Effects of Shoreline Modification on a Northern Puget Sound Beach: Microclimate and Embryo Mortality in Surf Smelt (*Hypomesus pretiosus*)

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Abstract

Human alteration of Puget Sound shorelines is extensive, yet its effects on habitats are largely undocumented. Surf smelt (*Hypomesus pretiosus*) is a forage fish that spawns (lays eggs) on gravel-sand shorelines. This study evaluates effects of natural vs. heavily modified beaches on the survival of surf smelt eggs. Electronic sensors were used to record beach conditions over time. They recorded light intensity, temperature, and humidity that affect egg survival. Substrate (sand and gravel) samples were collected at the end of the monitoring period to compare the environmental conditions and how many surf smelt eggs survived on each beach type. Human-modified beaches had significantly higher light intensity, substrate and air temperature, but lower humidity. Natural beaches had twice as many live surf smelt eggs, showing that changes made on modified beaches can greatly affect forage fish mortality (death).

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Introduction

Many fish and wildlife species depend on the beaches of Puget Sound. However, humans greatly change the nature of these beaches by armoring shorelines (with sea walls, dikes, etc.) and removing vegetation. We know little about how these changes affect the animals and how they use the area, but scientific studies suggest negative effects (Penttila 2001; Sobocinski 2003). This study examines effects of shoreline modification on beach microclimates to see if light, temperature, and humidity (moisture) affect egg survival of surf smelt. Surf smelt are a species of forage fish that spawns at high tide, leaving eggs stuck to sand and pebbles near the high tide line in the intertidal zone so they are out of the water much of the time.

Beaches link land and water ecosystems and are important in the cycling of dead plant and animal matter (detritus) through food webs. When shoreline plants and animals die, they feed or fertilize the organisms on the beach and nearshore waters. Beaches and nearshore waters provide habitats where many animals can find food, shelter and have babies. Some of these animals, like salmon and trout, are listed as threatened under the Endangered Species Act, meaning they are in danger of becoming endangered in the near future and at risk for extinction. When trees and plants can grow and sand and pebbles can fall to the beach over time to replace sand lost to erosion, habitats for these life forms are ensured (Day et al. 1989; Brennan and Culverwell 2004).

At least one third of the beaches in Puget Sound have been modified through activities including diking (building earthen walls to stop flooding), filling (adding sand/gravel), armoring (building walls to stop the loss of sand/gravel to erosion) and devegetation (removing plants). This can greatly change the structure of the beach, cutting off a fresh supply of sand and pebbles from uphill, causing the beach to turn to mostly larger rocks and cobble over time as its sands are lost to erosion. It also decreases the number of connections between the water and the land environments and changes how animals use the habitats.

For example, with fewer habitat types, the biodiversity is much lower on modified beaches compared to natural ones. Limited research in Puget Sound indicates that these types of changes can cause loss of food for fish and can damage the habitat fish use for spawning (making babies). Large increases in light and temperature and decreases in moisture can cause beach environments to dry out and become too hot for delicate life forms, especially in the egg and larval stages of life.

Spawning is a very important event as this creates the next generation of fish. The beach is a harsh environment for fish embryos, so fish depend on the eggs getting buried in gravel by the waves and on shade from plants and logs to protect the them. Beach modification by humans often removes shade trees and logs, which can cause stress to the embryos and affect their ability to develop correctly. Previous research shows that increased temperatures and light levels can negatively affect survival of surf smelt embryos, particularly in summer and at armored beaches with no land vegetation.

The health of surf smelt populations is of high concern in Puget Sound because it is a common food item for many fish and wildlife species and is important for human recreational fishing. They spawn high on the beaches where eggs attach to sand-gravel and incubate for 10-21 days. This study compares an armored beach with no vegetation to a natural beach with vegetation in Puget Sound during summer. Two hypotheses were tested to determine if:

1. Environmental conditions (light intensity, substrate and air temperature and humidity) were *not* any different between the beaches.

2. The amount of healthy eggs containing live surf smelt embryos were *not* different between the two beaches.

Materials and Methods

The two beaches used in this study are at the northern end of Camano Island, Washington. In this area, natural beaches are made of gravel-sand that are shaded with a variety of trees. The modified beach is armored with a vertical concrete wall and has no vegetation (no shade). Next to this is the natural beach which has no modifications and large amounts of land vegetation (lots of shade). Beaches were monitored for 5 days in summer, during the early/middle part of spawning season, July 16-20, 2001.

Electronic data loggers were installed at the start of the 5-day monitoring period to record the environmental variables: light intensity, substrate (sand-gravel) temperature, air temperature and humidity. Data was automatically recorded at 5 min intervals. After downloading the data, it was split into day (sunrise to sunset) and night (sunset to sunrise). Four of the five days were used in the analyses. Sand-gravel samples were collected on the last day near the logger locations. These were looked at for total amount of surf smelt eggs, and how many were alive vs. dead. Statistical tests were conducted to determine if any of the variables examined were significant and if they affected the development of surf smelt emybros.

Results

Environmental conditions

On the modified beach, sand-gravel temperature and air temperature were ***significantly higher*** and humidity was ***significantly lower*** compared to the natural beach (Figure 1). Enough heat was absorbed by the modified beach to keep the sand-gravel and air temperatures higher even at night.

The biggest difference was in sand-gravel temperatures. The modified beach was up to 11°C higher than the natural beach.

Overall, the modified beach was hotter and had larger variations in conditions (think about having to deal with large changes in temperature every day). This can cause stress on the embryos and affect their ability to develop.

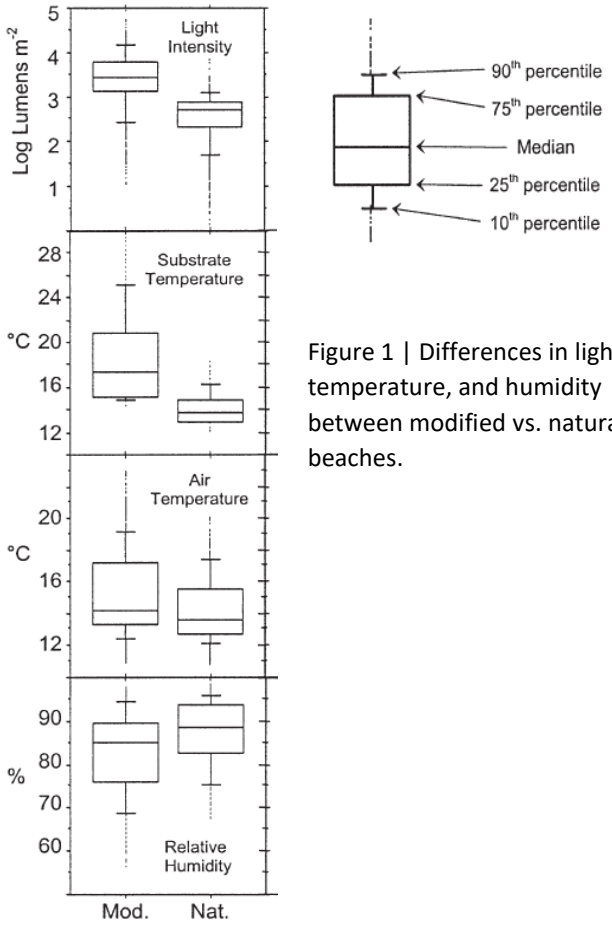

Figure 1 | Differences in light, temperature, and humidity between modified vs. natural beaches.

Egg survival

On the modified beach there were about half the total number of eggs, and about half the number of eggs with live embryos compared to what was found on the natural beach (Table 1). However, the small sample size means that the statistical power for these tests was lower (more data = more power to reveal what is truly going on).

Table 1 | Surf smelt eggs per sample (eggs per square cm) and percent of eggs containing live embryos at the natural and modified beaches. The average number of live eggs was significantly higher on the natural beach.

	Smelt egg density (eggs cm^{-5}; n = 5)		Percent of smelt eggs containing live embryos (n = 5)	
	Natural	Modified	Natural	Modified
Mean (± SD)	15.7 ± 17.6	7.9 ± 4.7	49.8 ± 13.6	24.8 ± 26.3
Median	5.7	7.9	51.7	12.1
Range	1.0–35.7	2.3–14.1	32.8–63.5	1.9–59.4

Discussion

In order to protect surf smelt populations, we must understand how human modifications affect their ability to survive. The results of this study show that human changes can make beaches in Puget Sound brighter, hotter, and drier and that can severely impact survival of surf smelt embryos. Although this study only looked at a small set of variables at 2 beaches, it demonstrates the potential changes that can occur on modified beaches.

How much sunlight reaches the beach is a primary reason the modified beaches were brighter, hotter and drier. Removing natural structure, such plants that provide shade, can create a harsher environment for life. Other studies also support the idea that natural beaches have less harsh conditions and are likely home to a greater variety of species than modified beaches.

It is clear that increased temperatures decreased the ability of surf smelt embryos to develop since the modified beaches had half the number of embryos survive compared to the natural beach. Increased temperatures can change how quickly the embryos develop, making them hatch at the wrong time. Increased temperatures can also lead to drying out, which kills the embryos. Both are bad for surf smelt survival, but drying may be worse because it directly kills the embryos, resulting in no possibility for survival.

This study shows there are significant differences in environmental conditions between modified and natural beaches. Beach modifications may decrease how much suitable habitat is available for spawning forage fish and that could lead to reduced reproduction and population declines. More research is needed on the surf smelt life cycle, habitat selection, what environmental conditions they can tolerate, the quality and location of potential spawning habitats, and predator/prey dynamics to better understand how beach modifications affect surf smelt populations throughout Puget Sound.

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