

V. IMPLICATIONS FOR FRESHWATER SPECIES , POPULATIONS, AND BIOLOGICAL COMMUNITIES

Climate change at global and regional scales is predicted to alter species distributions, life histories, community composition, and ecosystem function.⁸⁸⁵ The broad categories of climate change impacts on species composition and ecosystems are gradually becoming better defined, however the full implications of these types of changes, particularly at the site level, are still unknown and could be unique to each case.⁸⁸⁶ 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.⁸⁸⁷ Based on a search of the scientific and grey literature, the following implications of climate change for species, populations, and biological 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 biological communities.:

- **Observed Trends** – observed changes for southcentral and southeast Alaska, British Columbia,⁸⁸⁸ Washington, Oregon, and northwestern California. A few sections also include information on changes observed globally or across the NPLCC region.
- **Future Projections** – projected direction and/or magnitude of change for southcentral and southeast Alaska, British Columbia, Washington, Oregon, and northwestern California. Some sections also include information on global future projections.
- **Information Gaps** – information and research needs identified by reviewers and literature searches.

Chapter VI discusses implications for key fish, amphibians, and macroinvertebrates in the NPLCC region.

Almost every alteration in a species' environment – whether natural or human-induced, biotic or abiotic – is a potential source of new or intensified directional selection on traits important for fitness.⁸⁸⁹ In biology, the term *fitness* describes the sum of processes occurring throughout life history, often used as a measure of an individual's ability to reproduce or the chance an individual will leave more offspring than other individuals. When faced with

⁸⁸⁵ *McLaughlin et al. *Climate change hastens population extinctions*. (2002, p. 6070). The authors cite Gates (1993), Graham & Grimm (1990), McCarty (2001), Hughes (2000), and Kappelle et al. (1999) for this information.

⁸⁸⁶ *Burgiel and Muir. *Invasive species, climate change and ecosystem-based adaptation: Addressing multiple drivers of global change*. (2010, p. 10)

⁸⁸⁷ *IPCC. *Climate Change 2007: Synthesis Report*. (2007, p. 48)

⁸⁸⁸ At time of publishing, Austin et al. (2008, p. 189) state there has been no comprehensive evaluation of the potential effects of climate change on B.C.'s freshwater ecosystems, though impacts on salmon and other freshwater fish have received attention. Austin et al. cite Nelitz et al. (2007) and Tyedmers and Ward (2001) for information on salmon and other freshwater fish.

⁸⁸⁹ *Gienapp et al. *Climate change and evolution: disentangling environmental and genetic responses*. (2008, p. 167)

new selection pressures – such as those imposed by ongoing climate change – populations can respond basically in three ways:⁸⁹⁰

- They can evade by dispersing to suitable habitats elsewhere;
- They can remain in the habitat and adjust to the changed conditions by means of phenotypic plasticity without altering their genetic constitution; or,
- They can adapt to the changed conditions by means of genetic changes through the process of evolution.⁸⁹¹

While evading will lead to local extinction but persistence elsewhere, phenotypic plasticity (i.e., production of multiple phenotypes from a single genotype) and genetic adaptation can prevent local extinction.⁸⁹² Disentangling microevolutionary responses (i.e., genetic responses) from plastic responses is important for several reasons:

- Phenotypic plasticity provides an important mechanism to cope with changing environmental conditions, but there are limits to plastic responses and they are unlikely to provide long-term solutions for challenges faced by populations experiencing continued directional environmental change.⁸⁹³ This limitation becomes important when environmental change progresses to a point where plastic responses cannot anymore mitigate loss of fitness.⁸⁹⁴
- Coping with climate change via plastic responses is possible only as long as the relationship between existing reaction norm (i.e., the pattern of phenotypic expression of a single genotype across a range of environments) and fitness remains unchanged over time.⁸⁹⁵ However, this seems unlikely in the case of climate change.⁸⁹⁶
- A wide diversity of organisms express phenotypic plasticity in response to biotic and abiotic aspects of their environments.⁸⁹⁷ The ability of plasticity to stabilize a population is strongly dependent on the lag between the induction time of a plastic response and the timing of environmental changes⁸⁹⁸ As the lag time increases, the ability of plasticity to stabilize a population decreases, increasing the amplitude of population fluctuations.⁸⁹⁹
- Results of theoretical treatments suggest the predicted rate of climate warming may be too rapid for many populations to sustain continued response.⁹⁰⁰

⁸⁹⁰ Gienapp et al. (2008, p. 167). The authors cite Houghton et al. (2001) and Jones et al. (2001) for information on ongoing climate change, and Holt (1990) and Davis et al. (2005) as examples of the three population responses.

⁸⁹¹ *Gienapp et al. (2008, p. 167)

⁸⁹² *Gienapp et al. (2008, p. 167)

⁸⁹³ *Gienapp et al. (2008, p. 168). The authors cite Bradshaw (1965) and Przybylo et al (2000) as examples of coping with changing environmental conditions, and de Jong (2005), Pigliucci (1996), and DeWitt et al . (1998) for information on limits to plastic responses.

⁸⁹⁴ *Gienapp et al. (2008, p. 168)

⁸⁹⁵ *Gienapp et al. (2008, p. 168)

⁸⁹⁶ *Gienapp et al. (2008, p. 168)

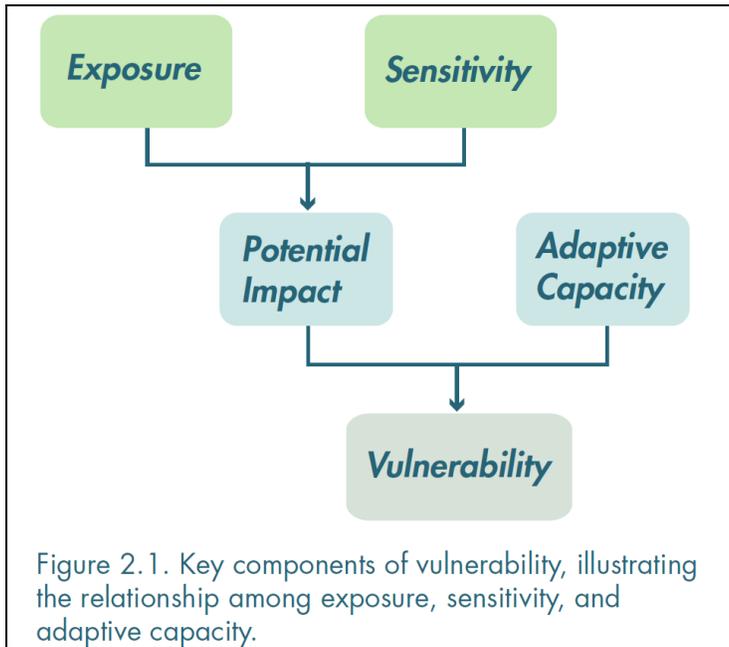
⁸⁹⁷ *Miner et al. (2005, p. 685). The authors cite Karban and Baldwin (Eds.) (1997), Tollrain and Harvell (Eds.) (1999), Sultan (2000), Pigliucci (2001), DeWitt and Scheiner (Eds.) (2004) and Young et al. (2003) for this information.

⁸⁹⁸ *Miner et al. (2005, p. 688). The authors cite Underwood (199), Abrams and Matsuda (2004), and Padilla nd Adolph (1996) for this information.

⁸⁹⁹ *Miner et al. (2005, p. 688). The authors cite Underwood (199), Abrams and Matsuda (2004), and Padilla nd Adolph (1996) for this information.

⁹⁰⁰ *Gienapp et al. (2008, p. 168). The authors cite Lynch & Lande (1993), Bürger & Lynch (1995), Lynch 1996, and Gomulkiewicz & Holt (1995) for this information.

- Although microevolutionary adaptations are generally envisioned to be ubiquitous and are a requisite for coping with environmental changes in the long run, no clear picture has yet emerged as to how effective microevolution will be in mitigating consequences of ongoing environmental changes.⁹⁰¹ One meta-analysis of 866 papers (published between 1899 and January 2006) concluded that although evolutionary responses have been documented (mainly in insects), there is little evidence that observed genetic shifts are of the type or magnitude to prevent predicted species extinctions.⁹⁰²



Increased risk of extinction due to climate change occurs where species possess biological traits or characteristics that make them particularly susceptible to change, and simultaneously occur in areas where climatic changes are most extreme (Figure 22)⁹⁰³ as well as where geography or existing stressors increase vulnerability. Considering the degree of change (i.e., exposure) a species or system is projected to experience, along with its likely response (i.e., sensitivity) to those changes, determines the potential impact.⁹⁰⁴ Understanding the likely consequences (i.e., vulnerability), however, requires further consideration of the ability for the species or system to reduce or moderate those potential impacts (i.e., its adaptive capacity) (Figure 21).⁹⁰⁵

Figure 21. Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity. Source: Reproduced from Glick, Stein, and Edelson. (2011b, Fig. 2.1, p. 20) by authors of this report.

⁹⁰¹ *Gienapp et al. (2008, p. 168). The authors cite Hendry & Kinnison 2001 and references therein for information on ubiquity of microevolutionary adaptations and cite Stockwell et al. (2003) and Davis et al. (2005) as examples for information on microevolutionary adaptations as a requisite for coping with environmental change in the long run.

⁹⁰² *Parmesan. (2006, p. 657)

⁹⁰³ *Foden et al. *Species susceptibility to climate change impacts*. (2008, p. Sec1:2)

⁹⁰⁴ *Glick, Stein, and Edelson. (2011b, p. 20)

⁹⁰⁵ *Glick, Stein, and Edelson. (2011b, p. 20)

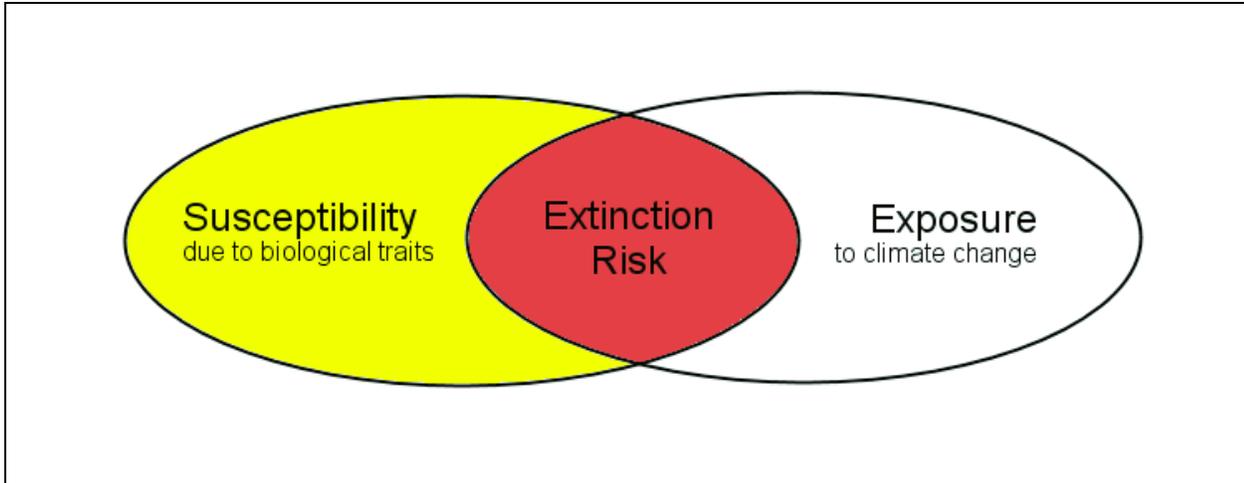


Figure 22. Increased risk of extinction due to climate change occurs where species possess biological traits or characteristics that make them particularly susceptible to change, and simultaneously occur in areas where climatic changes are most extreme. *Source: Reproduced from Foden et al. (2008, Sec1:2) by authors of this report.*

1. SHIFTS IN SPECIES RANGE AND DISTRIBUTION

A strong case can be made that future climate warming will alter the extent of habitat available for cold-, cool-, and warm-water organisms depending upon region, and result in range expansions and contractions.⁹⁰⁶ Species at the southern extent of their geographical distribution (in the north temperate zone) will shift northward and face local extirpation at their southern limit, while expanding at the northern limit of their range.⁹⁰⁷ Further, physical constraints such as drainage patterns, waterfalls, and land-locked areas play a large role in determining the boundaries of a species' range and the rate at which it may respond to changing conditions.⁹⁰⁸ For example, the impacts of climate-induced habitat shifts may be pronounced in stream ecosystems where biota are often ectothermic (body temperatures strongly influenced by external sources of heat) and movements are constrained to linear networks that are easily fragmented by thermal or structural barriers.⁹⁰⁹

Observed Trends

Southcentral and Southeast Alaska

In a modeling and connectivity study by Murphy et al. (2010), four species with very different connectivity issues were selected for evaluation.⁹¹⁰ Caribou were selected to represent mammal species with few migration constraints; Alaska marmot were selected to represent mammals with limited range and migration capability; trumpeter swans were selected to investigate how statewide landscape connectivity issues would apply to breeding bird populations; and reed canary grass was selected as an invasive plant species that uses the human footprint on the landscape for initial dispersal and may benefit from a warming climate.⁹¹¹ The latter three – Alaska marmot, trumpeter swan, and reed canary grass – are currently found in the NPLCC region. Alaska marmot and trumpeter swan are discussed in this Section, while reed canary grass is discussed in Section 4 (Altered interaction with invasive and non-native species) of this Chapter.

The Alaska marmot (*Marmota broweri*), a relic species from the Beringia Ice Age, has limited adaptability and dispersal ability and thus makes an excellent case study for connectivity and habitat loss for endemics (native species) in arctic environments.⁹¹² Data for thirty-four known occurrences of Alaska marmots were provided by the Alaska National Heritage Program, based on various sources including the Gunderson collections.⁹¹³ Murphy and colleagues used SNAP climate data for June and December mean temperature and precipitation for 2000–2009 to develop a climate envelope and current potential distribution based on known occurrence sites.⁹¹⁴ However, terrain roughness was also added as a covariate.⁹¹⁵ Rockiness, steepness, and associated biophysical

⁹⁰⁶ *Allan, Palmer and Poff. (2005, p. 279)

⁹⁰⁷ *Allan, Palmer and Poff. (2005, p. 279-280)

⁹⁰⁸ *Kling et al. (2003, p. 53)

⁹⁰⁹ *Isaak et al. (2010, p. 1350). The authors cite Pörtner and Farrell (2008) for information on climate-induced habitat shifts in stream ecosystems and Fagan (2002) for information on constraints to movement.

⁹¹⁰ Murphy et al. (August 2010, p. 32)

⁹¹¹ *Murphy et al. (August 2010, p. 32)

⁹¹² *Murphy et al. (August 2010, p. 35). The authors cite Gunderson et al. (2009) for information on adaptability and dispersal ability.

⁹¹³ *Murphy et al. (August 2010, p. 35). The authors cite Gunderson et al. (2009) for information on the Gunderson collections.

⁹¹⁴ *Murphy et al. (August 2010, p. 36)

⁹¹⁵ *Murphy et al. (August 2010, p. 36)

features are of great importance to marmot habitat, since Alaska marmots use rock piles for cover.⁹¹⁶ It cannot be presumed that the species is absent from areas for which no data exist (Figure 23).⁹¹⁷

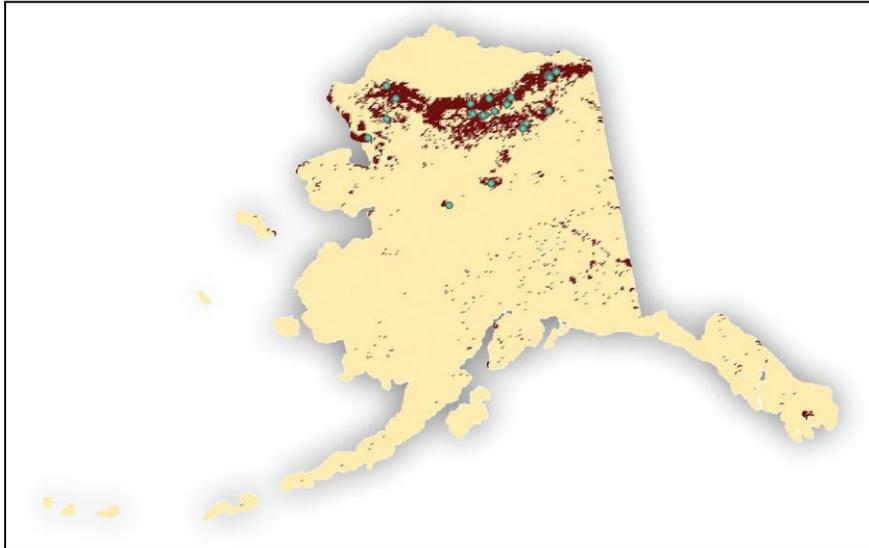


Figure 23. Known Alaska marmot distribution and modeled current distribution. Since no absence data exist, it cannot be assumed that marmots do not also inhabit similar habitat in which no confirmed presence data are available. Source: Reproduced from Murphy et al. (August 2010, Fig. 19, p. 36) by authors of this report.

The trumpeter swan (*Cygnus buccinator*) was selected as a species of interest because, like many other birds species in the state, it is migratory.⁹¹⁸ As such, statewide connectivity of habitat may not be an issue for them.⁹¹⁹ However, quantity and quality of habitat are pertinent to the survival of this species.⁹²⁰ Swans are limited, in part, by summer season length to fledge their young.⁹²¹ Trumpeter swans in Alaska require 138 ice-free days to fledge their young successfully.⁹²² Figure 25 shows the current and projected range for trumpeter swans.

British Columbia

Information needed.

Washington, Oregon, and Northwestern California

The bull trout *Salvelinus confluentus* is believed to be among the most thermally sensitive species in coldwater habitats in western North America.⁹²³ Dunham, Rieman, and Chandler (2003) developed models of thermal habitat associations using two data sets representing a geographically diverse range of sites and sampling methods in the western U.S.⁹²⁴ The concordance in parameter estimates and cross validation both within and between data sets indicates a consistent relationship between temperature and the occurrence of small bull trout throughout the

⁹¹⁶ *Murphy et al. (August 2010, p. 36)

⁹¹⁷ *Murphy et al. (August 2010, p. 35)

⁹¹⁸ *Murphy et al. (August 2010, p. 38)

⁹¹⁹ *Murphy et al. (August 2010, p. 38)

⁹²⁰ *Murphy et al. (August 2010, p. 38)

⁹²¹ *Murphy et al. (August 2010, p. 38)

⁹²² *Murphy et al. (August 2010, p. 38). The authors cite Mitchell (1994) for this information.

⁹²³ *Dunham, Rieman and Chandler. *Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range.* (2003, p. 894)

⁹²⁴ *Dunham, Rieman and Chandler. (2003, p. 894)

southern margin of the species' range.⁹²⁵ In both data sets, maximum temperature was strongly associated with the distribution of bull trout.⁹²⁶

- In both cases, the probability of the occurrence of bull trout exceeded fifty percent when the maximum daily temperature was less than 57.2 to 60.8°F (14-16°C), a result that is consistent with recent laboratory-based thermal tolerances.⁹²⁷

However, Crimmins et al. (2011) note the assumption that temperature is the principal factor defining species' distributions ignores the fact that many species are constrained by energy and water availability,⁹²⁸ as well as by interactions with other species or the availability of key resources such as nesting or foraging habitat. Consequently, considering changes in temperature alone may be inadequate for understanding distributional shifts of plant and animal species,⁹²⁹ although additional research is needed. For example, by comparing the altitudinal distributions of sixty-four plant species between the 1930s (historical period: 1920-1949) and present-day (modern period: 1976-2005) within California, Crimmins et al. (2011) show that climate changes have resulted in a significant downward shift in species' optimum elevations.⁹³⁰ Specifically, they found significant downhill shifts in optimum elevations (mean difference = -88.2 m, $t = -2.49$, $df = 63$, $P = 0.016$), with a higher proportion of species shifting their distributions downhill [proportion (p) = 0.72, 95% confidence interval = 0.59 to 0.82] than uphill [$p = 0.28$, 95% confidence interval = 0.18 to 0.41].⁹³¹

Future Projections

Southcentral and Southeast Alaska

Using the covariates mentioned above (see "Observed trends: Southcentral and Southeast Alaska"), results from Random Forests™ modeling showed shrinking range size for the Alaska marmot (A1B scenario; Figure 24).⁹³² Statewide, total range area shrank by 27% by 2039, 81% by 2069, and 87% by 2099, as compared with present estimated range size (2000-2099).⁹³³ In addition, previously contiguous habitat areas became disconnected.⁹³⁴

⁹²⁵ *Dunham, Rieman and Chandler. (2003, p. 898)

⁹²⁶ *Dunham, Rieman and Chandler. (2003, p. 894)

⁹²⁷ *Dunham, Rieman and Chandler. (2003, p. 894)

⁹²⁸ *Crimmins et al. *Changes in climatic water balance drive downhill shifts in plant species' optimum elevations*. (2011, p. 324). The authors cite Stephenson (1990) and Stephenson (1998) for this information.

⁹²⁹ *Crimmins et al. (2011, p. 324)

⁹³⁰ *Crimmins et al. (2011, p. 324)

⁹³¹ *Crimmins et al. (2011, p. 325). The authors refer to the reader to Fig. 3 in the cited report.

⁹³² *Murphy et al. (August 2010, p. 36)

⁹³³ *Murphy et al. (August 2010, p. 36)

⁹³⁴ *Murphy et al. (August 2010, p. 36)

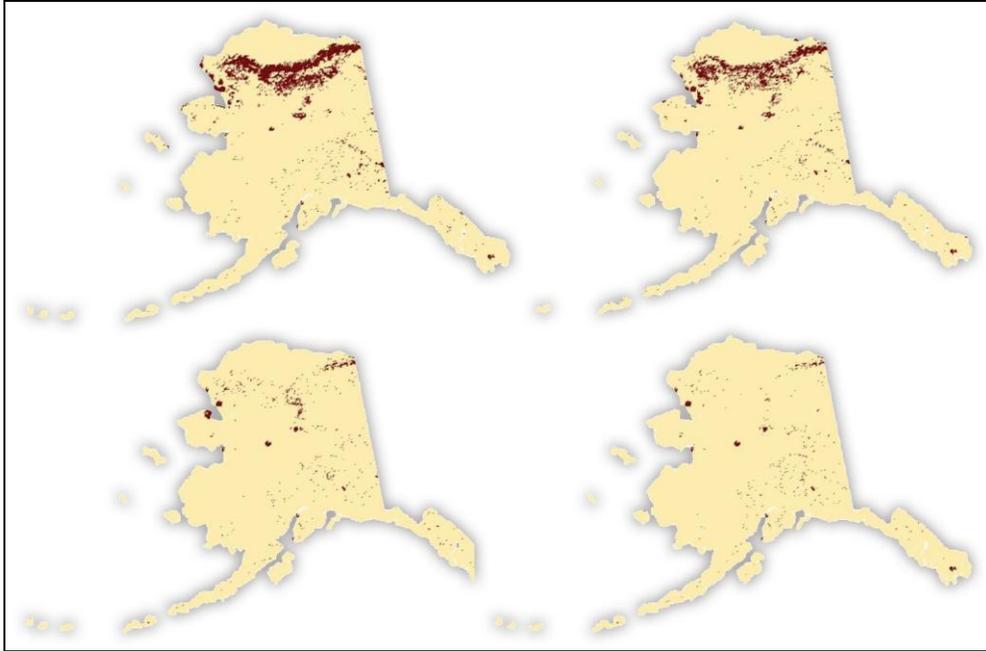


Figure 24. Projected Alaska marmot distribution. Marmot range is expected to diminish sharply as climate warms and alpine habitat shrinks. *Source: Reproduced from Murphy et al. (August 2010, Fig. 20, p. 37) by authors of this report.*

Using the same methodology and climate data described for modeling biomes (see Chapter IV Section 5 in this report), Murphy and colleagues modeled potential shifts in swan climate-linked habitat, using SNAP temperature and precipitation data for summer and winter for the current decade and three future decades (2000–2009, 2030–2039, 2060–2069, and 2090–2099).⁹³⁵ Model results showed distribution expanding west and north (Figure 25), but did not predict movement into the Arctic.⁹³⁶ It should be noted that this shift might be happening already.⁹³⁷ Since biologists cannot easily distinguish tundra versus trumpeter swans from the air, mixing is probably occurring already at the interface between habitats along the northern and western parts of the range.⁹³⁸

⁹³⁵ *Murphy et al. (August 2010, p. 38)

⁹³⁶ *Murphy et al. (August 2010, p. 38)

⁹³⁷ *Murphy et al. (August 2010, p. 38)

⁹³⁸ *Murphy et al. (August 2010, p. 38)

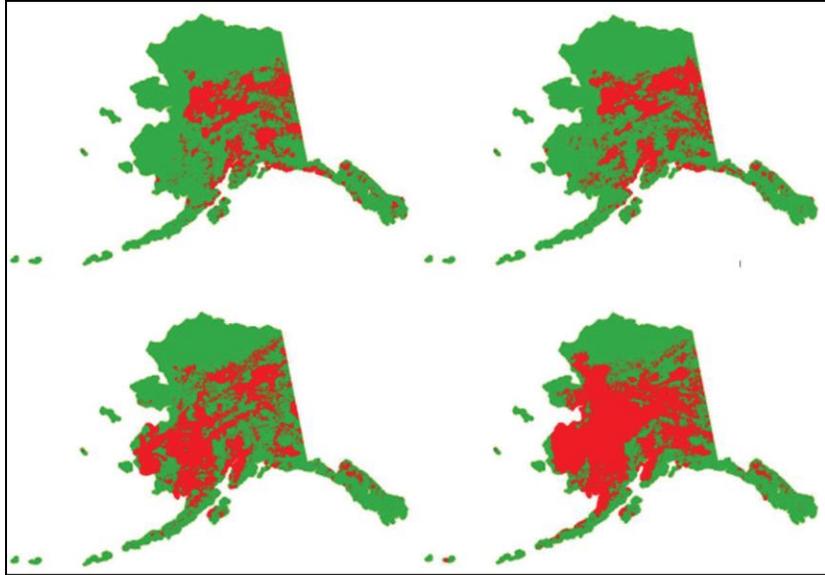


Figure 25. Potential expansion of trumpeter swan habitat. These predictions are based on 138-day ice-free season, summer and winter climate envelopes, as predicted by SNAP climate projections, and a competitive filter of non-forested biomes to represent tundra swans (not included in this figure). Trumpeter swans are predicted to shift their range northward and westward over the course of this century. **Red** indicates trumpeters present. **Green** indicates trumpeters absent. *Source: Reproduced from Murphy et al. (August 2010, Fig. 21, p. 39) by authors of this report.*

British Columbia

Information needed.

Washington

Information needed.

Oregon

Information needed.

Northwestern California

Information needed.

Information Gaps

Additional studies throughout the NPLCC region are needed to supplement the information on observed trends and future projections presented here. Information is especially needed for observed trends in British Columbia and for future projections in British Columbia, Washington, Oregon, and northwestern California.

2. ALTERED PHENOLOGY AND DEVELOPMENT

Given that species interactions can strongly determine the structure and dynamics of many natural communities, some of the most profound effects of climate change are likely to be driven by changes in the timing of biotic interactions between species.⁹³⁹ The effects of these altered interactions can be as strong as or stronger than the direct abiotic effects of climate change.⁹⁴⁰

Many organisms alter the timing of their seasonal activities in response to climate change, whether it be flowering in plants, budding of trees, emergence of insects or breeding in birds.⁹⁴¹ Despite this ability of some species to shift the timing of seasonal events, some species may still suffer if their phenological response differs from the response of organisms at lower levels of the food chain (or on which they depend in some other way, e.g. a pollinator-flower relationship),⁹⁴² leading to a mismatch between the timing of reproduction and the main food supply or between other time-dependent events such as the concurrence of flowering and pollinator presence.⁹⁴³ This mistiming can have a clear effect on species population dynamics and ecosystem functioning.⁹⁴⁴

Observed Trends

Global

Numerous ecological studies have now pointed to an important general pattern of species' responses to climate change around the world: on average, seasonal life-history events such as leaf unfolding, flowering, insect emergence, or the arrival of migratory birds are occurring earlier than they have in the historical past.⁹⁴⁵ For example, Parmesan and Yohe (2003) report global meta-analyses documented significant mean advancement of spring events by 2.3 days per decade,⁹⁴⁶ with a bootstrapped 95% confidence interval of 1.7-3.2 days advancement per decade (significant at $P < 0.05$).⁹⁴⁷ Despite this prevailing trend, however, it has also become evident that species within the same community often show variable phenological responses to climate change.⁹⁴⁸

⁹³⁹ *Yang and Rudolf. *Phenology, ontogeny and the effects of climate change on the timing of species interactions*. (2010, p. 1)

⁹⁴⁰ *Yang and Rudolf. (2010, p. 1). The authors cite Parmesan (2006) for this information.

⁹⁴¹ *Both et al. *Climate change and population declines in a long-distance migratory bird*. (2006, p. 81). The authors cite Walther et al. (2002), Parmesan and Yohe (2003), and Root et al. (2003) for this information. One reviewer noted that while spring events tend to shift earlier, fall events tend to shift later.

⁹⁴² *Both et al. (2006, p. 81). The authors cite Visser and Both (2005), Stenseth et al. (2002), Merila et al. (2001), Both and Visser (2001), Visser et al. (1998), and Visser and Holleman (2001) for this information.

⁹⁴³ *Both et al. (2006, p. 81). The authors cite Visser et al. (2004) for this information.

⁹⁴⁴ *Both et al. (2006, p. 81). The authors cite Stenseth et al. (2002) and McLaughlin et al. (2002) for this information.

⁹⁴⁵ *Yang and Rudolf. (2010, p. 1)

⁹⁴⁶ *Parmesan and Yohe. *A globally coherent fingerprint of climate change impacts across natural systems*. (2003, p. 37).

The authors cite Dunn & Winkler (1999), Walther et al. (2002), Parmesan & Yohe (2003), and Gordo & Sanz (2005) for this information.

⁹⁴⁷ *Parmesan and Yohe. (2003, p. 38)

⁹⁴⁸ *Yang and Rudolf. (2010, p. 1). The authors cite Visser & Both (2005), Miller-Rushing & Primack (2008), and Both et al. (2009) for this information.

In a literature review of 866 papers (published between 1899 and January 2006) documenting changes through time in species or systems that could, in whole or part, be attributed to climate change, Parmesan (2006) concludes with the following summary points:⁹⁴⁹

- The advance of spring events (bud burst, flowering, breaking hibernation, migrating, breeding) has been documented on all but one continent and in all major oceans for all well-studied marine, freshwater, and terrestrial groups.⁹⁵⁰
- Variation in phenological response between interacting species has already resulted in increasing asynchrony in predator-prey and insect-plant systems, with mostly negative consequences.⁹⁵¹
- Poleward range shifts have been documented for individual species, as have expansions of warm-adapted communities, on all continents and in most of the major oceans for all well-studied plant and animal groups.⁹⁵²
- These observed changes have been mechanistically linked to local or regional climate change through long-term correlations between climate and biological variation, experimental manipulations in the field and laboratory, and basic physiological research.⁹⁵³
- Shifts in abundances and ranges of parasites and their vectors are beginning to influence human disease dynamics.⁹⁵⁴
- Range-restricted species, particularly polar and mountaintop species, show more-severe range contractions than other groups and have been the first groups in which whole species have gone extinct due to recent climate change.⁹⁵⁵ Tropical coral reefs and amphibians are the taxonomic groups most negatively impacted.⁹⁵⁶
- Although evolutionary responses have been documented (mainly in insects), there is little evidence that observed genetic shifts are of the type or magnitude to prevent predicted species extinctions.⁹⁵⁷

Regional

In addition to a key role played by salmon in ecological interactions, coevolutionary association with other species is also evident.⁹⁵⁸ For example, there is evidence that aquatic insects may time their emergence from streams as adults such that they avoid disturbance caused by spawning salmon.⁹⁵⁹ It has also been shown that the timing of lactation in mink (*Mustela vison*)—which is decoupled from that predicted by latitude—occurs during salmon spawning periods.⁹⁶⁰ Salmon availability can also increase niche diversity within consumer populations, which is important because foraging behavior is a central and influential trait on which natural selection can act.⁹⁶¹ Salmon have also been linked to the maintenance of a rare polymorphic trait; recent evidence indicated that the

⁹⁴⁹ Parmesan. *Ecological and evolutionary responses to recent climate change*. (2006, p. 640)

⁹⁵⁰ *Parmesan. (2006, p. 657)

⁹⁵¹ *Parmesan. (2006, p. 657)

⁹⁵² *Parmesan. (2006, p. 657)

⁹⁵³ *Parmesan. (2006, p. 657)

⁹⁵⁴ *Parmesan. (2006, p. 657)

⁹⁵⁵ *Parmesan. (2006, p. 657)

⁹⁵⁶ *Parmesan. (2006, p. 657)

⁹⁵⁷ *Parmesan. (2006, p. 657)

⁹⁵⁸ *Darimont et al. (2010, p. 2)

⁹⁵⁹ *Darimont et al. (2010, p. 2). The authors cite Moore and Schindler (2010) for this information.

⁹⁶⁰ *Darimont et al. (2010, p. 2). The authors cite Ben-David (1997) for this information.

⁹⁶¹ *Darimont et al. (2010, p. 2). The authors cite Hocking et al. (2007) and Darimont et al. (2009a) for information on niche diversity within consumer populations.

unusual white phase of the black bear (*Ursus americanus*) in coastal British Columbia, Canada might be a salmon specialist.⁹⁶²

Southcentral and Southeast Alaska

Information needed.

British Columbia

Information needed.

Washington

In Lake Washington since 1976 (study period: 1962-2002), the dominant zooplankton species have been the rotifer *Keratella cochlearis*, the cladoceran *Daphnia pulicaria*, and the two copepod species *Cyclops bicuspidatus thomasi* and *Leptodiatomus ashlandi*.⁹⁶³ As described below, a long-term decline in *Daphnia* populations, the keystone herbivore, is associated with an expanding temporal mismatch with the spring diatom bloom and may have severe consequences for resource flow to upper trophic levels.⁹⁶⁴

Changes in the timing of thermal stratification in Lake Washington were transmitted through primary producers to herbivorous zooplankton.⁹⁶⁵ However, the ability to respond to changes in the timing of phytoplankton blooms differed among zooplankton species.⁹⁶⁶ The timing of the spring phytoplankton bloom changed in accordance with earlier stratification and has advanced twenty-seven days over the entire study period (1962–2002), or twenty days over the period 1977–2002, when the trophic state of Lake Washington was stable.⁹⁶⁷ *Keratella* and *Daphnia* show a pronounced seasonal succession that coincides with or lags the phytoplankton spring bloom:⁹⁶⁸

- The phenology of the herbivorous rotifer *Keratella* paralleled the advance in timing of the phytoplankton peak.⁹⁶⁹ More precisely, a significant trend towards earlier timing of peak densities was observed for *Keratella*, which advanced twenty-one days between 1962 and 1995.⁹⁷⁰ Therefore, the temporal offset in this predator–prey relationship did not exhibit any long-term trends (slope = 0.18 ± 0.51 , $P = 0.50$).⁹⁷¹
- In distinct contrast, a growing mismatch between peak algal densities and *Daphnia* populations in the water column has developed since 1977.⁹⁷² More precisely, the timing of the annual spring peaks of *Daphnia* exhibited no significant trend over the period from 1977 to 2002.⁹⁷³ Therefore, the offset in timing between the peak of the spring diatom bloom and the peak of the spring *Daphnia* bloom has increased significantly over the past twenty-six years (slope 1.57 ± 0.8 , $P < 0.001$), corresponding to a significant long-term decline in spring/summer *Daphnia* densities.⁹⁷⁴

⁹⁶² *Darimont et al. (2010, p. 2). The authors cite Klinka and Reimchen (2009) for this information.

⁹⁶³ *Winder and Schindler. (2004a, p. 2101)

⁹⁶⁴ *Winder and Schindler. (2004a, p. 2100)

⁹⁶⁵ *Winder and Schindler. (2004a, p. 2103)

⁹⁶⁶ *Winder and Schindler. (2004a, p. 2103)

⁹⁶⁷ *Winder and Schindler. (2004a, p. 2102-2103)

⁹⁶⁸ *Winder and Schindler. (2004a, p. 2101). The authors refer the reader to Fig. 1B in the cited report.

⁹⁶⁹ *Winder and Schindler. (2004a, p. 2103)

⁹⁷⁰ *Winder and Schindler. (2004a, p. 2103). The authors refer the reader to Fig. 2C in the cited report.

⁹⁷¹ *Winder and Schindler. (2004a, p. 2103). The authors refer the reader to Fig. 2C in the cited report.

⁹⁷² *Winder and Schindler. (2004a, p. 2103)

⁹⁷³ *Winder and Schindler. (2004a, p. 2103). The authors refer the reader to Fig. 2D in the cited report.

⁹⁷⁴ *Winder and Schindler. (2004a, p. 2103). The authors refer the reader to Fig. 2D for the timing offset and to Fig. 3D and Fig. 3F for the decline in spring/summer *Daphnia* densities in the cited report.

Oregon

Information needed.

Northwestern California

Information needed.

Future Projections

Global

In general, the populations that are most mistimed are expected to decline most in number.⁹⁷⁵ However, one reviewer noted some species may be able to shift the species on which they depend.⁹⁷⁶

Temperatures and hydrological patterns can control the timing of seasonal events such as reproduction and key life history stages (i.e., phenology). For example, for fishes dependent on water temperature for spawning cues, the spawning time of fishes may shift earlier if river waters begin to warm earlier in the spring.⁹⁷⁷ In snowmelt-dominated areas, the lifecycles of many species have evolved around predictable springtime peak flows whereas, in rain dominant areas, species life cycles have evolved around predictable wintertime peak flows.⁹⁷⁸

Southcentral and Southeast Alaska

Information needed.

British Columbia

Information needed.

Washington

Information needed.

Oregon

Information needed.

Northwestern California

Information needed.

Information Gaps

Additional studies throughout the NPLCC region are needed to supplement the information on observed trends and future projections presented here. Information is especially needed for observed trends in all jurisdictions except Washington and for species- and community-specific studies of future projections throughout the region.

⁹⁷⁵ *Both et al. (2006, p. 81)

⁹⁷⁶ Comment from reviewer. (June 2011)

⁹⁷⁷ *Palmer et al. (2008, p. 30). The authors cite Hilborn et al. (2003) for this information.

⁹⁷⁸ Mara Zimmerman, Washington Department of Fish and Wildlife. (Personal communication)

3. SHIFTS IN COMMUNITY COMPOSITION, COMPETITION, AND SURVIVAL

Changes in baseline conditions of aquatic ecosystems could influence the outcomes of competition between species with differential temperature tolerances, as well as affect the necessary habitat requirements and survivability of sensitive species.⁹⁷⁹ Temperatures that commonly exceed physiological thresholds or lethal limits will presumably set relatively hard limits to species occurrence, although variation in life history and behavior (including phenotypic plasticity), such as the increasing exploitation of thermal refugia, may mitigate hard constraints.⁹⁸⁰ For example, fish and amphibian species will experience increased stream and lake temperatures that will affect their food supply and fitness (e.g. reproductive fitness and survival).⁹⁸¹ Further, for fish, amphibians, and water-dispersed plants, habitat fragmentation due to dams or the isolation of tributaries due to drought conditions may result in local extirpations.⁹⁸² Particle size and hydraulic forces are major determinants of stream biodiversity (both the numbers and composition of algae, invertebrates, and fish) and excessive bottom erosion is well known to decrease abundances and lead to dominance by a few taxa.⁹⁸³ Further, physiological stress and increased predation resulting from crowding (less depth means less habitat), combined with habitat fragmentation in stream networks (isolated pools), may dramatically reduce survival and constrain dispersal.⁹⁸⁴ However, in very small, eutrophic lakes, by contrast, prolonged ice cover prevents the lake from absorbing oxygen from the atmosphere, and depletion of dissolved oxygen in winter often causes die-backs in fish populations.⁹⁸⁵ In these lakes, climate warming may enhance survival of fish in winter.⁹⁸⁶

Observed Trends

Regional

There is evidence that winter avifauna in North America has responded to climate change by shifting their distribution poleward.⁹⁸⁷ However, how these changes have been manifested within community composition and structure has yet to be determined.⁹⁸⁸ To address this information gap, La Sorte et al. (2009) examined trends in three community attributes from 1975 to 2001 for assemblages of terrestrial winter avifauna in North America.⁹⁸⁹ The attributes include species richness and two attributes summarized at the assemblage level: average body mass and average geographical occupancy.⁹⁹⁰ Their findings indicate:

- After accounting for possible effects of land-use change and survey effort, a general trend of increasing species richness, average body mass, and average geographical occupancy for assemblages of terrestrial winter avifauna in North America from 1975 to 2001 is indicated.⁹⁹¹

⁹⁷⁹ *Pike et al. (2010, p. 729). The authors cite Schindler (2001) for this information.

⁹⁸⁰ *Rieman and Isaak. *Climate change, aquatic ecosystems, and fishes in the Rocky Mountain West: implications and alternatives for management*. (2010, p. 14). The authors cite Crozier and others (2008) and Keefer and others (2009) as examples for this information.

⁹⁸¹ CA-NRA. (2009)

⁹⁸² *Palmer et al. (2008, p. 30). The authors cite Dynesius et al. (2004) and Palmer et al. (2008) for this information.

⁹⁸³ *Palmer et al. (2008, p. 31). The authors cite Allan (1995) for this information.

⁹⁸⁴ *Palmer et al. (2008, p. 31). The authors cite Poff (2002) for this information.

⁹⁸⁵ *Poff, Brinson and Day. (2002, p. 14)

⁹⁸⁶ *Poff, Brinson and Day. (2002, p. 14). The authors cite Fang and Stefan (2000) for this information.

⁹⁸⁷ *La Sorte et al. (2009, p. 3167). The authors cite La Sorte and Thompson (2007) for this information.

⁹⁸⁸ *La Sorte et al. (2009, p. 3167)

⁹⁸⁹ *La Sorte et al. (2009, p. 3167)

⁹⁹⁰ *La Sorte et al. (2009, p. 3167)

⁹⁹¹ *La Sorte et al. (2009, p. 3170)

- Modern global climate change is associated with community-level changes that cannot be comprehensively predicted using spatial ecological associations.⁹⁹² This outcome suggests that space-for-time substitution has limited applicability as a predictive tool under climate change and also suggests that species within communities are responding in a non-uniform manner to climate change.⁹⁹³

Southcentral and Southeast Alaska

The Kittlitz's murrelet (*Brachyramphus brevirostris*) has been reported to be experiencing an annual estimated decline of around eighteen percent, attributed primarily to climate change, although the specific causes of its decline have not been determined.⁹⁹⁴ Kittlitz's murrelet feeds in waters around tidewater glaciers and is considered a critically endangered species as glaciers recede.⁹⁹⁵ The southcentral Alaska landscape is one of its primary areas.⁹⁹⁶

British Columbia

Information needed.

Washington

Information needed.

Oregon

Information needed.

Northwestern California

Information needed.

Future Projections

Global

River temperature is a main determinant of community composition, and a general increase in temperature could cause communities to migrate upstream, or invasive species to spread.⁹⁹⁷ More precisely, it could cause community composition in a given location to shift towards warmer-adapted species due to changes in survival, reproduction, competitive dominance, and other factors that shift community composition.⁹⁹⁸

Warmer water can increase growth rates and stimulate ecosystem production.⁹⁹⁹ For example, assuming no change in food resources, invertebrate production of streams and rivers may increase, potentially yielding more food for fish.¹⁰⁰⁰ However, higher water temperatures will also increase the rate of microbial activity and thus the rate of

⁹⁹² *La Sorte et al. (2009, p. 3171)

⁹⁹³ *La Sorte et al. (2009, p. 3171)

⁹⁹⁴ *Haufler, Mehl and Yeats. (2010, p. 17)

⁹⁹⁵ *Haufler, Mehl and Yeats. *Climate change: anticipated effects on ecosystem services and potential actions by the Alaska Region, U.S. Forest Service.* (2010, p. 17)

⁹⁹⁶ *Haufler, Mehl and Yeats. (2010, p. 17)

⁹⁹⁷ *Euro-Limpacs (N.D.), *Climate Change and Freshwater* (website).

⁹⁹⁸ Comment from reviewer. (June 2011)

⁹⁹⁹ *Poff, Brinson and Day. (2002, p. 7)

¹⁰⁰⁰ *Poff, Brinson and Day. (2002, p. 7)

decomposition of organic material, which may result in less food being available for invertebrates and ultimately fish.¹⁰⁰¹ In either case, warmer water holds less dissolved oxygen, so water quality will be reduced for organisms such as invertebrates and fish that have a high oxygen demand.¹⁰⁰²

In general, nutrient enrichment leads to changes in the algal and diatom community composition of a stream, and sometimes, in some streams, to increased production and chlorophyll concentrations, leading to changes in primary invertebrate consumers which could cascade through the community.¹⁰⁰³ Reduction in salmonid populations in river systems may decrease food for forest-dwellers such as bears and impact nutrient cycling and terrestrial food webs.¹⁰⁰⁴

Predictions of climate-induced population extinctions are supported by geographic range shifts that correspond to climatic warming, but few extinctions have been linked mechanistically to climate change.¹⁰⁰⁵

Southcentral and Southeast Alaska, and British Columbia

In arctic and subarctic North America, top predators (grayling and lake trout) appear particularly vulnerable to climate change, and reductions in their abundance would likely have effects throughout the food web.¹⁰⁰⁶

Washington

Information needed.

Oregon

Information needed.

Northwestern California

Information needed.

Information Gaps

Additional studies throughout the NPLCC region are needed to supplement the information on observed trends and future projections presented here. Information is especially needed for observed trends everywhere but southcentral and southeast Alaska and for future projections throughout the region.

¹⁰⁰¹ *Poff, Brinson and Day. (2002, p. 7). The authors cite Meyer and Edwards (1991) for this information.

¹⁰⁰² *Poff, Brinson and Day. (2002, p. 7)

¹⁰⁰³ *U. S. EPA. (2008a, p. 1-8). The authors cite Gafner and Robinson (2007) as an example of the effects of nutrient enrichment on primary invertebrate consumers. The authors cite Power (1990) and Rosemond et al. (1993) for information on changes cascading through the community.

¹⁰⁰⁴ *Austin et al. (2008, p. 189). Austin et al. refer the reader to Section 2.5.1.3-F, p. 121 in their report. They also cite Compass Resource Management (2007) for information on major climate change impacts in B.C.

¹⁰⁰⁵ *McLaughlin et al. (2002, p. 6070)

¹⁰⁰⁶ *Meyer et al. (1999, p. 1376)

Table 11. Summary of possible responses of common categories of stream and river biological fish indicators to climate-related changes in water temperature and hydrologic regime

Source: Modified from U.S. EPA. Climate Change Effects on Stream and River Biological Indicators: A Preliminary Analysis. (2008, Table 3-1, p. 3-4) by authors of this report.

<i>Category</i>	<i>Expected climate change effects/sensitivities</i>	<i>References</i>
Richness and abundance measures	May have initial increase in diversity as more warm-water assemblages replace cool- or cold-water species. Habitat availability is expected to be diminished by altered flow regimes with an associated loss of diversity. If barriers to dispersal limit community replacements, richness also may decline. May also, for example, lose spring spawners (e.g., some salmon species) due to changes in timing of spring flows. Abundance of warm-water species may increase, while coldwater species may decrease.	Xenopoulos and Lodge, 2006; Xenopoulos et al., 2005; Poff et al., 2002; Grimm et al., 1997; Hayhoe et al., 2007; Wehrly et al., 2003
Composition measures	Expect fish community compositional changes resulting from losses of cold- and/or cool-water fishes (e.g., brook trout, dace and bleak), and increases in warm-water fishes (e.g., chub and barbell).	Daufresne et al., 2003; Mohseni et al., 2003; Schindler, 2001; Covich et al., 1997; Moore et al., 1997; Rahel et al., 1996, Eaton and Scheller, 1996
Tolerance/intolerance measures	Loss of temperature-sensitive cold- and cool-water species will decrease intolerant measures, increase tolerant measures.	Mohseni et al., 2003; Moore et al., 1997; Rahel et al., 1996; Eaton and Scheller, 1996
Feeding measures	Shift in food sources through attrition of lower trophic levels (and changes in community composition) will affect higher trophic levels, including top carnivores.	Schindler et al., 2005; Melack et al., 1997
Habitat measures	Changes in habitat features and connectivity fosters hybridization and drift in species gene pool.	Matsubara et al., 2001; Heggenes and Roed, 2006

4. ALTERED INTERACTION WITH INVASIVE AND NON-NATIVE SPECIES

Both invasive species and climate change are major ecosystems stressors.¹⁰⁰⁷ Although not well understood, particularly in aquatic ecosystems, the interaction of these stressors may exacerbate (or mitigate) the effects of each other.¹⁰⁰⁸ Some end-of-21st-century climates will include conditions not experienced at present (“novel” climates).¹⁰⁰⁹ Regions over much of the globe are likely to develop novel communities,¹⁰¹⁰ which could occur independent of novel climates. As temperatures warm, precipitation regimes fluctuate, and nutrient flows change, ecosystems may lose their ability to support a diverse set of native species, becoming more vulnerable to invasion (from both native and non-native species) as new resources become available.¹⁰¹¹

Climate change will have direct and second order impacts that facilitate the introduction, establishment, and/or spread of invasive species.¹⁰¹² 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.¹⁰¹³

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.¹⁰¹⁴ 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.¹⁰¹⁵ Warmer air and water temperatures may also facilitate movement of species along previously inaccessible pathways of spread, both natural and human-made.¹⁰¹⁶ Further, a rising number of species are expanding their ranges, often with large-scale impacts on ecosystems at the destination.¹⁰¹⁷ 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.¹⁰¹⁸

Invasive species can compromise the ability of intact ecosystems to sequester carbon which helps offset greenhouse gas emissions.¹⁰¹⁹ Thus, invasive species can increase the vulnerability of ecosystems to other climate-related stressors and also reduce their potential to sequester greenhouse gases.¹⁰²⁰

¹⁰⁰⁷ *U. S. EPA. (2008b, p. 4-1)

¹⁰⁰⁸ *U. S. EPA. (2008b, p. 4-1)

¹⁰⁰⁹ *Williams, Jackson and Kutzbach. *Projected distributions of novel and disappearing climates by 2100 AD*. (2007, p. 5738)

¹⁰¹⁰ *Williams, Jackson and Kutzbach. (2007, p. 475)

¹⁰¹¹ *U. S. EPA. (2008b, p. 2-14). The authors cite Melbourne et al. (2007), Byers and Noonburg (2003), and Davis et al. (2000) for this information.

¹⁰¹² *Burgiel and Muir. *Invasive species, climate change and ecosystem-based adaptation: Addressing multiple drivers of global change*. (2010, p. 5)

¹⁰¹³ *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)

¹⁰¹⁴ *Burgiel and Muir. (2010, p. 4)

¹⁰¹⁵ *Hoegh-Guldberg and Bruno. (2010, p. 1527). The authors cite Stachowicz et al. (2002) for this information.

¹⁰¹⁶ *Burgiel and Muir. (2010, p. 4)

¹⁰¹⁷ *Hoegh-Guldberg and Bruno. (2010, p. 1527)

¹⁰¹⁸ *Burgiel and Muir. (2010, p. 4)

¹⁰¹⁹ *Burgiel and Muir. (2010, p. 8)

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 section compiles general information on a few species. The focus groups planned for 2011 and 2012 will ultimately guide which invasive and non-native species are described in the final report.

Observed Trends

Southcentral and Southeast Alaska

In a modeling and connectivity study, Murphy et al. (2010) selected reed canary grass (*Phalaris arundinacea*) as a case study because it represents an aggressive invasive species.¹⁰²¹ It is already established on the Kenai Peninsula and elsewhere, and is projected to spread along road and trail systems, and along river systems statewide.¹⁰²² Because it clogs waterways, it can have a profound effect on riparian ecosystems.¹⁰²³ Dispersal of reed canary grass is clearly through roads and streams, although some isolated road systems are not yet impacted.¹⁰²⁴

British Columbia

Information needed.

Pacific Northwest and Northwestern California

Tamarisk (*Tamarix* spp.) are estimated to occupy approximately 650,000 ha (1.6 million acres) of primarily riparian floodplain habitat in twenty-three western states.¹⁰²⁵ Although eight to twelve species were introduced and have been found in the west, only about four species are highly invasive.¹⁰²⁶ Detrimental effects documented or proposed in association with tamarisk invasion are numerous and include decreased stream flow, excessive water use, loss of native biodiversity, effects on primary consumers and food web structure, salinization issues, and changes in channel morphology.¹⁰²⁷

Based on a presence database, populations of tamarisk species are prevalent in the northwestern United States, most notably east of the Cascade Mountains.¹⁰²⁸ Major population centers are limited to the warmest and driest environments found in the Northern Basin and Range (43% of presence grid cells), Columbia Plateau (33%), and central Snake River Plain (22%).¹⁰²⁹ All other ecoregions had < 2% tamarisk presence grid cells.¹⁰³⁰ The presence database used in this study does not represent a complete or randomized field survey, and data could be biased toward larger, accessible, and known populations of tamarisk.¹⁰³¹ Currently, major population centers in

¹⁰²⁰ *Burgiel and Muir. (2010, p. 5)

¹⁰²¹ *Murphy et al. (August 2010, p. 40)

¹⁰²² *Murphy et al. (August 2010, p. 40)

¹⁰²³ *Murphy et al. (August 2010, p. 40). The authors cite Zedler and Kercher (1994) for this information.

¹⁰²⁴ *Murphy et al. (August 2010, p. 40)

¹⁰²⁵ *Kerns et al. (2009, p. 200). The authors cite Zavaleta (2000a) for this information.

¹⁰²⁶ *Kerns et al. (2009, p. 200). The authors cite Gaskin and Schaal (2002) for this information.

¹⁰²⁷ *Kerns et al. (2009, p. 201). The authors cite Bailey et al. (2001), Birken and Cooper (2006), DiTomaso (1998), Kennedy et al. (2005), Ladenberger et al. (2006), and Shafroth et al. (2005) for this information.

¹⁰²⁸ *Kerns et al. (2009, p. 206). The authors refer the reader to Fig. 1 in the cited report.

¹⁰²⁹ *Kerns et al. (2009, p. 206-207)

¹⁰³⁰ *Kerns et al. (2009, p. 207)

¹⁰³¹ *Kerns et al. (2009, p. 207)

Washington, Oregon, and Idaho are limited to the warmest and driest environments in the central Snake River Plain, Columbia Plateau, and Northern Basin and Range.¹⁰³²

Oregon Sea Grant's (2008) identification guide provides information on over thirty freshwater organisms, freshwater and riparian plants, and fish that are already established or likely to become established in the Pacific Northwest.¹⁰³³

- Freshwater organisms include nutria, feral swine, zebra and quagga mussel, Asian clam, New Zealand mudsnail, bullfrog, red-eared slider, rusty crayfish, ringed and virile crayfish, and red swamp crayfish.
- Freshwater and riparian plants include hydrilla, Brazilian elodea, milfoil, giant salvinia, didymo, yellow flag iris, reed canarygrass, purple loosestrife, and knotweed.
- Fish include Asian leaping carp, Atlantic salmon, other nonnative anadromous fish, and nonnative carp, panfish, gamefish, trout, catfish, aquarium and ornamental fish, mosquitofish, tui chub, and northern snakehead.

Future Projections

Southcentral and Southeast Alaska

As with Murphy and colleagues' other models described in previous sections, the known occurrences of reed canary grass (*P. arundinacea*) were mapped and sites were linked with SNAP climate data for June and December 2000-2009.¹⁰³⁴ Using this training data, Murphy and colleagues extrapolated the potential habitat for the species for three future time steps (2030–2039, 2060–2069, and 2090–2099; see Figure 26).¹⁰³⁵ The predictions are very conservative since they do not account for spread via water.¹⁰³⁶ In addition, the models do not take into account the potential spread by airplanes (terrestrial and floatplanes).¹⁰³⁷

¹⁰³² *Kerns et al. (2009, p. 200)

¹⁰³³ Wiedemer and Chan. *On the lookout for aquatic invaders: Identification guide for the Pacific Northwest*. (2008)

¹⁰³⁴ *Murphy et al. (August 2010, p. 40)

¹⁰³⁵ *Murphy et al. (August 2010, p. 40)

¹⁰³⁶ *Murphy et al. (August 2010, p. 40)

¹⁰³⁷ *Murphy et al. (August 2010, p. 40)

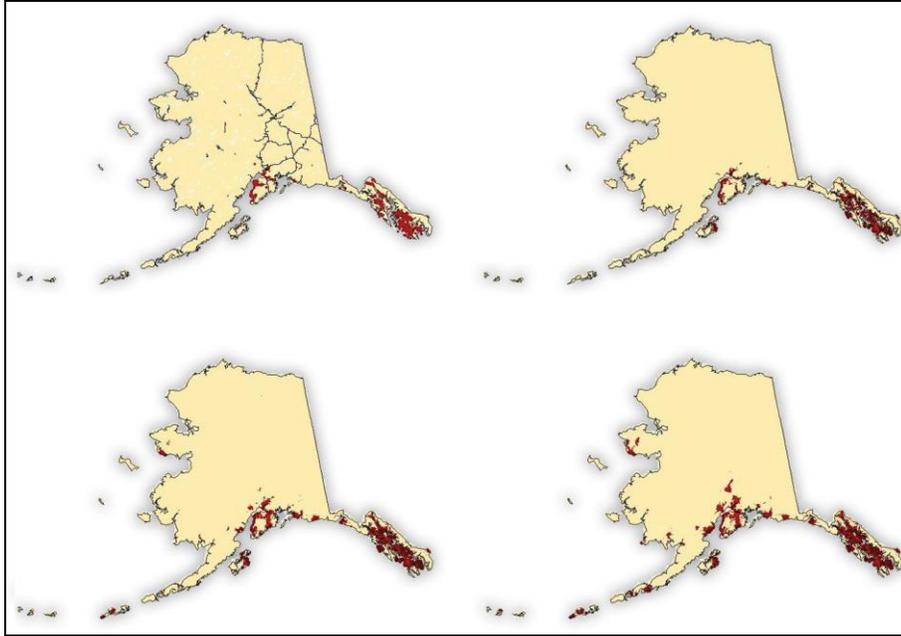


Figure 26. Potential spread of reed canary grass, using climate and all-season roads as predictors. Inclusion of waterways, proposed roads, and trails would be likely to broaden the modeled range of this invasive species. See Technical Addendum VIII in the cite report. Top left: Known occurrences and existing roads. Top right: 2030-2039. Bottom left: 2060-2069. Bottom right: 2090-2099. Source: Reproduced from Murphy et al. (August 2010, Fig. 22, p. 41) by authors of this report.

In addition, current and future range map scenarios were created for sixteen invasive plant species in Alaska.¹⁰³⁸ Twelve of these species currently inhabit, or could inhabit, southcentral and southeast Alaska (Table 12).

Table 12. Invasive plant species modeled in southcentral and southeast Alaska.
 Table created by authors of this report.

<ul style="list-style-type: none"> • Garlic mustard (<i>Alliaria petiolata</i> (M. Bieb.) Cavara & Grande) • Leafy spurge (<i>Euphorbia esula</i> L) • Giant hogweed (<i>Heracleum mantegazzianum</i> Sommier & Levier) • Hydrilla (<i>Hydrilla</i> spp. Rich., mainly <i>H. verticillata</i> (L. f.) Royle) • Ornamental jewelweed (<i>Impatiens glandulifera</i> Royle) • Purple loosestrife (<i>Lythrum salicaria</i> L.) 	<ul style="list-style-type: none"> • Eurasian watermilfoil (<i>Myriophyllum spicatum</i> L.) • White waterlily (<i>Nymphaea alba</i> L.) • Reed canarygrass (<i>Phalaris arundinacea</i> L) • Knotweed complex (<i>Polygonum sachalinense</i> F. Schmidt ex Maxim., <i>P. ×bohemicum</i> (J. Chrtk & Chrtkovß) Zika & Jacobson [<i>cuspidatum</i> × <i>sachalinense</i>], <i>P. cuspidatum</i> Siebold & Zucc.) • Common tansy (<i>Tanacetum vulgare</i> L.) • Scentless false mayweed (<i>Tripleurospermum perforatum</i> (Mérat) M. Lainz)
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Species distributions were modeled using two different predictive models (DIVA-GIS and MaxEnt), two different future climates (Hadley and CCC), two emissions scenarios (A2, high and B2, low), for current climate plus three time steps (2020, 2050, 2080). All species show an increase in range over time,

¹⁰³⁸ HDR. *Invasive Plant Species Response to Climate Change in Alaska: Bioclimatic models of current and predicted future changes (pdf)*. (2009, p. 2)

particularly aquatic species including hydrilla (*Hydrilla* spp.), Eurasian watermilfoil (*Myriophyllum spicatum* L.), and white waterlily (*Nymphaea alba* L.).¹⁰³⁹ Range maps across all climate scenarios and all species studied are available at http://alaska.fws.gov/fisheries/invasive/reports_maps.htm#distribution_maps (accessed 4.21.2011).

British Columbia

In British Columbia, alien warm-water fish species, such as smallmouth and largemouth bass (*Micropterus dolomieu* and *M. salmoides*) and yellow perch (*Perca flavescens*), may thrive as water temperatures increase.¹⁰⁴⁰ These species may out-compete and/or prey on cold-water native species.¹⁰⁴¹

Pacific Northwest

Water hyacinth in Washington is thought to be limited in its ability to become established because of the state's cold winters.¹⁰⁴² As increasing temperatures warm water bodies in the region, the waters of Washington may be more suitable to water hyacinth, allowing the plant to become widely established.¹⁰⁴³

Tamarisk (*Tamarix* spp.) species are shrubs or small trees considered by some to be among the most aggressively invasive and potentially detrimental exotic plants in the United States.¹⁰⁴⁴ Kerns et al. (2009) obtained distribution data for the northwest (Oregon, Washington, and Idaho), developed a habitat suitability map, and projected changes in habitat due to climate change in a smaller case study area using downscaled climate data.¹⁰⁴⁵ Key results include:

- Although considerable uncertainty exists regarding future climate change, a two- to ten-fold increase in highly suitable tamarisk habitat is projected by the end of the 21st century.¹⁰⁴⁶
- Habitat suitability model results indicate twenty-one percent of the region supports suitable tamarisk habitat.¹⁰⁴⁷ Less than one percent of these areas are occupied by tamarisk; the remainder is highly vulnerable to invasion.¹⁰⁴⁸

Northwestern California

Information needed.

Information Gaps

Additional studies throughout the NPLCC region are needed to supplement the information on observed trends and future projections presented here.

¹⁰³⁹ *HDR. (2009, p. 2)

¹⁰⁴⁰ *Austin et al. (2008, p. 192). The authors cite Compass Resource Management (2007) for information on major climate impacts in B.C.

¹⁰⁴¹ *Austin et al. (2008, p. 192)

¹⁰⁴² *U. S. EPA. (2008b, p. C-25). The authors cite Washington Department of Fish and Wildlife (2001) for this information.

¹⁰⁴³ *U. S. EPA. (2008b, p. C-25)

¹⁰⁴⁴ *Kerns et al. *Modeling Tamarisk (Tamarix spp.) habitat and climate change effects in the northwestern United States.* (2009, p. 200)

¹⁰⁴⁵ *Kerns et al. (2009, p. 200)

¹⁰⁴⁶ *Kerns et al. (2009, p. 200)

¹⁰⁴⁷ *Kerns et al. (2009, p. 200)

¹⁰⁴⁸ *Kerns et al. (2009, p. 200)