FORAGE FISH AND CRITICAL PREY

INTRODUCTION

Forage fish play a critical role in marine ecosystems and are culturally and economically vital for the Port Gamble S'Klallam Tribe. Not only do they serve as a source of food and income, they also form a critical link in the marine food web between plankton and other fish, marine mammals, and birds [1]. Forage fish are found in every marine nearshore habitat in Washington state—the most common being Pacific herring (*Clupea pallasii*), surf smelt (*Hypomesus pretiosus*), and Pacific sand lance (*Ammodytes hexapterus*) [1]. According to the Tribe's Natural Resources staff, other important species of forage fish and critical prey for the Tribe include northern anchovy (*Engraulis mordax*), plainfin midshipman (*Porichthys notatus*), and three-spined stickleback (*Gasterosteus aculeatus*).

There are significant knowledge gaps in terms of forage fish abundance, assemblage, and their roles in marine ecosystems [1]. Most of the research and monitoring conducted in Puget Sound has focused on Pacific herring, while comparatively little has been directed to Pacific sand lance, surf smelt, northern anchovy, and others [1]. Most of what is known about forage fish and their lifecycles is related to spawning, which occurs in nearshore marine habitats [1].

Forage fish are vulnerable to several climate stressors. Impacts that could likely affect forage fish include increased water temperatures [2], lower dissolved oxygen levels in nearshore habitat [3], reductions in suitable habitat [4], predator and prey lifecycle event asynchrony [5], and sea level rise [6]. However, the vulnerability of forage fish to such impacts is less than certain due to a lack of knowledge regarding the lifecycles of many forage fish species.

MARINE ISSUES

Forage fish and other critical prey species live in marine ecosystems, which will be affected by climate change primarily through changes in sea surface temperature, altered upwelling patterns, lower dissolved oxygen, increases in harmful algal blooms, reduced spawning habitat, changes in zooplankton community, and increasing acidity [6].

Table 1 lists known optimal temperature, salinity, and dissolved oxygen ranges for forage fish and other critical prey species. Thresholds for some species and thresholds for pH were not found in the literature review.

Table 1. Critical thresholds for forage fish and other critical prey species

Species	Temperature	Salinity	Dissolved oxygen
Pacific herring	40 – 68°F 41 – 50°F (spawning) [7]	0 – 35 ppt 8 – 28 ppt (spawning) [7]	Moderate to high
Pacific sand lance	28 – 75°F [8]	---	---
Surf smelt	---	---	---
Northern anchovy	44 – 85°F [9]	---	---
Plainfin midshipman	---	>15 ppt [10]	---
Three-spined stickleback	---	---	---

The remainder of this section describes potential impacts on forage fish health, reproduction, and survival as a result of projected changes in climatic conditions.

SURVIVAL AND SPAWNING

Ocean Temperature

Ocean temperatures in the Northeast Pacific are projected to increase by around 2.2°F by the 2040s [6]. Warmer water is directly stressful to cold water fish, including herring and anchovy, and could cause fish populations to shift northward in search of suitable habitat [11]. Spawning and smaller juvenile cohorts of herring have already been observed shifting north in Washington, a trend that could continue as waters warm [11]. Shallow water spawning areas are likely to be more heavily influenced by air temperatures [11].

Temperature also directly controls the rates of metabolic processes in fish, which impact swimming, digestion, and enzyme activity. Warm temperatures increase these rates and can be stressful, especially for larvae and juvenile fish [12]. Temperature also controls incubation time for eggs, with warmer temperatures resulting in shorter incubation times and earlier hatching [8]. More research is needed to better understand the relationship between temperature and growth to further project potential impacts on forage fish as the climate changes.

RESEARCH NEED: What are the sub-lethal effects of temperature increases, and how do they affect salmon survival?

Dissolved Oxygen

Higher water temperatures will also result in less dissolved oxygen. Pacific herring require moderate to high levels of dissolved oxygen for survival [13], while other species, such as sand lance and midshipman, can withstand hypoxic conditions at least temporarily as they are often exposed to air at low tide [8]. Sand lance in particular can withstand temporary dissolved oxygen concentrations as low as 2 ml/L when they are buried and dormant in exposed sand [8].

Low dissolved oxygen concentrations have been demonstrated in studies to increase incubation time and egg mortality; in one study on sand lance, eggs failed to hatch at concentrations of 2.1 ppm [8]. Another study on herring egg incubation found that the minimum dissolved oxygen requirement at egg surface was 2.5 mg/ml [14].

Salinity

Several species of forage fish are euryhaline, meaning that they can tolerate a wide range of salinities [8]. Still, at spawning times, optimal salinities can be more restricted than the full range of adult tolerance in some species [8]. Because different species of forage fish and different stocks within species spawn at different times in Puget Sound, the impacts of any changes in salinity on forage fish (e.g., via changes in freshwater streamflow into estuaries, changes in evaporation rates, and changes in sea ice) will vary. More research is needed to determine what these specific impacts could be.

Changes in water temperature and salinity, as well as projected delayed and shorter upwelling patterns, all have the potential to impact forage fish at various life stages, although the timing, scale, and interaction of these changes is uncertain [11]. One study found that increased water temperature was associated with slower growth and higher mortality [14]. The age of irreversible starvation after forage fish consumed their yolk-sac decreased from 8.5 days at a water temperature of 43°F to 6 days at a temperature of 50°F [14].

FOOD WEBS

Forage fish serve a critical function in the marine food web by transferring energy between trophic levels [13]. Growing pressure from climate change, in addition to commercial fishing and other anthropogenic stressors, could have ripple effects not only for forage fish populations, but also for the larger marine food web [13]. In an example of potential implications of reduced forage fish productivity, an analysis of forty years of inconsistently sampled catch data showed that individual basins within Puget Sound have shown divergent trends in species composition and forage fish population abundance [13]. Central and south Puget Sound exhibited greater differences from historic conditions than northern basins (Whidbey and Rosario) [13]. These basins also experienced large increases in the proportion of jellyfish catches, while northern basin catches remained fish-dominant with higher fish species richness [13]. According to Greene et al. (2015), jellyfish have fewer predators than fish, and the shift to jellyfish abundance could indicate a truncated food web with little energy transfer to higher trophic levels and reduced capacity to support forage fish [13]. While this particular trend was better explained by anthropogenic stressors (population density) than by climatic drivers, an increase in jellyfish populations worldwide is hypothesized to be linked to climate change [15].

Using the A2 climate change scenario, various food web and predator-prey models do show changes in the structure of coastal marine food webs [16]. More specifically, they show that future food webs could be composed of smaller species and become highly disconnected, which would likely impact overall ecosystem functionality [16].

Harmful Algal Blooms

Forage fish feed on planktonic organisms and therefore are already exposed to negative impacts from harmful algal blooms (HABs). HABs are predicted to worsen under changing climate conditions and warmer ocean temperatures (more information can be found in the Harmful Algal Blooms chapter). Paralytic shellfish toxins have been detected in several forage fish species such as anchovy and herring [17], which have served as vectors for domoic acid toxin transfer to higher levels of the food web, resulting in the death of birds and marine mammals [18].

Ocean Acidification

Little research has been done on the direct effects that ocean acidification will have on forage fish; however, it will likely indirectly impact them through their main sources of food. Forage fish feed primarily on plankton; copepods are a primary food source for sand lance, herring, and surf smelt and are negatively impacted by ocean acidification [8, 19]. While this could potentially lead to increased competition for less food, more research needs to be done on the complex food web interactions to understand the cascading impacts of ocean acidification on forage and other fish species [20].

Predation

Predation is also a major factor affecting the abundance of herring and other forage fish [21]. Pacific hake, whose current northernmost distribution extends to British Columbia, prey on several species of forage fish [22]. However, as temperatures warm, hake could move farther north and increase predation on herring and other fish stocks [22].

PATHOLOGY

Diseases of Concern

Temperature plays a key role in regulating physiological processes related to disease susceptibility and progression in fish [19]. Common pathogens affecting Pacific herring and other forage fish in Puget Sound are *Ichthyophonus hoferi*, the viral hemorrhagic septicemia virus, and the erythrocytic necrosis virus [19]. *Ichthyophonus hoferi* is a parasite that causes heart and liver lesions in several species of fish, including Pacific herring and surf smelt [23]. While more research needs to be done on possible linkages between climate change and increased prevalence of these marine diseases, a synthesis of the current literature found increased infection prevalence, disease progression, and mortality on different fish species at elevated temperatures, as well as decreased swimming ability [23].

Susceptibility to disease can also be impacted by other external factors, such as exposure to hydrocarbons and other chemicals in water and sediments [24]. More research is needed on how these concurrent factors, many of which could become worse as the human population of the Puget Sound area grows, will exacerbate the impacts of climate change on forage fish, as well as their predators at higher trophic levels.

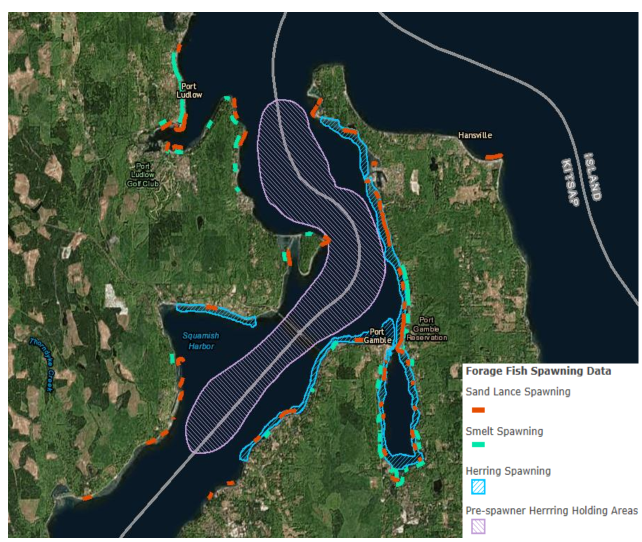
SHORELINE ISSUES

CRITICAL HABITAT

Most of what is known about the lifecycle of forage fish focuses on spawning stages when they are present in the nearshore environment [1]. Forage fish are found in every marine and estuarine nearshore habitat in Puget Sound, and various species of forage fish have different habitat requirements and use different areas of beach and intertidal zones for spawning at different times of the year [1].

Figure 32 shows spawning and holding areas for several forage fish species near the Port Gamble S'Klallam reservation.

Figure 1. Forage fish spawning location map [38].



Eelgrass beds, which are favored by forage fish species for spawning and egg deposition, are also under threat from non-climate stressors such as shoreline development and armoring, as well as climate change impacts like sea level rise and temperature change [25]. Optimal Puget Sound eelgrass growth conditions include temperatures between

41 and 46°F and high salinity [26]. Lower spring streamflows and increased water acidity (and thus carbon dioxide availability) have the potential to increase eelgrass productivity [26]. However, increased water temperature and reduced sunlight for photosynthesis as water depth increases or epiphyte growth increases could negatively impact productivity [26]. More research is needed to better understand the impacts of climate change on this type of forage fish habitat.

The most common forage fish species in Washington—Pacific herring, surf smelt, and sand lance—as well as plainfin midshipman all utilize nearshore zones and beaches for spawning [1]. Other forage fish species such as northern anchovy do not spawn on beaches but spend parts of their life in nearshore habitat and thus are also vulnerable to impacts to these areas [1].

Figure 2. Herring eggs deposited on eelgrass [19].

Pacific herring utilize the shallow subtidal and lower intertidal zones of sheltered bays, inlets, sounds, and estuaries for spawning rather than open coastlines [1]. Herring deposit their eggs primarily on eelgrass, as well as algae substrates and some other types of marine vegetation (see Figure 33) [1]. Sand lance and surf smelt both spawn on beaches [1]. Surf smelt spawn in the upper intertidal areas of beaches with coarse sand and gravel [27]. They deposit eggs a few inches deep in the sand, which adhere to the sand granules while they incubate [24]. Sand lance spawn on fine sand and gravel beaches by burrowing and depositing eggs in the sand and also spend parts of their life dormant, burrowing into the sand (see Figure 34). They also appear to spawn in the habitat they spend their lifecycles in without migrating [8].

Figure 3. Pacific sand lance burrowing into the sand [39].

Nearshore ecosystems, including intertidal areas and estuaries, are among the most threatened environments with regard to climate change [28]. As a result, the possibility of the loss of spawning grounds for forage fish is likely.

IMPACTS FROM HUMAN DEVELOPMENT

The construction of structures like docks, bulkheads, houses, and roads, as well as activities like shipping, logging, and aquaculture along Washington's coast, is not uncommon and can threaten forage fish with loss of spawning habitat [29]. Removal of vegetation, dredging, beach grooming, and especially shoreline armoring (see the following section for more discussion on this issue) can all change the quality and quantity of sediment available for spawning [1]. Disruptions of these ecosystems and natural processes can not only destroy critical habitat such as beach and eelgrass beds, but also change predator-prey relationships and disrupt fish behavior [30].

Shoreline Armoring in Response to Sea Level Rise

Sea level rise has the potential to adversely impact forage fish and other critical prey species by directly reducing habitat available for spawning, especially where shoreline armoring restricts inland migration of intertidal habitat [31]. Sea level in the Puget Sound region will vary from place to place depending on local rates of vertical land motion. See the Observed and Projected Climate Changes chapter for detailed projections.

In response to rising sea levels, some communities are increasing shoreline armoring to protect infrastructure and development close to the water (see Figure 4) [32]. Shoreline armoring disrupts natural processes of wave and sedimentation patterns and, because the beach cannot move inland, causes further beach erosion and habitat degradation [32]. As water levels come closer to the armoring infrastructure, critical beach habitat will be lost for several forage fish species [32]. According to a study on the impacts of sea level rise on surf smelt and sand lance habitat, since much of Puget Sound shoreline is already armored and armoring will likely increase with rising sea levels, extensive habitat loss has occurred and is likely to continue to occur in the next few decades, and most spawning habitat could disappear by 2100 [33].

Figure 4. Seahurst Park Seawall in Burien. Photo credit: John Ryan / KUOW [34]

LOOKING AHEAD

Forage fish serve a critical function for marine ecosystems and are a source of prey for other important species such as salmon, pinnipeds, and birds. Since comparatively little is known about these species in general, further research is necessary to assess their populations and the risks posed to them by climate change.

Puget Sound has 2,500 miles of shoreline, yet only 760 miles have been surveyed for forage fish. In 2015, Governor Inslee signed a bill initiating a comprehensive study of forage fish in Puget Sound, including spawning habitat and mid-water trawl surveys [35]. The results will provide more information about these species as well as help develop conservation and adaptation strategies [35]. The study is due to be completed by mid-2017 [35]. This may, in addition, help resource managers evaluate whether various species of forage fish should be considered threatened or endangered under the Endangered Species Act

(ESA). For example, while past petitions to list Puget Sound herring stocks found that such stocks were not threatened or endangered, future monitoring will be needed to assess altering conditions due to climate change that may impact forage fish enough to warrant a listing under the ESA.

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