2.7 to 13°F (1.5-7.2°C), with the largest increases projected in Alaska.[11] These temperature increases will drive a rise in sea surface temperature and contribute to declining oxygen solubility in seawater,[12] species range shifts,[13] and potential uncoupling of phenological interdependencies among species.[14]
- **Seasonal precipitation varies but is generally wetter in winter.** Cool season precipitation (Oct-March) increased 2.17 inches (5.51 cm) in Alaska from the 1971-2000 to 1981-2010 period.[15] In Washington and Oregon winter precipitation (Jan-March) increased 2.47 inches (6.27 cm) from 1920 to 2000.[16] In California, winter precipitation increased between 1925 and 2008,[17] while in British Columbia, both increases and decreases in winter precipitation were observed, depending on the time period studied.[18] Over the 21st Century, winter and fall precipitation is projected to increase 6-11% in BC and 8% in Washington and Oregon, while summer precipitation is projected to decrease (-8 to -13% in BC and -14% in WA and OR).[19] In southeast Alaska, however, warm season precipitation is projected to increase 5.7%.[20] Projected increases in winter rainfall, declining snow accumulation[21] and glacial extent,[22] and decreased summer precipitation (where occurring) will shift the frequency, volume,[23] and timing[24] of freshwater inflow to marine

systems. Coastal areas with enhanced riverine input such as the Columbia River estuary will see greater stratification associated with increases in precipitation,[25] a condition that exacerbates low-oxygen conditions associated with harmful algal blooms and hypoxic waters.[26]

Impacts of climate change on marine and coastal systems

Increases in CO_2 and air temperature, combined with changing precipitation patterns, are already altering conditions and processes in marine and coastal ecosystems. These trends are projected to continue.

- **The oceans are increasing in acidity.** Increasing atmospheric CO_2 concentrations have caused global ocean pH to decline from 8.2 to 8.1 since pre-industrial times, increasing the ocean's acidity by approximately 26%.[27] pH declines in the NPLCC region are generally consistent with those observed globally, although some coastal areas such as Hood Canal (WA) report significantly lower pH (less than 7.6 in 2008).[28] By the end of this century, global surface water pH is projected to drop to approximately 7.8, increasing the ocean's acidity by about 150% relative to the beginning of the industrial era.[29] If atmospheric CO_2 levels reach 550 ppm, pH in the NPLCC region is projected to decline approximately 0.14 units[30]and the saturation state of aragonite will approach the critical threshold for undersaturation ($\Omega < 1$), below which the shells of some marine organisms may begin to dissolve or have difficulty forming.[31] Ocean water detrimental to shell-making has already been observed in shallow waters from Queen Charlotte Sound (BC) south to Baja California.[32] Aragonite-shelled pteropods, which are prey for salmon[33] and other fish,[34] appear particularly vulnerable to continued ocean acidification.[35]

- **Sea surface temperatures are rising.** Global mean sea surface temperature (SST) increased approximately 1.1°F (0.6°C) since 1950.[36] By 2050, an increase in winter SST of 1.8 to 2.9°F (1.0-1.6°C) is projected for most of the northern Pacific Ocean (compared to 1980-1999).[37] Warmer SST contributes to sea level rise, increased storm intensity, and greater stratification of the water column.[38] Increased SST is also associated with species range shifts,[39] altered nutrient availability and primary production,[40] and changes in algal, plankton and fish abundance in high-latitude oceans.[41]

- **Storm intensity and extreme wave heights are projected to increase.** Off the Oregon and Washington coasts, the heights of extreme storm waves increased as much as eight feet since the mid-1980s and deliver 65% more force when they come ashore.[42] During the 21st century, extra-tropical storms are likely to become more intense in the NPLCC region.[43] This will combine with higher sea levels to increase storm surges, the height of extreme waves[44] and the frequency of extreme events. [45] Increased extreme wave heights and more intense storms are projected to increase beach and bluff erosion[46] and lead to shoreline retreat,[47] loss of coastal habitat,[48] and damage to coastal infrastructure.[49]

- **Sea levels are rising, but the relative effect varies by location.** Since the end of the 19th century global sea levels have risen approximately 6.7 inches (17 cm).[50] In the NPLCC region, however, relative sea level change from 1898 to 2007 ranges from -0.67 to +0.23 inches/yr (-1.7 to 0.575 mm/yr).[51] Relative sea level rise in the NPLCC region is less than the global average at most monitoring stations because of localized increases in land elevation as a result of glacier recession, plate tectonics, and/or sediment accretion.[52] By the end of the 21st century, global sea level is projected to increase 5.1 to 70.0 inches (13-179 cm) compared to the end of the 20th century.[53] In the NPLCC region by 2100, relative change in sea levels are projected to range from -25.2 inches (-64 cm) to +55 inches (+139.7 cm).[54] Sea level is projected to rise in British Columbia and parts of Washington, Oregon, and California,[55] while sea level is projected to decline or remain relatively stable in southcentral and southeast Alaska and the northwest Olympic Peninsula (WA).[56] Rising sea level often results in loss of nearshore or coastal habitat[57] and harm to dependent species.[58]

- **Recent anomalous hypoxic events in the California Current Ecosystem may be characteristic of future change.** Severe hypoxia, corresponding to dissolved oxygen (DO) levels ranging from 0.21 to 1.57 mL/L, was observed off the central Oregon coast in 2002.[59] Dungeness crab surveys showed mortality rates of up to 75% in some regions during this period.[60] In 2006 off the Washington coast, the lowest DO concentrations to-date (<0.5 mL/L) were recorded at the inner shelf.[61] During an anoxic event in 2006 off the Oregon coast, surveys revealed the complete absence of all fish from rocky reefs[62] and near-complete mortality of macroscopic benthic invertebrates.[63] While anomalous events such as these are consistent with potential climate-induced changes in coastal systems, it has not been shown that climate change is the cause of the anomalies.[64]

Implications of climate change for ecosystems, habitats, and species

Climate change effects, independently or in combination, are fundamentally altering ocean ecosystems.[65] Effects on habitats (habitat loss and transition) and species (invasive species interactions, range shifts and phenological decoupling) are highlighted here.

Coastal Erosion and Habitat Loss

Rising sea-level and increases in storms and erosion are projected to result in significant habitat impacts. In Alaska, low-lying habitats critical to the productivity and welfare of coastal dependent species could be lost or degraded,[66] including staging areas that support millions of shorebirds, geese, and ducks.[67] As sea level rises along Puget Sound's armored beach shorelines, most surf smelt spawning habitat is likely to be lost by 2100.[68] In Skagit Delta marshes (WA), the rearing capacity for threatened juvenile Chinook salmon is projected to decline by 211,000 fish with 18 inches (45 cm) of sea level rise.[69]

Habitat loss due to sea level rise is likely to vary substantially depending on geomorphology and other factors. In Washington and Oregon, analysis of coastal habitats under 27.3 inches (0.69 m) of sea level rise projects loss of two-thirds of low tidal areas in Willapa Bay and Grays Harbor and a loss of 11 to 56% of freshwater tidal marsh in Grays Harbor, Puget Sound, and Willapa Bay.[70] Much of these habitats are replaced by transitional marsh.[71] However, the Lower Columbia River may be fairly resilient to sea level rise because losses to low tidal, saltmarsh, and freshwater tidal habitats are minimized (-2%, -19%, -11%, respectively), while gains in transitional areas are substantial (+160%).[72]

Invasive Species, Range Shifts, and Altered Phenology

Climate change will affect species in varying ways. Ocean acidification significantly and negatively impacts survival, calcification, growth and reproduction in many marine organisms, but thus far, has no significant effect on photosynthesis.[73] Among calcifying organisms, corals, calcifying algae, coccolithophores, and mollusks are negatively affected, while crustaceans and echinoderms are positively affected.[74] Warmer waters are likely to promote increased populations of Pacific salmon in Alaska while promoting decreased populations elsewhere in the NPLCC region.[75] If oxygen levels decline[76] and coastal upwelling strengthens as some studies project,[77] oxygenated habitat will be lost.[78] A few species, such as sablefish and some rock fishes, tolerate low-oxygen conditions and may expand their territory.[79] However, most species will be forced to find shallower habitat or perish.[80] Overall, smaller specimens seem to be the winners under low-oxygen conditions, as they outcompete larger organisms due to their advantageous body-mass to oxygen-consumption ratio.[81]

Many sea and shorebirds have medium or high vulnerability to climate change.[82] These include the Aleutian Tern, Kittlitz's Murrelet,[83] beach-nesting black oystercatchers,[84] and the Cassin's auklet.[85] For coastal birds, loss of habitat and food sources are the largest climate change-related concerns.[86] Reproductive failure among seabirds has been documented as a result of changes in marine productivity, often observed during El Niño years when sea surface temperatures are warmer than average.[87] Population recovery is less likely if climate change results in catastrophic events that are more frequent, more intense, or of longer duration.[88]

Climate change may enhance environmental conditions such that some species are able to survive in new locations, known invasive species expand into new territories, and species that currently are not considered invasive could become invasive, causing significant impacts.[89] Invasive and non-native species that appear to benefit from climate change include Spartina, Japanese eelgrass, and New Zealand mud snail.[90]

In response to warming temperatures and changing currents, many marine species are expanding their ranges toward the poles.[91] The abundance and distribution of jumbo squid in the NPLCC region increased between 2002 and 2006, with sightings as far north as southeast Alaska.[92] Loggerhead turtle, brown pelican, and sunfish are reported recent arrivals to the northern Washington coast.[93]

Climate change may also lead to significant phenological decoupling, such as occurred in the Pacific Northwest in 2005 when the upwelling season occurred three months later than usual, resulting in a lack of significant plankton production until August (rather than the usual April-May time period).[94] The delay was accompanied by recruitment failure among plankton-reliant rockfish species, low survival of coho and Chinook salmon, complete nesting failure by Cassin's Auklet, and widespread deaths of other seabirds (common murres, sooty shearwaters).[95] Similar mismatches also occurred in 2006 and 2007 when upwelling began early but was interrupted at a critical time (May-June).[96]

As a result of these effects, novel assemblages of organisms will inevitably develop in the near future due to differing tolerances for changes in environmental conditions.[97] These novel communities will have no past or present counterparts and are likely to present serious challenges to marine resource managers.[98]

Adaptation to climate change for marine and coastal systems

Given that CO_2 concentrations will continue to increase and exacerbate climate change effects for the foreseeable future,[99] adaptation is emerging as an appropriate response to the unavoidable impacts of climate change.[100] Adaptive actions reduce a system's vulnerability,[101] increase its capacity to withstand or be resilient to change,[102] and/or transform systems to a new state compatible with likely future conditions.[103] Adaptation actions typically reflect three commonly cited tenets: (1) remove other threats and reduce non-climate stressors that exacerbate climate change effects;[104] (2) establish, increase, or adjust protected areas, habitat buffers, and corridors;[105] and, (3) increase monitoring and facilitate management under uncertainty, including scenario-based planning and adaptive management.[106]

Adaptation actions may occur in legal, regulatory, or decision-making processes, as well as in on-the-ground conservation activities.[107] For example, to counteract loss of coastal habitat due to erosion and sea level rise, options include removing shoreline hardening structures,[108] enhancing sediment transport,[109] establishing ecological buffer zones,[110] and acquiring rolling easements.[111] To manage invasive species, whose spread is exacerbated by increased sea surface temperatures and other climate-related effects, options include restoring native species, physically removing invasive species, and strengthening regulatory protections against invasive species introduction.[112] Decision-makers may also create or modify laws, regulations, and policies governing coastal management to promote living shorelines that protect coastal property and habitat,[113] incorporate climate projections into land use planning to safeguard coastal habitats,[114] and implement coastal development setbacks to address rising sea levels and increased storm intensity, maintain natural shore dynamics, and minimize damage from erosion.[115]

Although uncertainty and gaps in knowledge exist, sufficient scientific information is available to plan for and address climate change impacts now.[116] Implementing strategic adaptation actions early may reduce severe impacts and prevent the need for more costly actions in the future.[117] To identify and implement adaptation actions, practitioners highlight four broad steps:

1. Assess current and future climate change effects and conduct a vulnerability assessment.[118]
2. Select conservation targets and a course of action that reduce the vulnerabilities and/or climate change effects identified in Step 1.[119]
3. Measure, evaluate, and communicate progress through the design and implementation of monitoring programs.[120]
4. Create an iterative process to reevaluate and revise the plan, policy, or program, including assumptions. [121]

Adaptive approaches to addressing climate change impacts will vary by sector and management goal, across space and time, and by the goals and preferences of those engaged in the process.[122] In all cases, adaptation is not a one-time activity, but is instead a continuous process, constantly evolving as new information is acquired and interim goals are achieved or reassessed.[123] Ultimately, successful climate change adaptation supports a system's capacity to maintain its past or current state in light of climate impacts or transform to a new state amenable to likely future conditions.[124]

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[1] USFWS. (2010)
[2] NOAA. (2011c)
[3] Forster et al. (2007, p. 141)
[4] CIG. (2008).
[5] Meehl et al. (2007, p. 803)
[6] Feely et al. (2009, Table 2, p. 46). By 2100, the projected declines are associated with a doubling (~550 ppm) or tripling (~830 ppm) of atmospheric CO_2 compared to ~1750: -0.14 to -0.15 or -0.30 to -0.31, respectively.
[7] Hauri et al. (2009, p. 67-68)
[8] Kroeker et al. (2010, p. 1424, 1427)
[9] Mote (2003, p. 276); Butz and Safford (Butz and Safford 2010, 1)
[10] U.S. Global Change Research Program (2009, p. 139)
[11] For AK, Karl, Melillo and Peterson. (2009, p. 139). For WA and OR, CIG. (2008, Table 3) and Mote et al. (2010, p. 21). For CA, California Natural Resources Agency. (2009, p. 16-17) and PRBO. (2011, p. 8).
[12] California Natural Resources Agency (2009, p. 66); Levin et al. (2009, p. 3568); Najjar et al. (2000, p. 226)
[13] Cheung et al. (2010, p. 31); IPCC. (2007e, p. 8); Karl, Melillo, and Peterson. (2009, p. 144)
[14] NABCI. (2010, p. 7)

[15] This information was obtained from and approved by Tom Ainsworth and Rick Fritsch (Meteorologists, NOAA/National Weather Service, Juneau) on June 10, 2011. Data for 1971-2000 are official data from the National Climatic Data Center (NCDC). Data for 1981-2010 are preliminary, unofficial data acquired from Tom Ainsworth and Rick Fritsch (Meteorologists, NOAA/National Weather Service, Juneau) on May 12, 2011. The NCDC defines a climate normal, in the strictest sense, as the 30-year average of a particular variable (e.g., temperature).
[16] Mote (2003, p. 279)
[17] Killam et al. (2010, p. 4)
[18] Pike et al. (2010, Table 19.1, p. 701)
[19] For BC, BC Ministry of Environment. (2006, Table 10, p. 113); For OR and WA, Mote and Salathé, Jr. (2010, p. 42-44); Seasonal precipitation projections for California were not available.
[20] Alaska Center for Climate Assessment and Policy. (2009, p. 31).
[21] Elsner et al. (2010, Table 5, p. 244); Pike et al. (2010, p. 715); PRBO. (2011, p. 8)
[22] AK Department of Environmental Conservation (DEC). (2010, p. 2-3); Chang and Jones. (2010, p. 84); Howat et al. (2007, p. 96); Pike et al. (2010, p. 716)
[23] AK DEC. (2010, p. 2-3, 5-2); Chang and Jones. (2010, p. 94); Mantua, Tohver and Hamlet. (2010, p. 204-205); Pike et al. (2010, p. 719); Stewart. (2009, p. 89); Tohver and Hamlet. (2010, p. 8)
[24] Chang and Jones. (2010, p. 192); Pike et al. (2010, p. 719); Stewart. (2009, p. 89)
[25] Peterson, W. & Schwing, F. (2008, p. 56)
[26] Levin et al. (2009, p. 3567)
[27] Orr et al. (2005); Feely, Doney and Cooley. (2009)
[28] Feely et al. (2010, Table 1, p. 446).
[29] Feely et al. (2009, p. 37)
[30] Feely et al. (2009, Table 2, p. 46). The projected decline is associated with a doubling of atmospheric CO_2 compared to ~1750, to ~550 ppm by 2100. With a tripling of atmospheric CO_2 (~830 ppm by 2100 compared to ~1750), pH is projected to decline -0.30 to -0.31 in North Pacific Ocean waters.
[31] Feely et al. (2009, p. 39); Hauri et al. (2009, p. 67-68)
[32] Feely, Sabine, et al. (2008, p. 1491)
[33] Sigler et al.(2008, p. 7)
[34] Sigler et al.(2008, p. 12)
[35] Hauri et al. (2009, p. 67-68); Sigler et al.(2008, p. 12)
[36] Nicholls et al. (2007, p. 320)
[37] Overland and Wang. (2007, Fig. 2b, p. 7)
[38] Hoegh-Guldberg and Bruno. (2010, p. 1524)
[39] IPCC. (2007e, p. 8)
[40] Hoegh-Guldberg and Bruno. (2010, p. 1524)
[41] IPCC. (2007e, p. 8)
[42] OCMP. (2009, p. 66)
[43] Field et al. (2007, p. 627)
[44] Field et al. (2007, p. 627)
[45] Hoffman. (2003, p. 135)
[46] Bauman et al. (2006); OCMP. (2009)
[47] OCMP. (2009, p. 17)
[48] AK State Legislature. (2008); Brown and McLachlan. (2002, p. 62); Littell et al. (2009); Nicholls et al. (2007, p. 325-326).
[49] OCMP. (2009)
[50] IPCC. (2007f, p. 7)
[51] NOAA. (2007)
[52] B.C. Ministry of Environment. (2007, p. 26); Bornhold. (2008, p. 6); Mote et al. (2008)
[53] Grinsted, Moore and Jevrejeva. (2009, Table 2, p. 467); IPCC. (2007c, Table 3.1, p. 45); Meehl et al. (2005, p. 1770-1771); Rahmstorf. (2007, p. 369); Vermeer and Rahmstorf. (2009, Table 1, p. 21530-21531).
[54] AK DEC. (2010, p. 2-4); Bornhold (2008, Table 1, p. 8); CA Natural Resources Agency. (2009, p. 18); Mote et al. (2008); Ruggiero et al. (2010, p. 218)

[55] Bornhold (2008, Table 1, p. 8); CA Natural Resources Agency. (2009, p. 18); Mote et al. (2008); Ruggiero et al. (2010, p. 218)
[56] AK DEC. (2010, p. 2-4); Mote et al. (2008)
[57] AK State Legislature. (2008, p. 91); Glick, Clough and Nunley. (2007); Philip Williams and Associates, Ltd. (2009)
[58] AK State Legislature. (2008, p. 91); Krueger et al. (2010, p.176)
[59] Grantham et al. (2004, p. 750)
[60] Grantham et al. (2004, p. 750)
[61] Connolly et al. (2010, p. 1, 8)
[62] Chan et al. (2008, p. 920)
[63] Chan et al. (2008, p. 920)
[64] PISCO. (2009)
[65] Hoegh-Guldberg and Bruno. (2010, p. 1523)
[66] AK State Legislature. (2008, p. 91). Report by the Alaska State Legislature, available online at http://www.housemajority.org/coms/cli/cli_final report_20080301.pdf (last accessed 12.14.2010).
[67] AK State Legislature. (2008, p. 91)
[68] Krueger et al. (2010, p.176)
[69] Martin and Glick. (2008, p. 15). The authors cite Hood, W.G. (2005) for this information.
[70] DU. (2010a); DU. (2010c); DU. (2010d)
[71] DU. (2010a); DU. (2010c); DU. (2010d)
[72] DU. (2010b)
[73] Kroeker et al. (2010, p. 1424)
[74] Kroeker et al. (2010, p. 1424)
[75] ISAB. (2007, p. 64)
[76] Whitney, Freeland and Robert. (2007)
[77] Snyder et al. (2003, p. 8-4); Wang, Overland and Bond. (2010, p. 265)
[78] Whitney, Freeland and Robert. (2007, p. 197)
[79] Whitney, Freeland and Robert. (2007, p. 197)
[80] Whitney, Freeland and Robert. (2007, p. 197)
[81] Ekau et al. (2010, p. 1690)
[82] NABCI. (2010, p. 8)
[83] NABCI. (2010, p. 8)
[84] NABCI. (2010, p. 8)
[85] Wolf et al. (2010, p. 1930)
[86] NABCI. (2010, p. 8)
[87] NABCI. (2010, p. 6)
[88] NABCI. (2010, p. 6-7)
[89] U.S. EPA. (2008, p. 2-14)
[90] Boe et al. (2010); Davidson et al. (2008); Mach, Wyllie-Echeverria and Rhode Ward. (2010)
[91] Field et al. (2007, p. 142). The authors cite Perry et al. (2005) for this information.
[92] Field et al. (2007)
[93] Papiez. (2009, p. 17) (2009)
[94] Peterson, W. & Schwing, F. (2008, p. 45)
[95] Peterson, W. & Schwing, F. (2008, p. 54)
[96] Peterson, W. & Schwing, F. (2008, p. 45)
[97] Hoegh-Guldberg and Bruno. (2010, p. 1526)
[98] Hoegh-Guldberg and Bruno. (2010, p. 1526-1527)
[99] ADB. (2005, p. 7)
[100] Gregg et al. (2011, p. 30)
[101] Gregg et al. (2011, p. 29)
[102] Glick et al. (2009, p. 12)
[103] Glick et al. (2009, p. 13); U.S. Fish and Wildlife Service. (2010, Sec1:16)
[104] Gregg et al. (2011); Lawler (2009); Glick et al. (2009)
[105] Gregg et al. (2011); Lawler (2009); Glick et al. (2009)

[106] Gregg et al. (2011); Lawler (2009); Glick et al. (2009)
[107] Gregg et al. (2011); Heinz Center. (2008); Littell et al. (2009)
[108] U.S. EPA. (2007, p. 332); U.S. EPA. (2009, p. 12)
[109] NOAA. (2010, p. 83)
[110] NOAA. (2010, p. 85)
[111] Kling and Sanchirico. (2009, p. 46)
[112] Kling and Sanchirico. (2009, p. 41); U.S. EPA. (2009, p. 16)
[113] NOAA. (2010, p. 80)
[114] U.S. EPA. (2009, p. 17)
[115] U.S. AID. (2009, p. 98)
[116] Littell et al. (2009)
[117] Binder. (2010, p. 355)
[118] Gregg et al. (2011); Glick et al. (2009); Heller & Zavaleta (2009); NOAA (2010a); U.S. AID. (2009); CIG (2007); ADB (2005); Pew Center (2009)
[119] Gregg et al. (2011); Glick et al. (2009); Heller & Zavaleta (2009); NOAA (2010a); U.S. AID. (2009); CIG (2007); Pew Center (2009)
[120] Gregg et al. (2011); Glick et al. (2009); Heller & Zavaleta (2009); NOAA (2010a); U.S. AID. (2009); CIG (2007); ADB (2005)
[121] Gregg et al. (2011); Glick et al. (2009); NOAA (2010a); U.S. AID. (2009); CIG (2007); ADB (2005)
[122] Gregg et al. (2011); Littell et al. (2009)
[123] Littell et al. (2009)
[124] Glick et al. (2011a)

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CASE STUDIES

List of frequently used acronyms and abbreviations

AOGCM	Atmosphere-Ocean General Circulation Model
AR4	4th Assessment Report (produced by IPCC)
BC	Province of British Columbia, Canada
CA	State of California, United States
CCE	California Current Ecosystem
CIG	Climate Impacts Group
CO_2	Carbon Dioxide
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency, United States
GCM	Global Circulation Model
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
LCC	Landscape Conservation Cooperative
LEK	Local Ecological Knowledge
LME	Large Marine Ecosystem
MoE	Ministry of Environment, British Columbia
NASA	National Aeronautics and Space Administration, United States
NOAA	National Oceanic and Atmospheric Administration, United States
NPLCC	North Pacific Landscape Conservation Cooperative
O_2	Oxygen
OCAR	Oregon Climate Assessment Report (produced by OCCRI)
OCCRI	Oregon Climate Change Research Institute
OMZ	Oxygen Minimum Zone
OR	State of Oregon, United States
PCIC	Pacific Climate Impacts Consortium
PDO	Pacific Decadal Oscillation
PNW	Pacific Northwest
SLR	Sea Level Rise
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperature
TEK	Traditional Ecological Knowledge
WA	State of Washington, United States
WACCIA	Washington Climate Change Impacts Assessment (produced by CIG)

PREFACE

This report is intended as a reference document – a science summary – for the U.S. Fish and Wildlife Service (FWS) Region 1 Science Applications Program. The report compiles findings on climate change impacts and adaptation approaches in marine and coastal ecosystems within the North Pacific Landscape Conservation Cooperative area (NPLCC). The report is intended to make scientific information on climate change impacts within the NPLCC region accessible and useful for natural resources managers and others. It is produced by National Wildlife Federation under a grant from the U.S. FWS (FWS Agreement Number 10170AG200).

This report is a complete "Draft Final" version and represents the fulfillment of Phase One of a two phase project. Under Phase Two, funded through a separate grant, NWF will convene expert focus groups and produce a final report in 2012 that incorporates additional information. A companion report compiling similar information on freshwater aquatic and riparian ecosystems within the NPLCC area will also be completed under the same timeline.

Production and Methodology

This report draws from peer-reviewed studies, government reports, and publications from non-governmental organizations to summarize climate change and ecological literature on historical baselines, observed trends, future projections, policy and management options, knowledge gaps, and the implications of climate change for species, habitats, and ecosystems in the marine and coastal environment. Because the report strives to reflect the state of knowledge as represented in the literature, in most cases language is drawn directly from cited sources. By compiling and representing verbatim material from relevant studies rather than attempting to paraphrase or interpret information from these sources, the authors sought to reduce inaccuracies and possible mis-characterizations by presenting data and findings in their original form. The content herein does not, therefore, necessarily reflect the views of National Wildlife Federation or the sponsors of this report. Given the extensive use of verbatim material, in order to improve readability while providing appropriate source attributions, we indicate those passages that reflect verbatim, or near verbatim, material through use of an asterisk (*) as part of the citation footnote. In general, verbatim material is found in the main body of the report, while the Executive Summary, Boxes, and Case Studies reflect the report authors' synthesis of multiple sources.

To produce this report, the authors worked with the University of Washington Climate Impacts Group (CIG) and reviewers from federal, state, tribal, non-governmental, and university sectors. CIG provided expert scientific review throughout the production process, as well as assistance in the design and organization of the report. Reviewers provided access to local data and publications, verified the accuracy of content, and helped ensure the report is organized in a way that is relevant and useful for management needs. In addition, we engaged early with stakeholders throughout the NPLCC region for assistance and input in the production of this report. More than 100 people provided input or review of this document.

Description of Synthesis Documents Utilized

This report draws from primary sources as well as synthesis reports. In synthesis reports, we accepted information as it was presented. Readers are encouraged to refer to the primary sources utilized in those synthesis reports for more information. In most cases, the page number is included for reference. In cases where a primary source is referenced in a secondary source, it is indicated in the footnote. The global, regional, state, and provincial level synthesis reports drawn from include:

- *Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4): Climate Change 2007.*
- *Global Climate Change Impacts in the United States.* (2009).
- *Alive and Inseparable: British Columbia's Coastal Environment* (2006).
- *Environmental Trends in British Columbia: 2007.*
- *Taking Nature's Pulse: The Status of Biodiversity in British Columbia* (2009).
- *Climatic Change*, Volume 102, Numbers 1-2 (September 2010). This volume published the findings of the Washington Climate Change Impacts Assessment (WACCIA).
- *Washington Climate Change Impacts Assessment (WACCIA)* (2009).
- *Oregon Climate Assessment Report (OCAR)* (2010).
- *2009 California Climate Adaptation Strategy: A Report to the Governor of the State of California in Response to Executive Order S-13-2008.*
- *Synthesis of Adaptation Options for Coastal Areas.* (2009).
- *The State of Marine and Coastal Adaptation in North America: A Synthesis of Emerging Ideas.* (2011).
- *Strategies for Managing the Effects of Climate Change on Wildlife and Ecosystems.* (2008).

How to Use This Document

Being the first reference document of its kind for the North Pacific LCC region, the extensive details on climate change trends and projections are necessary to provide baseline information on the NPLCC. However, we encourage the reader to focus on the general magnitude and direction of projections, their implications, and on the range of options available to address climate change impacts. It is our hope that this document will provide useful information to North Pacific LCC members and stakeholders, and help facilitate effective conservation that accounts for climate change and its impacts in the region.

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We are indebted to the 100+ individuals who gave generously of their time and knowledge to inform the development of this report. With the expertise of reviewers and interviewees, we were able to acquire and incorporate additional peer-reviewed reports and publications evaluating climate change impacts on relatively small geographic scales. This allowed us to add nuance to the general picture of climate change impacts throughout the NPLCC geography. Further, this report benefitted tremendously from the resources, thoughtfulness, expertise, and suggestions of our 29 reviewers. Thank you for your time and effort throughout the review process. Reviewers and people interviewed are listed in Appendix 6.

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