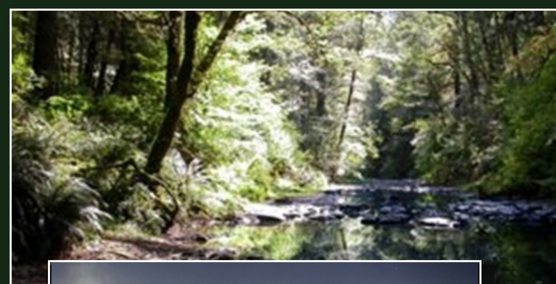
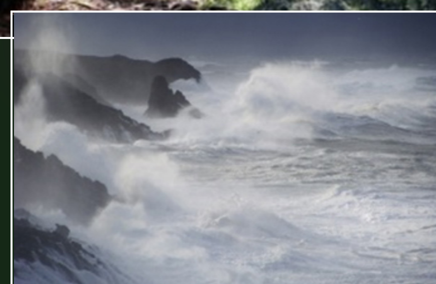
Effects of Climate Change on Local Marine, Estuarine, and Riverine Fishes

Several climate-related changes have the potential to affect critical fish habitat as well as abundance and distribution of fish on the Oregon coast.

- *Changes to marine habitats may reduce biodiversity and alter the distribution of fishes.*
- *Degradation and loss of estuarine habitats may jeopardize the reproductive success of local fish.*
- *Alterations to stream hydrology may result in critical habitat loss for cold water species.*



Salmon spawning habitat Photo: Umpqua Watersheds



Pacific storm
Photo: Partnership for Coastal Watersheds

Climate-related changes such as sea level rise (SLR), ocean acidification, and increasing ocean temperature are expected to affect marine and estuarine fish habitats. Other changes, such as altered precipitation patterns and increased frequency and severity of flood and drought, are expected to affect freshwater fish habitats. Fish that inhabit a variety of environments at different life stages, such as anadromous (migratory spawning) salmonids, are likely to be affected by all climate-related changes that affect both marine and estuarine habitats as well as freshwater habitats.

Sea Level Rise (SLR)

Many fish species use estuarine and near-shore ocean habitats at various parts of their life stages. Pacific herring (*Clupea pallasii*), require eelgrass beds, rocky shorelines or other substrates on which to attach their eggs during breeding season (Monaco and Emmett 1990). Many foraging fish species vital to the marine food web, such as surf smelt (*Hypomesus pretiosus*) and sand lance (*Ammodytes hexapterus*), use estuaries as breeding areas (Glick et al. 2007). Estuaries are vital to anadromous species by providing rearing habitats, the availability and quality of which affects ocean survival (Miller and Simenstad

Sea Level Rise

Our local NOAA tide station in Charleston has documented an average rate of sea level rise (SLR) of 0.84 mm (0.03 inches) per year averaged over the past 30 years (0.27 feet in 100 years). The rate of SLR is expected to accelerate over time. For example, according to the National Research Council (NRC), predicted SLR rates for the area to the north of California's Cape Mendocino (the study's closest site to the Coos estuary), are reported as high as +23 cm (9 inches) by 2030; +48 cm (19 inches) by 2050; and +143 cm (56 inches) by 2100.

Sources: NOAA Tides and Currents 2013, NRC 2012

1997).

The availability of high quality estuarine habitats may be threatened by SLR. Scientists have not yet determined whether sand flat and mudflat elevations relative to tidal levels will be able to keep pace with SLR. In other words, sedimentation rates may adjust with sea level rise so sand and mud flats remain about the same elevation relative to tidal levels as they are now, resulting in very little change in fish habitat availability. However, it is unlikely that coastal communities will allow intertidal habitats to migrate inland where high value real estate exists (Glick et al. 2007; Yamanaka et al. 2013). As SLR threatens rocky, intertidal habitats, the availability of hard substrate for egg deposition may decline. Species diversity and distribution may be affected by SLR in instances where salt water encroaches on brackish and freshwater habitats. Glick et al. 2007 note that since aquatic animals have specific salinity tolerances, SLR-driven salinity changes will be beneficial for some species and unfavorable for others. They also suggest SLR may still affect fishes less sensitive to these changes because their food sources may be affected by changing salinity regimes even if they are not.

Ocean Acidification (OA)

Few studies have been conducted investigating the effect of OA on fish in temperate marine ecosystems (Ishimatsu et al. 2004). However, a growing body of research suggests that OA causes a wide range of deleterious physiological responses in marine fishes. Ishimatsu et al. (2004) explain that elevated levels of ambient CO2 are associated with a condition in fish known as "hypercapnia," which causes disturbances that limit the function of the respiratory, circulatory, and nervous systems in fish. They suggest that the long-term effects of hypercapnia may inhibit important life functions by reducing growth, reproduction, and calcification.

Scientists who are studying tropical ecosystems report that OA may have significant effects on tropical fish. Dixson et al. (2010), Devine et al. (2012) and Munday et al. (2009) found significant effects of OA on the development of sensory mechanisms in tropical fish, and report that exposure to acidified seawater may impair the ability of these fish to recognize olfactory clues necessary for predator avoidance in tropical reefs.

Studies have shown that the effects of exposure to elevated CO_2 levels are greatest in fish eggs, larvae, and juveniles, suggesting that fish in early developmental stages may be the most vulnerable to the impacts of ocean acidification (Kikkawa et al. 2003; Ishimatsu et al. 2004).

Other studies suggest that OA may change important fish habitats. Palacios and Zimmerman (2007) found that higher CO_2 concentrations are positively correlated with reproductive output, below-ground biomass, and vegetative proliferation in eelgrass (Zostera marina). However, they note that this response is not necessarily beneficial to fish that are associated with eelgrass meadows, because other characteristics of CO_2-rich environments (e.g., prolific algae growth and diminished water quality) are likely to overwhelm the positive effects of increased eelgrass productivity.

Although the precise effect of acidification on local fish populations is uncertain, it's likely that ocean acidification would reduce marine biodiversity through the loss of pH- and CO_2-sensitive species and the likely reduction of habitat complexity (Widdicombe and Spicer 2008).

Ocean Acidification

Since the late 18th century, the average open ocean surface pH levels worldwide have decreased by about 0.1 pH units, a decrease of pH from about 8.2 before the industrial revolution to about 8.1 today. A 0.1 change in pH is significant since it represents about a 30 percent increase in ocean acidity (the pH scale is logarithmic, meaning that for every one point change in pH, the actual concentration changes by a factor of ten). Scientists estimate that by 2100 ocean waters could be nearly 150% more acidic than they are now, resulting in ocean acidity not experienced on earth in 20 million years. The best Pacific Northwest ocean acidification data we have so far are from the Puget Sound area, where pH has decreased about as much as the worldwide average (a decrease ranging from 0.05 to 0.15 units).

Sources: Feely et al. 2010, NOAA PMEL Carbon Program 2013

Increasing Ocean Temperatures

Worldwide, ocean temperatures rose at an average rate of 0.07° C (0.13° F) per decade between 1901 and 2012. Since 1880, when reliable ocean temperature observations first began, there have been no periods with higher ocean temperatures than those during the period from 1982 – 2012. The periods between 1910 and 1940 (after a cooling period between 1880 and 1910), and 1970 and the present are the times within which ocean temperatures have mainly increased.

Describing how the worldwide trend translates to trends off the Oregon coast is a complicated matter. Sea surface temperatures are highly variable due to coastal upwelling processes and other climatic events that occur in irregular cycles (e.g., El Niño events). We do have 27 years (1967-1994) of water temperature data collected from near the mouth of the Coos estuary that indicate through preliminary analyses a very weak trend towards warming water temperatures. Fifteen years (1995-2010) of data from multiple stations further up the South Slough estuary show very little water temperature change.

Sources: USEPA 2013, SSNERR 2013, Cornu et al. 2012

Increasing Ocean Temperature

Increasing ocean temperatures may affect the distribution of marine and estuarine fish, with warmer temperatures creating more favorable habitats closer to the poles and nearer to the bottom of the ocean (Perry et al. 2005). Radovich (1961) has documented this phenomenon on the Pacific coast of North America by correlating unusually warm sea-surface temperatures with an increased number of anomalous fish landings between 1957 and 1959. He cites several instances of warm-water species being caught north of their expected ranges including the following: Pacific bonito (*Sarda chiliensis*) in Eureka, California, skipjack tuna (*Katsuwonus pelamis*) off Cape Blanco in Oregon, swordfish (*Xiphias gladius*) in Monterey Bay, and dolphinfishes (*Coryphaena spp.*) as far north as Grays Harbor, Washington.

Perry et al. (2005) note that fish with slower developmental rates or more complex life histories are less capable of adjusting to warming temperatures through rapid demographic responses like movement towards the poles. They anticipate that fish with these characteristics are more likely to be affected by rising ocean temperatures due to their inability to rapidly respond to unfavorable habitat changes.

In addition to distributional responses, increased temperatures may affect fish by encumbering basic life functions. The amount of energy allocated toward growth and reproduction in fish usually declines as

Local Effects of Changing Ocean Conditions

The physical conditions of an estuary are sensitive to changes in long-term oceanographic fluctuations. O'Higgins and Rumrill have studied the physical response of the South Slough to changes in the Pacific Decadal Oscillation (PDO) index by monitoring water quality in the South Slough estuary from 2000 to 2006. Their data show a positive and statistically significant relationship between temperature and the PDO index. They also found a negative and statistically significant relationship between dissolved oxygen and the PDO index. This suggests that local estuaries are both anomalously warm and less oxygenated during the warmer (positive) phases of the PDO. Similarly, Hamilton has studied the relationship between the physical conditions of local waters and El Niño Southern Oscillation (ENSO) events between 2004 and 2010. Her data demonstrate a positive and statistically significant relationship between temperature and a multivariate ENSO index at stations in Charleston, South Slough's Valino Island, and South Slough's Winchester Creek.

Sources: O'Higgins and Rumrill 2007, Hamilton 2011

temperatures approach the extreme ends of species-specific tolerance ranges (Roessig et al. 2004). This is demonstrated in the English sole, which exhibits significantly slower growth in temperatures above 17.5° C (63.5° F) and is likely to experience reduced growth in extreme estuarine temperatures (Yoklavich 1982; Rooper et al. 2003). Similarly, studies of sand lances (*Ammodytes spp.*) indicate that water temperature plays an important role in spawning timing and affects both recruitment and growth rates (Monaco and Emmett 1990).

Increased water temperatures also compromise habitat quality for cold water species. According to the Oregon Department of Fish and Wildlife (ODFW 2014), higher water temperatures may accelerate the loss of areas that provide important cool water refugia and resting habitats for anadromous salmonid species.

Marine and Estuarine Hypoxia

Most of the climate-related alterations to fish habitats suggest increased likelihood of secondary effects. For example, the potential loss of tidal marshes can lead to reduced water quality in estuaries, because tidal marshes regulate nutrients and filter pollutants (Glick et al. 2007). High nutrient levels combined with increasing ocean temperatures and adequate light provide the ideal conditions for explosive algae growth. The overproduction of algae can damage aquatic ecosystems by blocking sunlight and reducing oxygen levels in the water column (USEPA 2013a). Hypoxia, low levels of dissolved oxygen in water, has deleterious effects on fish. Hypoxic conditions are linked to limited reproductive function in several species of marine and estuarine fish (Giorgi and Congleton 1984; Landry et al. 2007; Thomas et al. 2007). In extreme circumstances, low oxygen levels have caused mass mortalities (Pacific Fishery Management Council 1983).

Changing Ocean Conditions

Climate change is likely to cause changes in a variety of ocean conditions that will affect fish:

- Climate change will likely affect ocean circulation and have some effect on Pacific coast upwelling patterns (Hayward 1997, Bakun 1990).

- Research suggests a correlation between ocean temperature and increased severity and frequency of storms (Knutson et al. 2010, Webster et al. 2005, McGabe et al. 2001).

- The oceanographic effects of climate change may directly affect the abundance and distribution of marine fishes by affecting the availability of food resources. For example, Monaco and Emmett (1990) found that food availability for larval northern anchovy (*Engraulis mordaxis*) is reduced by storms or strong upwell-

Pacific Decadal Oscillation and El Niño Southern Oscillation

The Pacific Decadal Oscillation (PDO) and El Niño Southern Oscillation (ENSO) are cyclical climatic patterns that affect weather and ocean currents in and around the Pacific ocean. PDO is a pattern of oceanic conditions that shift every few decades. During a cold (negative) phase, the west Pacific warms, and the east Pacific cools; the opposite is true of a warm (positive) phase. ENSO is a climatic event that tends to occur every two to seven years and is characterized by anomalous warming of tropical Pacific waters. Locally, this warming is associated with drier conditions, warmer temperatures, and lower precipitation and streamflow, although it can also result in greater winter "storminess" and flooding.

Source: Mysak 1986

ing conditions. However, they also find that storms increase food abundance for adults.

- ODFW (2014) suggests that rising temperature may be cause for increased ocean stratification, a trend which has previously been associated with poor foraging conditions for salmonids.

In addition to the effects of climate change, Pacific Decadal Oscillation (PDO) and El Niño Southern Oscillation (ENSO) are cyclical patterns of climate variability (see sidebar) that influence ocean conditions, as well as fish abundance and distribution. The ecological response to shifts in PDO first affects primary producers and consumers before working to higher level consumers such as salmon. Warm PDO periods may be associated with decreased primary productivity in local waters due to the increased stratification of the California Current off the Oregon coast (Mantua et al. 1997; Hare et al. 1999). These events are likely to affect salmon marine survival rates (Hare el a. 1999).

Changing ocean conditions may affect fish populations through abiotic mechanisms such as modifications to critical habitats. Changes in precipitation regimes associated with the El Niño Southern Oscillation (ENSO), for example, may limit access to spawning grounds, and systems located near the southern end of salmon distribution ranges may reach critical levels as waters warm (Naiman et al. 2002).

Stream Hydrology

Many aspects of climate change are expected to alter the water cycle. The anticipated changes include increased and earlier peak stream flows and reduced summer stream flows (Defenders of Wildlife and ODFW 2008). ODFW (2014) suggests that these changes are likely to compound existing factors that are already limiting the suitability of fish habitats. They recognize the following as factors that are currently affecting critical fish habitats:

- Loss of peripheral stream connections
- Degradation of in-stream structures
- Unfavorable changes to water temperature, sedimentation regimes, barriers to upstream passage, and availability of gravel.

Increased water temperatures may limit the reproductive function of riverine fish that are already vulnerable. The white sturgeon (*Acipenser transmontanus*), for example, has been shown to have substantial egg mortality in water temperatures above 18° C (64° F) (Wagoner et al. 1990). Additionally, warmer waters may accelerate habitat loss by effectively eliminating cool backwaters and other areas that provide important refugia and resting habitats for salmon species (ODFW 2014; Defenders of Wildlife and ODFW 2008).

Warmer air temperatures and altered patterns of precipitation are a likely to directly influence the frequency, magnitude, and extent of extreme weather including flooding and drought (Reiman and Isaak 2010; Defenders of Wildlife and ODFW 2008). In instances where these extreme weather events compromise riparian habitats, the effects of climate change on fish may be accelerated by reductions in shading, bank stabilization, food availability, and nutrient and chemical mediation (ODFW 2014).

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