# Puget Sound Notes

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**Editors:** Lori Scinto and Toni Droscher, PSWQAT

inside:

## Assessing the ecological impact of an introduced species:

# The Asian mud snail finds a home in Padilla Bay

By **Mary O'Connor,** Marine Ecologist

After tumbling down mountain cascades and winding through fields of cows and corn, a chinook salmon (*Oncorhynchus tshawytscha*), beginning its seaward migration in the Skagit River, swims through Swinomish Slough and arrives in Padilla Bay (see map, Page 2). At the mouth of the Skagit River, the salmon will swim over beds of eelgrass (*Zostera spp.*) as it encounters salt water for the first time. If the fish nestles in the eelgrass, it might feed on small crustaceans and share the habitat with crabs, other fish and mud snails.

Continuing on toward the ocean, the young salmon might pass a kayaker on her way out to Saddlebag Island or a tanker coming to collect oil from the Shell oil refinery on the western shore of Padilla Bay. The young salmon might dodge the piercing bill of a Great Blue Heron (*Ardea herodias*) or the talons of a bald eagle (*Haliaeetus leucocephalus*). Finally, the salmon will pass Guemes Island on its way to the Pacific Ocean through the Strait of Juan de Fuca.

## Notes from the North...

Some environmental problems are unique or more pronounced in certain parts of Puget Sound. For example, the introduction of the invasive cordgrass, *Spartina*, is a problem that for now plagues the Sound only north of Tacoma Narrows.

In this issue of *Puget Sound Notes,* we present scientific findings on an introduced snail in Padilla Bay and on forage fish in Cherry Point. We also highlight a protocol developed to collect more complete scientific data on forage fish spawning habitat in the San Juan islands.

Although the environmental topics discussed in this issue of *Puget Sound Notes* all take place in the context of northern Puget Sound, they represent concerns that could occur anywhere in the Sound—the threat of an introduced species, the decline of a fish stock, or the need to fill data gaps on a vital marine resource.

In addition to providing food and shelter for salmon, the Padilla Bay estuary provides food, refuge and habitat for many marine and terrestrial organisms, from the butter clam (*Saxidomus giganteus*) to the bald eagle. This rich ecosystem is designated as a National Estuarine Research Reserve and is managed by the Washington State Department of Ecology as a protected area and research site.

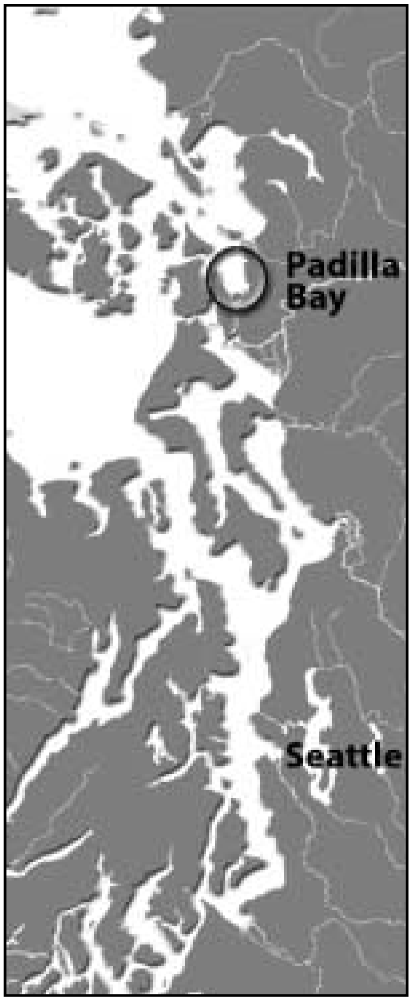
But are the inhabitants of Padilla Bay the same species the salmon's ancestors met 80 or 100 years ago? A close look at the species inhabiting the bay's mudflat community today reveals that important changes have occurred. For example, the two most common species of eelgrass in Padilla Bay are not native; they originated in Japan. Additionally, the cordgrass *Spartina alterniflora,* which has begun to radically alter the mudflat habitat of Padilla Bay, is native to east coast salt marshes.

At low tide when miles of mudflat are exposed, a visitor cannot take a step without squishing a dozen small conical mud snails. These snails are *Batillaria attramentaria* (hereafter referred to as *Batillaria*), a species native to the mudflats of Japan.

The presence of non-native species in Padilla Bay evokes many questions: How were these species introduced to the bay? Why are they successful in an ecosystem so far from where they evolved? What effect do they have on the native ecosystem? To answer some of these questions, researchers from the University of Washington recently conducted an experimental study to explore the ecological role of the Asian mud snail *Batillaria* in Padilla Bay.

### Introduced Species

Most species are restricted to the geographical area in which they evolved. When a few individuals of a certain



species are incidentally transported beyond their original range, they may be lucky enough to arrive in a habitat in which they will not immediately become prey or starve to death. In some cases, they might reproduce and become established in the new location.

Species are introduced by myriad mechanisms, such as driftwood carrying a small lizard to an island in a strong storm, or ships transporting ballast water (and floating larvae) from one port to another. The problem of introduced species is relatively new, increasing dramatically with the proliferation of transcontinental and transoceanic travel.

Once established, the potential impact of an introduced species on the native community ranges from undetectable to catastrophic. If the invader is a predator, impacts on the native fauna might be irreversible, such as when the brown tree snake (*Bioga irregularis*) was introduced to the island of Guam. This snake rapidly consumed to extinction many species of birds, small mammals and lizards on the island. An introduced species also has the capacity to alter the physical or chemical character of its adopted habitat and to make it suddenly unsuitable to the organisms that originally inhabited the system. For example, the zebra mussel (*Dreissena polymorpha*) is expected to affect nearly two thirds of America's freshwater bodies by increasing water clarity through filter feeding. The resulting reduction in certain planktonic species and greater amounts of sunlight penetration can greatly alter fish communities in these bodies of water.

Because introduced species can have severe impacts on a native system, a solid understanding of the mechanisms of invasions and a method of predicting the timing and effects of invasions would be highly valuable to managers working to preserve native communities. Modeling invasions is no easy task, however. Every ecosystem has unique combinations of physical elements and organisms, and all systems are defined by complex ecological interactions among many groups of organisms. Thus, it is very difficult to determine in advance the ecosystem's response to an introduced species. The first step toward a more complete understanding of invasions is to gain a basic knowledge of how and why they occur. Little research has been done to quantify specific invasions in such a way as to compare invasions and discover a pattern that might be used to predict future invasions. The Asian mud snail study in Padilla Bay was designed within a framework for comparing biological invasions and will provide important data for future invasion studies.

## 'Batillaria attramentaria'

Although *Batillaria* was first documented in Padilla Bay in 1960, it is thought to have been accidentally introduced up to 30 years before with the importation of the Japanese oyster *(Crassostrea gigas*), which began in 1932. Anecdotal information does not include a description of the mudflat community before the arrival of *Batillaria*, and there is no scientific documentation predating the invasion. Today *Batillaria* is the most abundant macrofauna on the mudflat. In fact, this 1.5 cm-long mud snail might be the only animal noticed by a casual observer! Total numbers of *Batillaria* in Padilla Bay are well over 1.4 billion. These numbers illustrate that this mud snail from Japan has little problem surviving in Padilla Bay.

*Batillaria* consume live benthic diatoms. They forage along the surface of the mud and burrow into the upper two centimeters, continuously disturbing the top layer of sediment. There is no larval stage in *Batillaria*'s life cycle to float about and disperse individuals to new habitats. Instead, egg pouches are laid and young mature near their parents. The absence of a pelagic larval stage restricts the species' mode of dispersal to crawling. For this reason, these snails do not inhabit the western shores of Padilla Bay, which is separated from the southern and eastern shores by Swinomish Slough. There are no specialized or abundant predators of *Batillaria* in Padilla Bay. A few snails fall prey to predatory crabs (*Hemigrapsus spp.*), red rock crabs (*Cancer productus*), Dungeness crabs (*Cancer magister)* and drilling snails (*Nucella spp.)*. After the mud snail dies, the shell is often occupied by a hermit crab (*Pagurus spp.*).

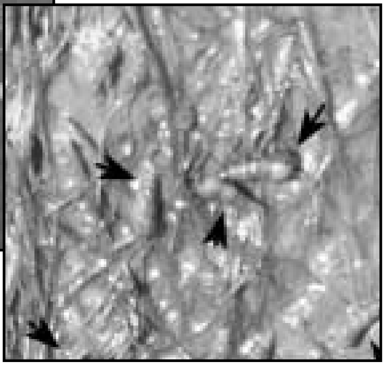
## The Study

To demonstrate the ecological impact of *Batillaria*, the study had two main objectives:

- to describe the abundance and distribution of *Batillaria* in Padilla Bay and
- to experimentally manipulate the density of *Batillaria* to reveal potential effects on native communities on several spatial and temporal scales.

**Assessing an invader in Padilla Bay:**
Researchers from University of Washington set up cages at 12 locations throughout the bay to explore the ecological role of the Asian mud snail *(Batillaria attramentaria)*—a species native to the mudflats of Japan.

Photos courtesy of Mary O'Connor



Tiny, 1.5-cm-long Asian mud snails are the most abundant macrofauna found on the Padilla Bay mudflats.

The ecological impact of an invader may be direct (through consumption) or indirect (through competition or habitat modification). Direct impact was addressed by quantifying *Batillaria*'s primary food source (benthic diatoms) using sediment chlorophyll *a* concentrations. *Batillaria*'s indirect effects on the Padilla Bay ecosystem are less easily assessed.

To identify effects of mud snail removal on other species in the community, we counted organisms living on the sediment surface and within the upper two centimeters of mud in experimental *Batillaria* exclusion and inclusion treatments. In addition, we quantified the effect of habitat modification through analysis of particle size distributions in several different habitats containing *Batillaria.*

## Abundance and Distribution

*Batillaria* were found throughout the portion of Padilla Bay lying east of Swinomish Slough in densities ranging from 20 snails/m$^2$ to more than 1000 snails/m$^2$. A negative relationship exists between shell height and *Batillaria* density. This pattern was present across all habitat types in the bay but was less clear at densities below 200 individuals/m$^2$, suggesting a threshold density level for growth limitation. The average height of *Batillaria* ranged from 20 mm at the most densely populated areas to 35 mm in the most barren areas on the southern mudflats.

## Community Effects

Two variations of a basic exclusion experiment were used to determine different aspects of *Batillaria*'s ecological role in Padilla Bay. The first experiment began in August 1999 and consisted of one set of treatments (an exclusion cage, an inclusion cage and an open control area) installed at 12 locations throughout the bay. The set was placed at 100 meters seaward from the high-tide mark. Sites were sampled for snail density, other infaunal density, surface sediment chlorophyll *a* concentration and surface sediment particle size in August, November, January and April. The second experiment began in April 2000 and consisted of eight sets of treatments installed at one site 100 meters from high tide to minimize variation between treatments. This site was sampled in April and September 2000.

Results described here are preliminary. In the first design, removal of *Batillaria* appeared to have an effect on sediment chlorophyll *a* concentrations. However, the effect was not consistent at all sites. This variability in response is attributed to the high variability in habitat characteristics between sites. For example, certain sites had no vegetation and were characteristically sandy. Other sites had dense eelgrass and very fine sediments.

In the second design, where all treatments were at one site in the bay, some interesting trends were notable in response to the removal of *Batillaria*. Preliminary observation suggests that without the relatively large mud snails present to consistently disturb the upper layer of sediment, finer particles are allowed to settle. The settling of finer sediments appears to diminish the percent cover of eelgrass. If *Batillaria* indeed facilitate the growth of eelgrass (which further analysis of our data will determine), the role of *Batillaria* is then indirectly important to the well-being of young fish and the animals that feed on them. Eelgrass provides a sheltered, nutrient-rich nursery habitat for many species of fish, such as herring. In turn, many species of resident and migrating birds take advantage of this concentrated energy source.

The infaunal species for which we sampled, such as tube-building polychaete worms, copepods and amphipods, did not respond to the removal of *Batillaria* and the subsequent shift in surface particle size.

It is possible, though, that certain other organisms require the turbid environment maintained by *Batillaria*. Specifically, another mud snail, *Nassarius fraterculus,* (about 4-mm long and also introduced from Japan) generally decreased in density in the *Batillaria* exclusion cages. It is an interesting pattern, and the relationship between these two mud snails remains unexplained.

Other potential effects of *Batillaria* on the soft sediment community might be estimated by understanding the dynamics of the community and by studying the literature of other mud snails. The foraging and burrowing of mud snails can be a consistent and important disturbance to the soft sediment community. It has been shown that the eastern mud snail, *Ilyanassa obsoleta*, has strong effects on mudflat community structure through bioturbation. These mud snails disturb the upper layers of sediment particles, keeping the smaller particles in suspension and the surface particles loosely packed. At low levels, this disruption of settling mud is beneficial to diatom productivity within the system, but higher levels of disturbance (i.e., more snails) cause diatom productivity to decrease. Changes in primary production within the system can in turn affect organism populations at levels higher in the food web. In addition to bioturbation, snails may manipulate the average particle size of the surface sediments by ingesting small clay particles with food and later egesting them aggregated in fecal pellets. This increases the particle size of the sediments. Bioturbation and pelletization by mud snails are habitat-modifying processes that have been found to influence the distribution of other benthic organisms such as amphipods, oligochaetes and diatoms. Responses of these and other organisms to sediment disturbance can also be important in determining community structure.

Another important mechanism of mud snail impact on the soft-sediment community is through consumption and the resulting competition for food. The benthic diatoms that mud snails eat are a major food source for many mud flat organisms. It is therefore thought that some species may compete with each other for access to this food source. For example, an increase in diatom-consuming nematode worm populations following the removal of *I. obsoleta* has been explained as a response to the sudden disappearance of the competitively dominant mud snail. Consumption of diatoms can also have direct effects such as the restructuring of the diatom community. One study has shown that grazing by *I. obsoleta* affects diatom communities by increasing the proportion of non-migratory diatoms to migratory diatoms. In addition, selective grazing by mud snails based on size and shape of diatoms leads to the removal of certain diatom species or sizes, changing microalgal community dynamics. In some cases, if snails preferentially consume diatoms such that the more productive types are not preyed upon, then the net primary production of the diatom community might even increase due to snail consumption. However, in other situations, high densities of mud snails can overgraze diatom populations and suppress primary production.

One other mechanism of interaction between mud snails and the basic trophic levels of the community is through fertilization. Mud snails add ammonium to the system through the deposition of feces and acceleration of nutrient cycling.

The possible interactions between *Batillaria* and the diatom community are many and the character of the overall interaction remains unclear. Several studies have shown that *Batillaria* selectively consume diatoms according to size and shape, and therefore potentially influences diatom community structure in a manner similar to that of other mud snails. Our results suggest high variation in the quality of the response of sediment chlorophyll *a* concentrations to the removal of *Batillaria* in different habitats. If real, this pattern indicates that the presence of *Batillaria* does affect productivity of the diatom community and that the effect varies with time and space. A possible explanation for this variability is that multiple mechanisms of impact occur between snails and diatoms, and the relative importance of each mechanism varies with habitat.

## Conclusion

As the most numerous benthic organism of is size on the mudflats, *Batillaria* has affected the Padilla Bay ecosystem. This study begins to explore the complex community of which *Batillaria* is a member. Our new knowledge of this community inspires many more questions about *Batillaria* as a non-indigenous species—and about other invasive species in other systems. If the activities of the Asian Mud Snail create a friendlier habitat for eelgrass, was *Batillaria* in any way responsible for the success of the relatively recent invasion of *Zoestra japonica*, a Japanese eelgrass, to Padilla Bay? If so, what have been the effects of the eelgrass invasion? Does the presence of this apparently harmless little mud snail have any effect on the populations of migrating birds or local salmon that pass through Padilla Bay?

This is the first experimental study of the ecological role of *Batillaria* in Padilla Bay. Few studies to date have focused on the benthic ecology of Padilla Bay. The baseline ecological data provided here will be useful to the science-based management of the Padilla Bay National Estuarine Research Reserve. Final results and analysis of this study will be available after December 2000. There is much to learn from the new data, and there are many new questions to ask about the extent of the ecological impact of this non-native mud snail on a local ecosystem.

# Egg incubation studies provide clues to the future of the once-largest herring stock in Puget Sound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## Introduction

Discrete spawning populations of Pacific herring (*Clupea pallasi*) occur throughout Puget Sound and at least one population spawns along the Pacific coast of Washington in Grays Harbor and Willapa Bay. For management purposes, the Washington Department of Fish and Wildlife classifies each spawning population of herring as a discrete "stock" based on distinguishable subadult growth rates as well as temporally and spatially distinct spawning patterns.

The Cherry Point herring population was historically the largest stock in Puget Sound and once supported a herring roe fishery. However, a precipitous decline in biomass of spawning herring from this stock has occurred since Fish and Wildlife began spawning surveys in the early 1970s. Herring spawning biomass at Cherry Point, which was nearly 15,000 tons in 1973, has declined to less than 1,000 tons in 2000. Speculated causes of this decline include: over-fishing; predation by marine mammals and birds; straying of reproductively mature adults to other spawning locations; climatic effects (Pacific decadal oscillations); disease; and pollution.

Analysis of the cause for the decline in biomass at Cherry Point is confounded by the fact that biomass of most other herring stocks in Puget Sound is not in a state of decline. However, a unifying theme among Cherry Point herring and the Discovery Bay stock (another spawning population that has undergone a population decline) is the belief that both groups subscribe to an oceanic life history phase as non-spawning adults. Most other populations of herring in Puget Sound are believed to be resident sub-populations that never leave the confines of the Sound, even as non-spawning adults.

Industrialization along the Cherry Point shoreline has led to the possibility of herring embryo exposure to waterborne contaminants. The shoreline, which was historically used as spawning habitat, now contains two petroleum tanker off-loading docks and a similar dock used by an aluminum smelting operation. Additionally, negotiations are currently underway for construction of a new pier along the shoreline. Exposure levels of petroleum hydrocarbons as low as 0.01 ppm can cause low hatch weight and genetic damage to developing herring larvae while higher levels can result in premature hatch and physical defects (Kocan et al. 1996). These effects are most likely manifested early in embryonic development because the first few cleavage stages of a fertilized egg are generally the most likely to be killed by toxic substances and the pre-differentiated developmental stages are most likely to produce birth defects (McKim 1985). After that time, when cellular and organ differentiation are underway, biochemical and carcinogenic effects are most likely to occur.

This study was conducted to estimate the survival potential of herring larvae from Puget Sound through a series of *in situ* herring egg incubations along the Cherry Point shoreline and collections of naturally spawned eggs from various Puget Sound stocks. Results are discussed in terms of possible causes of the abnormalities and implications for the future of Cherry Point herring stock.

## METHODS

### 1999 STUDY

Sexually mature herring were captured by gill net along the Cherry Point reach on May 14, 1999. Eggs were removed and pooled from eight females and milt from five males was pooled into a separate container. The pooled eggs were then evenly distributed over 36, 4-inch x 4-inch Nytex swatches and fertilized with the milt for one hour. Fertilized egg swatches were placed inside individual cassettes constructed of 6-inch lengths of 4-inch ABS plastic pipe capped with 1/8-inch nylon mesh on both ends. Five replicate herring egg cassettes were deployed nine feet from the bottom in 18 feet of water (mean lower low water) at each of six stations along the Cherry Point shoreline. Additionally, six replicate control cassettes containing fertilized eggs were immediately returned to the Marrowstone Marine Station and incubated in sand-filtered, UV-sterilized seawater throughout the entire developmental period.

*In situ* incubation of the herring eggs at the six Cherry Point stations proceeded for five days, after which cassettes were retrieved and developing embryos were transferred to the Marrowstone Marine Station. At this point, each replicate swatch of eggs was removed from the respective cassette, washed of debris and placed into an individual, flow-through, 10-gallon aquaria supplied with sand-filtered, UV-sterilized seawater. Within 24 hours of peak hatch, approximately 100 larvae from each aquarium were euthanized with an overdose of tricaine methane sulfonate (MS-222) and preserved in 5 percent neutral-buffered (NB) Formalin for later evaluation. The remaining hatched larvae were similarly sampled after five days.

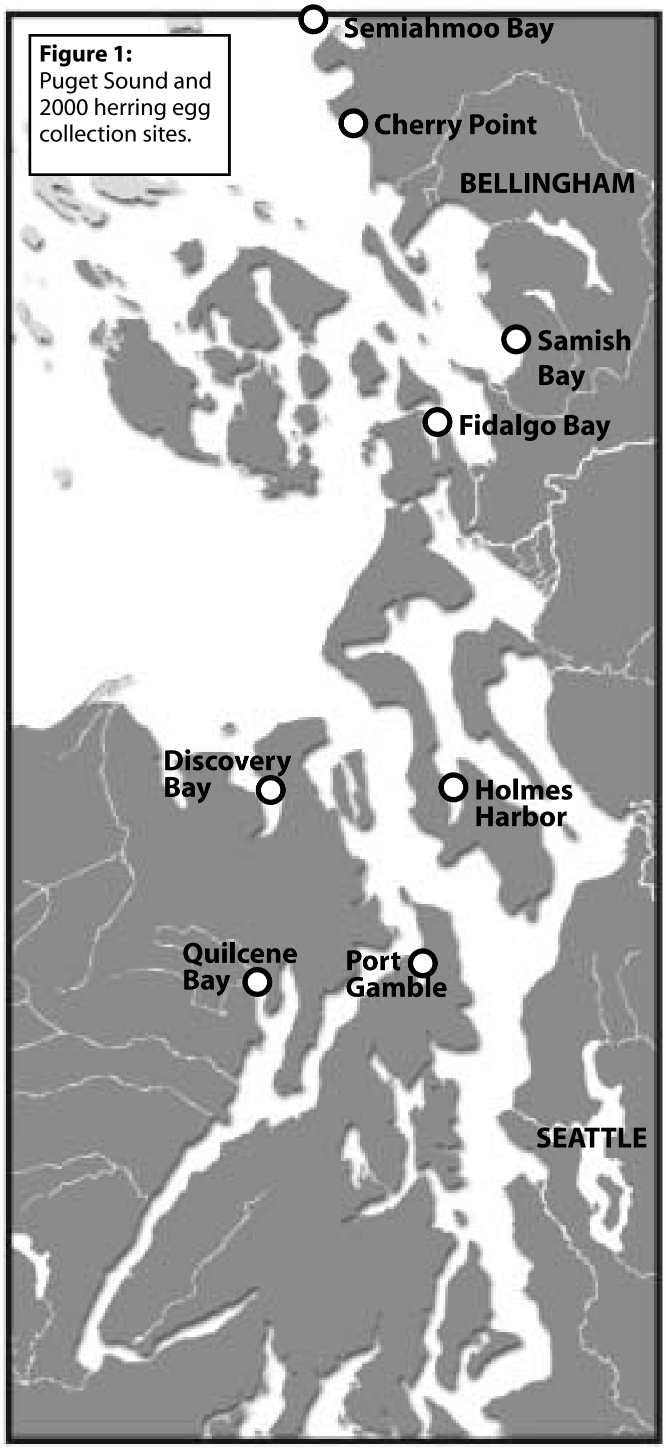

**Figure 1:** Puget Sound and 2000 herring egg collection sites.

Preserved larvae were analyzed for mean dry weight at time of hatch and percent of larvae with gross skeletal abnormalities. Approximately 20 newly hatched larvae from each replicate were dried at 70°C for 17 hours and mean dry weight/larvae was calculated. The percent of larvae with skeletal abnormalities was determined by examining approximately 100 larvae (five days post-hatch) from each replicate for signs of scoliosis and/or lordosis.

Additionally, eelgrass containing naturally spawned herring eggs was collected from two sites in Holmes Harbor on April 21 and one site at Cherry Point on May 25. All eggs were presumed to be newly oviposited due to the absence of a blastulodisc at time of collection. These naturally spawned eggs were transported to the Marrowstone Marine Station and embryonic development proceeded in flow-through, 70-gallon tanks supplied with sand-filtered seawater. On the day of the primary hatch and five days later, larval subsamples from each collection were euthanized, preserved in 5 percent NB Formalin and later analyzed for abnormalities and hatch weight.

### 2000 Study

Naturally spawned herring eggs on eelgrass were collected from herring stocks in Puget Sound including:

- Fidalgo Bay—Feb. 15, March 1 and March 14
- Semiahmoo Bay—March 6
- Port Gamble—March 9
- Samish Bay - March 10
- Discovery Bay—March 15
- Quilcene Bay—March 16
- Holmes Harbor—April 4
- Cherry Point—May 4 and two other Cherry Point locations—May 15.

(See Figure 1, left.)

All collections were transported to flow-through 70-gallon tanks supplied with sand-filtered seawater at the Marrowstone Marine Station. On the day of the primary hatch and five to seven days later, larval subsamples from each collection were euthanized, preserved in 5 percent NB Formalin and later analyzed for skeletal abnormalities and hatch weight. Additionally, the percent of larvae with no yolk was determined by counting 100 newly hatched larvae from each egg collection site.

Data on the percent of larvae with skeletal abnormalities from the *in situ* incubations were arcsine transformed and statistically analyzed using ANOVA and all other proportions were statistically compared using the Z-test for proportions. Larval dry weights were statistically compared with a t-test (Zar 1983). Statistical significance was assigned to comparisons with $p < 0.05$.

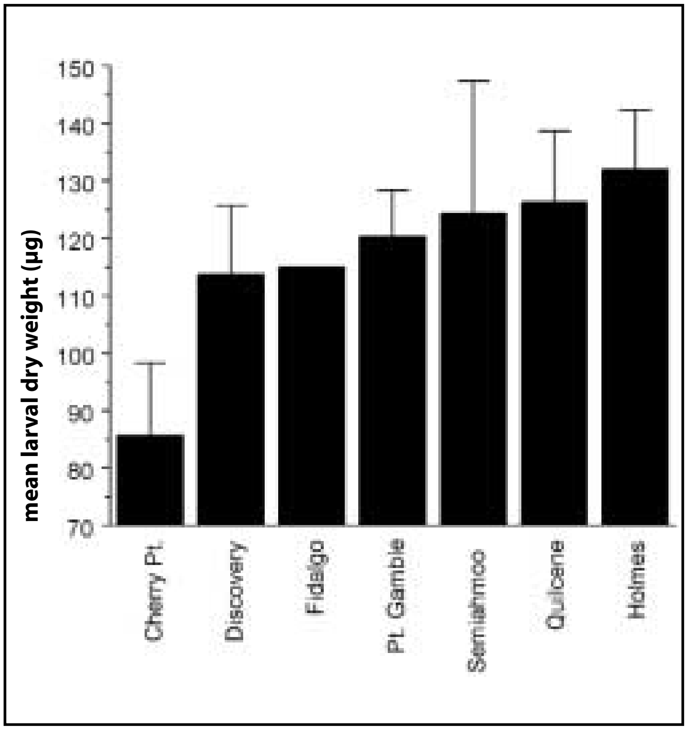

**Figure 2:** Mean larval dry weight at hatch from Puget Sound herring stocks during 2000. Error bars indicate one standard deviation.

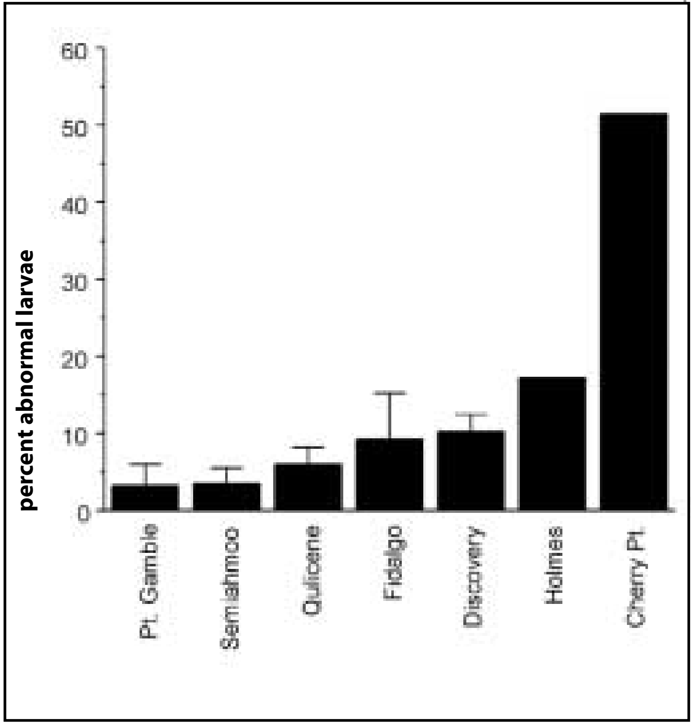

**Figure 3.** Percent of herring larvae with skeletal abnormalities from each Puget Sound herring stock . Error bars indicate 95 percent confidence interval.

## RESULTS

### 1999 STUDY

The primary larval hatch from all artificially spawned eggs incubated *in situ* as well as those incubated in the laboratory occurred on May 28, 14 days after fertilization of the eggs. Mean dry weight at time of hatch was similar among newly hatched larvae from all 1999 *in situ* stations and control replicates, ranging from 72.7 to 80.3 µg/larvae, with an overall mean of 76.9 µg.

Greater percentages of skeletal abnormalities (24.4 to 46.6 percent) occurred among larvae incubated *in situ* than among control larvae (23 percent) that underwent complete development in the laboratory. The highest prevalence of skeletal abnormalities occurred among larvae that were incubated at the southernmost Cherry Point stations but none were significantly different from controls ($p > 0.05$).

The mean larval dry weight at hatch from naturally spawned herring eggs deposited at Cherry Point was 77 µg, similar to the mean dry weight of larvae from artificially spawned eggs incubated *in situ* (76.9 µg), but significantly less ($p < 0.001$) than the mean dry weight of larvae from naturally spawned herring eggs in Holmes Harbor, which weighed 100-111 µg/larvae.

### 2000 STUDY

The mean larval dry weight at hatch from naturally spawned herring eggs at Cherry Point was 85 µg, significantly less ($p<0.02$) than that of larvae from other Puget Sound herring stocks sampled during 2000, which ranged from 114 µg in Discovery Bay to 132 µg in Holmes Harbor (Figure 2, above). Additionally, a significantly greater percentage ($p<0.001$) of larvae from Cherry Point hatched with no yolk (86 percent) than did larvae from other Puget Sound herring stocks (1 to 28 percent).

A significantly greater percentage ($p<0.001$) of herring larvae from the Cherry Point stock had skeletal abnormalities (52 percent) than did those from other Puget Sound herring stocks, which ranged from 3 percent in Port Gamble to 17 percent in Holmes Harbor (Figure 3, above).

## Discussion

Decreased survival potential among herring from the Cherry Point stock was indicated by reduced larval hatch weights, greater percentage of larval skeletal abnormalities and insufficient larval yolk reserves at time of hatch compared to larvae from other Puget Sound stocks. Normal herring larvae hatch from the egg with underdeveloped mouthparts and rely on yolk reserves for survival until mouthparts develop and intestinal colonization with biota permit exogenous feeding and digestion. Thus, absence of yolk among 86 percent of the newly hatched larvae from Cherry Point in 2000, which also had underdeveloped mouthparts, probably led to a high early life-stage mortality among larvae from this stock.

Cause(s) of the low hatch weights and lack of yolk among Cherry Point herring larvae remain undetermined.

Low larval weights at hatch can be caused by a number of factors including young/small adult spawners, disease, inadequate food supply, etc. (Hay and Brett 1988). Among Pacific herring, older and larger spawning females tend to produce larger eggs and subsequently larger larvae than do younger, smaller adults (Hay 1985). Data from Fish and Wildlife spawning biomass surveys indicate that young fish (primarily 2-year-olds) have begun predominating the spawning biomass at Cherry Point in recent years rather than older, 3-plus-year fish, which have historically predominated. Simultaneously, mean dry weight at hatch among Cherry Point larvae was 15 percent greater in 1991 than in 1999 (Kocan 1991). Such a decrease in adult spawner age and size may partially explain the reduced weights at hatch among Cherry Point larvae, but fails to account for the high percentage of larvae which hatched with no yolk in 2000.

The low weights at hatch among Cherry Point larvae appear to be a stock-specific occurrence rather than a larger-scale pattern. Not only were larval dry weights from Cherry Point less than those from other Puget Sound herring stocks, but they were also significantly less ($p < 0.001$) than those reported for herring larvae in British Columbia (Schnack 1981) and Prince William Sound, Alaska (Kocan et al. 1996). Similarly, a stock-specific problem is indicated by a significantly greater percentage of larvae with gross signs of scoliosis and/or lordosis relative to all other Puget Sound herring stocks analyzed in 2000.

Presence of petroleum processing and aluminum smelting operations along the Cherry Point shoreline have led to speculation regarding the correlation of these industries with the decline in spawning herring biomass along this reach. Although the mean dry weight at hatch among herring larvae at Cherry Point (77 µg) was similar to that reported for herring larvae continuously exposed to high levels of petroleum hydrocarbons (PAHs) throughout embryonic development (Kocan 1996), it is unlikely that contaminant exposure directly resulted in the low weights at hatch recorded among Cherry Point larvae. Artificially fertilized Cherry Point herring eggs incubated *in situ* produced larvae with low hatch weights that were similar to those of control larvae that were incubated in the laboratory throughout the entire pre-hatch developmental period.

It is also unlikely that the eggs used for the bioassay were exposed to contaminants from the industrialized shoreline because pre-spawn adult herring at Cherry Point stage in deep water, far off shore prior to spawning. Additionally, preliminary data from the Puget Sound Ambient Monitoring Program indicate that bile sacs from Cherry Point herring contained similar or lower levels of napthalene, phenanthrene, and benzo (a) pyrene relative to those of the two other north Puget Sound herring stocks analyzed in 1999 (Sandra O'Neill, personal communication). However, the possibility of early life-stage exposure of herring eggs and/or larvae to waterborne contaminants should not be dismissed as a potential cause in the decline in Cherry Point spawning herring biomass. Such exposure at critical developmental stages may chronically affect the reproductive potential of the fish and ultimately manifest abnormal effects such as skeletal abnormalities and low hatch weights in the F2 generation.

Spawning herring biomass at Cherry Point has declined to low enough numbers in recent years that the population may currently be below levels which are necessary to sustain genetic diversity. Herring no longer spawn along the entire length of shoreline at Cherry Point. Instead, only a short stretch of shoreline, located well north of the industrialized section, is currently used as spawning habitat. Thus, although semblance of a trend in increasing larval abnormalities occurred among artificially spawned eggs which were incubated at the southern extreme of the Cherry Point study range during 1999, natural spawn has not occurred in this southern region for several years. Curiously, the spawning herring biomass has not rebounded or even stabilized since cessation of spawning in the southern zone.

It is not known whether the abnormalities detected among larval herring caused, or are, instead, a consequence of the decline in herring spawning biomass at Cherry Point. The real significance of these results is that they provide insight into the probable future trends of the herring stock at Cherry Point. With the lowest recorded adult herring spawning biomass in history occurring during 2000 and 52 percent of the resulting larvae hatching with skeletal abnormalities and 86 percent with no yolk, all available data indicate the decline in spawning biomass will continue at least through the next two to three years until the 2000 cohorts enter the spawning population.

Although the overall herring population in Puget Sound has remained somewhat steady, with increasing biomasses from other stocks compensating for the reduced biomass at Cherry Point, forage fish managers must decide how best to protect the residual population, which is currently under consideration for proposed listing as threatened or endangered under the Endangered Species Act by the National Marine Fisheries Service. Therefore, it is imperative that future research be conducted to determine the cause(s) of the larval abnormalities at Cherry Point in order to predict or even prevent this occurrence among other stocks.

## Acknowledgments

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# San Juan County strives to protect forage fish spawning areas

By **Lawrence L. Moulton,** Forage Fish Coordinator
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An abundance and diversity of marine fauna, including marine mammals, sea birds and a diverse fish assemblage are key attributes of the waters surrounding the San Juan Islands. The marine mammal populations attract observers from far and wide, but these mammals are showing signs of stress. Puget Sound chinook and Hood Canal summer chum were recently listed as threatened under the Endangered Species Act and Puget Sound coho are a candidate for listing. In addition, bottomfish stocks in San Juan County are depressed and have prompted the county to initiate a recovery program.

> **"The amount of potential forage fish spawning habitat varies greatly by island, with Lopez Island containing the greatest linear amount of potential habitat, and Waldron Island containing the highest percent of shoreline as potential habitat.**

A key to maintaining the health of the marine ecosystem and to the success of recovery programs is ensuring that critical elements of the habitat and food chain are available to recovering populations.

The San Juan County Marine Resources Committee (MRC) has been committed to proactive planning to ensure continued viability of marine resources within the county's boundaries since the committee's inception in 1996. In 1998, the MRC recognized that current planning for bottomfish recovery, salmon recovery and continued viability of marine mammal and sea bird populations using county waters, required that forage fish stocks receive aggressive protection.

Many of the marine mammals and sea birds in the region and salmon populations migrating between coastal streams and the ocean use the waters around the San Juan Islands as feeding grounds. Some of the more abundant forage fish species used by these diverse species include Pacific herring (*Clupea pallasi*), surf smelt (*Hypomesus pretiosus*) and Pacific sand lance (*Ammodytes hexapterus*). All of these forage fish species spawn in intertidal or shallow, subtidal areas in nearshore regions. Surf smelt and Pacific sand lance in particular, use the upper intertidal portion of mixed sand and gravel beaches for spawning. Not all shorelines that appear suitable seem to be used by forage fishes. In fact, it appears that less than 20 percent of beaches with potential spawning habitat actually support spawning activity.

The Washington Department of Fish and Wildlife attempts to protect all known, documented Pacific herring, surf smelt and Pacific sand lance spawning habitats from the impacts of shoreline development. "No net loss" regulations for protection of known spawning sites are included in the Washington Administrative Code

**Figure 1.**

▨ Indicates surf smelt spawning area in the upper intertidal region of Hunter Bay, Lopez Island. Note that the spawning area has been split and reduced by construction of a dock and launch ramp.

Photo by Washington State Department of Transportation.

“Hydraulic Code Rules” (WAC 220-110), which are applied by Fish and Wildlife marine habitat managers during considerations for granting hydraulic permits for in-water shoreline development proposals. However, forage fish habitat protection regulations only apply to shorelines where spawn has actually been detected by Fish and Wildlife biologists or other qualified surveyors. Formerly productive spawning habitat has been degraded or destroyed by shoreline practices in the absence of information (or concern) regarding forage fish spawning activity (see Figure 1, above). Thus, it is critical for overall protection of these habitats that spawn deposition site inventories be complete and comprehensive.

Fish and Wildlife conducted a systematic survey of forage fish spawning beaches from 1991 to 1996 throughout Puget Sound, but lost funding for the effort in 1997, just as San Juan County beaches were to be surveyed. As a result of the diminished program, only a small portion of potential beach spawning habitat has been surveyed (Penttila 1999). To complete surveys initiated by Fish and Wildlife, the San Juan County MRC is conducting a project to identify forage fish spawning sites within the county. The objective of the project is to provide information to help prevent further loss of forage fish spawning habitat. Identifying spawning areas will allow more complete protection as provided for under existing regulations.

The initial two phases of the forage fish assessment project were to:

- develop field protocols to be used during sample collection to ensure that information resulting from the project would be standardized and acceptable to WDFW habitat managers and
- identify and map known and potential intertidal spawning areas

The protocols essentially document methods developed and used by Dan Penttila and Kurt Stick of Fish and Wildlife in previous forage fish investigations throughout Puget Sound (see Penttila 1995 and Stick 1990). The protocols document was developed and published in June 2000 (Moulton and Penttila 2000) through funding by the Northwest Straits Commission.

Mapping of potential spawning areas was accomplished by identifying potential spawning beaches from low-level oblique aerial photographs looking towards the beach. Potential spawning beaches were mapped onto 1:24,000 scale USGS topographical sheets, and each mapped beach was assigned a unique identifying number. In addition, mapped potential spawning beaches on Shaw Island were visually surveyed to evaluate the reliability of the classification based on interpretation of aerial photographs.

As part of the mapping program, a letter was sent to each landowner whose property adjoined a potential spawning beach. The letter informed the landowner of the project and their proximity to potential forage fish spawning habitat. Permission was requested to access their beach during the field investigation phase of the project.

Field verification reduced the number of potential spawning beaches on Shaw Island by about 20 percent, so it is expected that a similar reduction will occur when other islands are field-verified. The beach information was then transcribed to the San Juan County GIS base map, where it is being made available to the county permit center for use when evaluating potential development

| Island | Number of Beaches | Potential Habitat (miles) | Island Perimeter (miles) | Percent Potential Habitat |
|---|---|---|---|---|
| Lopez | 90 | 25.43 | 63.37 | 40.1% |
| San Juan | 138 | 21.32 | 74.59 | 28.6% |
| Orcas | 172 | 16.69 | 77.27 | 21.6% |
| Waldron | 12 | 7.19 | 11.17 | 64.3% |
| Shaw | 60 | 6.04 | 25.81 | 23.4% |
| Decatur | 15 | 4.85 | 12.44 | 39.0% |
| Blakely | 19 | 4.53 | 12.20 | 37.2% |
| Henry | 20 | 4.19 | 10.87 | 38.6% |
| Stuart | 15 | 2.54 | 14.89 | 17.1% |
| Johns | 9 | 1.15 | 4.18 | 27.6% |
| Sucia | 12 | 1.04 | 11.79 | 8.8% |
| Satellite | 11 | 0.83 | 2.92 | 28.6% |
| Obstruction | 8 | 0.44 | 2.90 | 15.1% |
| Turn | 4 | 0.38 | 1.05 | 36.6% |
| Jones | 6 | 0.37 | 2.99 | 12.3% |
| Patos | 7 | 0.37 | 3.77 | 9.7% |
| Crane | 8 | 0.33 | 2.69 | 12.4% |
| Matia | 7 | 0.31 | 3.41 | 9.1% |
| Pearl | 1 | 0.29 | 1.24 | 23.8% |
| Brown | 5 | 0.26 | 1.57 | 16.4% |
| Charles | 2 | 0.15 | 1.37 | 10.9% |
| James | 3 | 0.15 | 2.34 | 6.3% |
| Canoe | 3 | 0.10 | 1.14 | 8.6% |
| Center | 1 | 0.03 | 2.00 | 1.5% |

NOTE: Shaw Island beaches were subjected to an on-water visual verification, which reduced the potential habitat from 73 beaches to 60 beaches.

**Table 1.** Distribution of potential spawning habitat for surf smelt and Pacific sand lance in San Juan County based on interpretation of oblique aerial photography.

proposals. The report for this phase of the project was completed in August 2000 (Moulton 2000).

The amount of potential forage fish spawning habitat varies greatly by island, with Lopez Island containing the greatest linear extent of potential habitat, and Waldron Island containing the highest percent of shoreline as potential habitat (Table 1). To date, 14 surf smelt and eight Pacific sand lance spawning sites have been identified, all through the Fish and Wildlife sampling program (Penttila 1999).

The initial phases of the project were funded by a Northwest Straits Commission grant to the San Juan County Marine Resources Committee. The results of the project are in some ways specific to San Juan County, but many elements of the protocols and mapping process are adaptable to other parts of Puget Sound. The Marine Resources Committee has requested funds to complete the field assessment portion of the project and hopes to initiate that phase in the near future. Both the protocols document and habitat report can be obtained through the Northwest Straits Commission:

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