Technical Report 2007-03

Marine Forage Fishes in Puget Sound

Prepared in support of the Puget Sound Nearshore Partnership

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Washington Department of Fish and Wildlife

Valued Ecosystem Components Report Series

PUGET SOUND NEARSHORE PARTNERSHIP

RESTORING OUR ECOSYSTEM HEALTH

The Puget Sound Nearshore Partnership (PSNP) has developed a list of valued ecosystem components (VECs). The list of VECs is meant to represent a cross-section of organisms and physical structures that occupy and interact with the physical processes found in the nearshore. The VECs will help PSNP frame the symptoms of declining Puget Sound nearshore ecosystem integrity, explain how ecosystem processes are linked to ecosystem outputs, and describe the potential benefits of proposed actions in terms that make sense to the broader community. A series of "white papers" was developed that describes each of the VECs. Following is the list of published papers in the series. All papers are available at *www.pugetsoundnearshore.org.*

Brennan, J.S. 2007. Marine Riparian Vegetation Communities of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-02. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Buchanan, J.B. 2006. Nearshore Birds in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Dethier, M.N. 2006. Native Shellfish in Nearshore Ecosystems of Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Eissinger, A.M. 2007. Great Blue Herons in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Fresh, K.L. 2006. Juvenile Pacific Salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Johannessen, J. and A. MacLennan. 2007. Beaches and Bluffs of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Kriete, B. 2007. Orcas in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-01. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Leschine, T.M. and A.W. Petersen. 2007. Valuing Puget Sound's Valued Ecosystem Components. Puget Sound Nearshore Partnership Report No. 2007-07. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Mumford, T.F. 2007. Kelp and Eelgrass in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Penttila, D. 2007. Marine Forage Fishes in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-03. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Front cover: Pacific herring (courtesy of Washington Sea Grant).

Back cover: Schooling Pacific sand lance, left, and surf smelt, right. (Photos courtesy of Dan Penttila.)

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Executive Summary

Forage fishes are small, schooling fishes that are key prey items for larger predatory fish and wildlife in a marine food web. In Puget Sound, forage fish species occupy every marine and estuarine nearshore habitat. Because of their role as critical prey species, including for economically important predators such as salmon, recent attention has been paid to their conservation and protection. Nearshore habitats are of special concern, because many species use them for spawning.

Pacific herring (*Clupea pallasi*), surf smelt (*Hypomesus pretiosus*), Pacific sand lance (*Ammodytes hexapterus)*, and their critical spawning habitats, all commonly occur within the nearshore zone of Pacific Northwest beaches. Within the Puget Sound Basin, where their spawning areas have been most completely mapped, each species appears to use approximately 10 percent of the shoreline spawning habitat during the year. Some, like herring, spawn in only a few geographically disjunct areas, whereas surf smelt and sand lance have widespread spawning grounds. Each species has particular habitat requirements for spawning; for example, a relatively restricted sediment grain size, particular tidal heights, or specific vegetation types. For all species, however, only a fraction of the apparently appropriate habitat area within Puget Sound is actually used. Some species tend to use the same beaches annually. Adjacent nearshore habitats are used as nursery grounds by all three species.

Other forage fish species do not spawn on Puget Sound beaches but use nearshore ecosystems in other ways. Northern anchovy (*Engraulis mordax*) are pelagic schooling fish that spawn and incubate their eggs in open water. Eulachon ("Columbia River smelt", *Thaleichthys pacificus*) and longfin smelt (*Spirinchus thaleichthys*) are anadromous, using gravel in freshwater streams for their spawning habitat. Longfin smelt stocks are known to spawn in Puget Sound Basin rivers (Nooksack and Cedar), and its non-spawning life stages may occur in the marine nearshore zone. These species represent the largest biomass in Lake Washington.

Little is known about any forage fish species away from their spawning grounds. Herring appear to be either resident or migratory but generally do not persist in the nearshore system in large schools after spawning. Herring spawning biomasses have been closely monitored and have stayed moderately stable for 20 years. Other species have not been monitored soundwide, and regular monitoring of some spawning beaches has only recently been initiated. However, spawning beaches are vulnerable to a wide variety of impacts from human development, especially removal of riparian vegetation and processes such as armoring and dredging that change the sediment quality and quantity in the intertidal and shallow subtidal zones. This means that these valued ecosystem components must be considered at risk and in need of conservation and restoration actions.

Preface

The status of Puget Sound forage fishes, especially herring stocks, is of general public interest in the region because of the large population of recreational anglers and wildlife watchers. Their societal importance is based largely on their apparent importance to provide forage for creatures higher in the marine food web (Figure 1) that are of either consumptive (e.g., salmon) or non-consumptive (e.g., herons) importance to society. In the past, sizeable commercial fisheries occurred on local herring stocks (for fish meal, fish oil, sac-roe and roe-on-kelp). Now, however, herring are commercially important in Puget Sound only as fresh or frozen sport-bait for recreational fishing. Northern anchovy are not harvested within Puget Sound, although relatively small quantities are harvested for recreational fishing bait on the outer coast of Washington state.

Surf smelt are recreationally and commercially important harvests for human consumption at scattered locations throughout the Puget Sound Basin. Most such harvests, by sport dip nets and small commercial beach seines, take place as the fish come into very shallow water to deposit their eggs at predictable times and places. Some docks and piers in Puget Sound support hook-and-line "jig" fisheries for non-spawning surf smelt during the winter months. Long-fin smelt occasionally support some harvest activity for human consumption, by long-handled dip nets, during their winter spawning migrations to the lower Nooksack River.

Pacific sand lance have never been harvested commercially in the Puget Sound Basin, and commercial exploitation of the species has recently been banned by the Washington Department of Fish and Wildlife (WDFW), given their important ecological role. Incidental catches of sand lances are dip-netted from "bird-balls" or "bait balls" by recreational anglers during local salmon fishing seasons as a preferred sport-bait for Chinook salmon.

Introduction

Forage fishes are loosely defined as small, schooling fishes that form critical links between the marine zooplankton community and larger predatory fish and wildlife in a marine food web (Figure 1). Forage fish species occupy every marine/estuarine nearshore habitat in Washington state. In the last 30 years, the conservation and management of critical habitats for forage fish species, largely limited to their known spawning sites, has been an integral part of local habitat management programs.

The three most common forage fish species are Pacific herring, surf smelt and sand lance; many of the intertidal and shallow subtidal areas within the Puget Sound Basin constitute spawning habitat for these species. Nearshore ecosystems also provide important nursery and feeding grounds for these species during their first year of life. Other forage fish species (northern anchovy, eulachon and longfin smelt) do not spawn on the beaches but do use nearshore habitats during other parts of their life histories and thus are included in this document.

Obligate spawning in nearshore habitats by herring, surf smelt and sand lance make them vulnerable to the cumulative negative impacts of a wide variety of shoreline development activities. The use of relatively limited portions of marine shorelines for spawning habitat by all three species may also produce vulnerable aggregations of pre-spawning adults during this portion of their life cycles. A very large proportion of the shoreline of the Puget Sound Basin has been altered in various ways by human development activities, to the possible detriment of these species. This vulnerability has resulted in this species group being given special regulatory attention in recent decades. The language of Washington Administrative Code (WAC) 220-110, the Hydraulic Code Rules governing hydraulic permit approvals by the WDFW, lists herring, surf smelt and sand lance spawning habitats as "marine habitats of special concern." A "no net loss" approach is applied to these habitats. The state Growth Management Act (GMA) includes herring and surf smelt spawning areas as examples of priority fish and wildlife habitat conservation "critical areas", for which there is an expectation of mapping and protective designations. This species group's ecological importance and critical habitat vulnerability have led to their inclusion in the species and habitat lists of the WDFW's Priority Habitats and Species (PHS) Program.

Puget Sound forage fish populations are not generally considered threatened or endangered. Two petitions to list Puget Sound herring stocks as threatened or endangered under the Endangered Species Act in recent years have failed to produce sufficient evidence to do so. However, the status or relative abundance of Puget Sound surf smelt, sand lance, northern anchovy or longfin smelt stocks are currently unknown, for lack of a cost-effective methodology and funding priority to assess them.

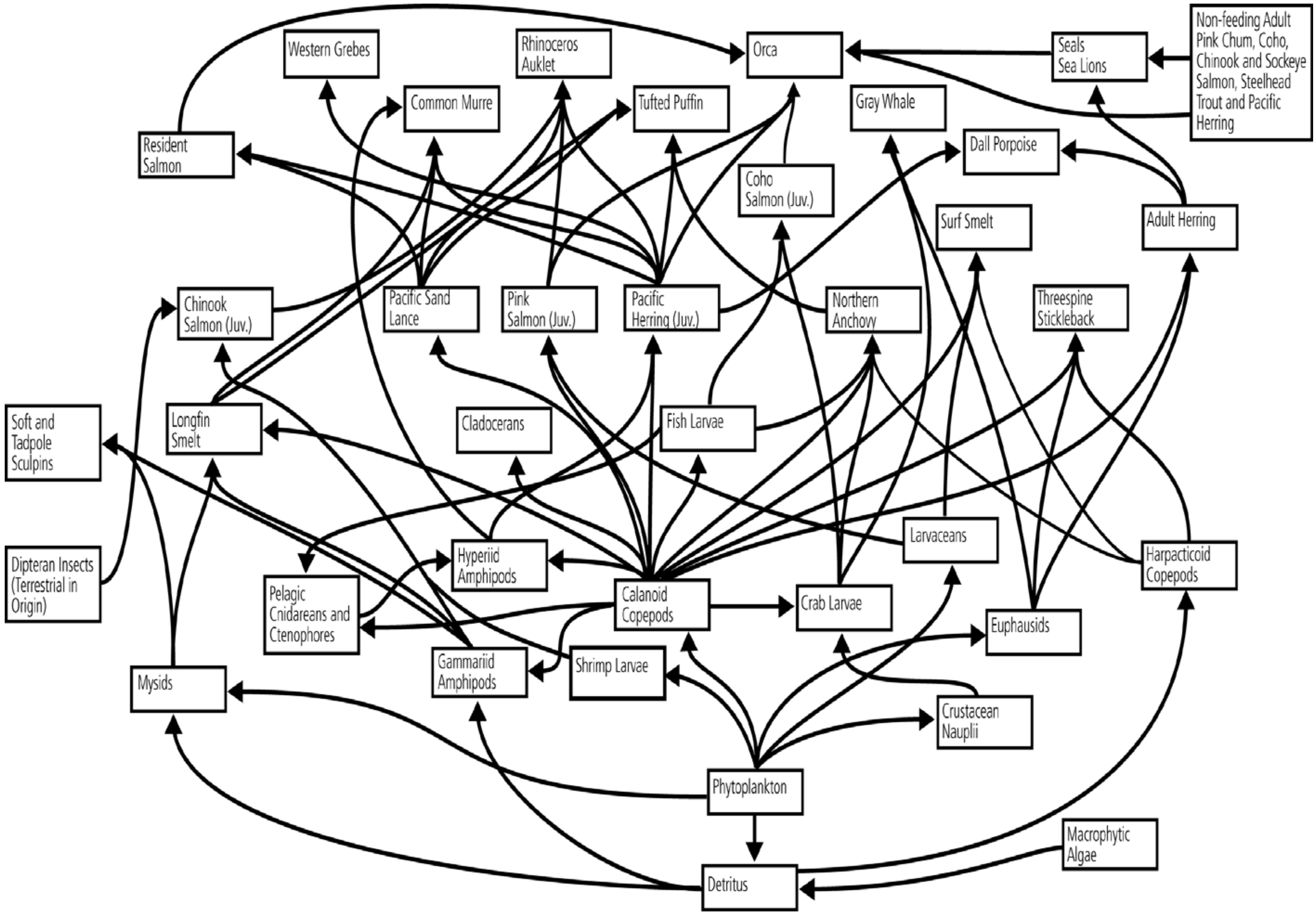

Figure 1. Nearshore open water food web. Note forage fish positions between macro-zooplankton and secondary predators (adapted from Simenstad et al. 1979).

Background: Distribution And Spawning Areas

Pacific Herring

Pacific herring are a pelagic species widespread throughout the marine waters of Washington. Approximately 20 individual herring stocks occupy the Puget Sound Basin, from Dungeness Bay east, and from the United States-Canada border south to the Olympia area (Figure 2). Spawning herring also frequent Grays Harbor and Willapa Bay on Washington's outer coast (Lemberg et al. 1997, Stick 2005). Each stock, defined by a geographically distinct spawning area with predictable timing of spawning activity (Figure 3), is thought to be autonomous. WDFW monitors the status of most of the herring spawning stocks of Washington on an annual basis, through a program of hydro-acoustic/mid-water trawl assessment surveys of certain pre-spawning holding areas, or a spawn-deposition survey program for priority spawning areas. Annual spawning-escapement biomasses are estimated (Stick 2005). For many spawning populations, these data have been collected annually by WDFW since the mid-1970s.

Figure 2. Documented herring spawning areas in the Puget Sound basin.

Northern Anchovy

Northern anchovy populations in the Puget Sound Basin have not been a specific target of assessment by WDFW. This species occurs throughout the region, as evidenced by their incidental occurrence in WDFW's hydro-acoustic/midwater trawl survey catches targeting herring during the winter months. Also, anchovy spawning is known to occur in both southern Puget Sound and the Strait of Georgia (Whatcom County) during the summer months, suggesting resident populations.

Surf Smelt

The surf smelt is a common and widespread nearshore forage fish throughout Washington marine waters. Spawning activity occurs in a wide variety of wave-exposure regimes, from very sheltered beaches in southernmost Puget Sound and Hood Canal to fully-exposed pebble beaches on the outer coast of the Olympic Peninsula. Spawning activity is distributed throughout the Puget Sound Basin, and stock boundaries cannot be defined geographically. Currently, about 10 percent of the shoreline of the Puget Sound Basin is documented to be surf smelt spawning habitat (Figure 4). Spawning regions are commonly occupied during the summer (May-August), fall-winter (September-March), or year-round (spawning every month, perhaps with a seasonal peak) (Figure 5).

WDFW does not attempt to assess the annual status of surf smelt spawning stocks Puget Sound-wide. Their nearshore behavior, and the distribution of many tiny spawning events over long reaches of shoreline over long periods each year, have precluded the application of hydro-acoustic/midwater trawl surveys or spawning ground surveys for stock monitoring, as is done for herring. Present-day surf smelt fishery harvests are relatively small and limited by markets and privatization of the local shorelines.

Pacific Sand Lance

Sand lance, colloquially referred to as candlefish by local anglers, are also a common and widespread forage fish of the nearshore marine waters of Washington, including all of the greater Puget Sound Basin. It is the least known of the three shore-spawning forage species. Very little species-specific

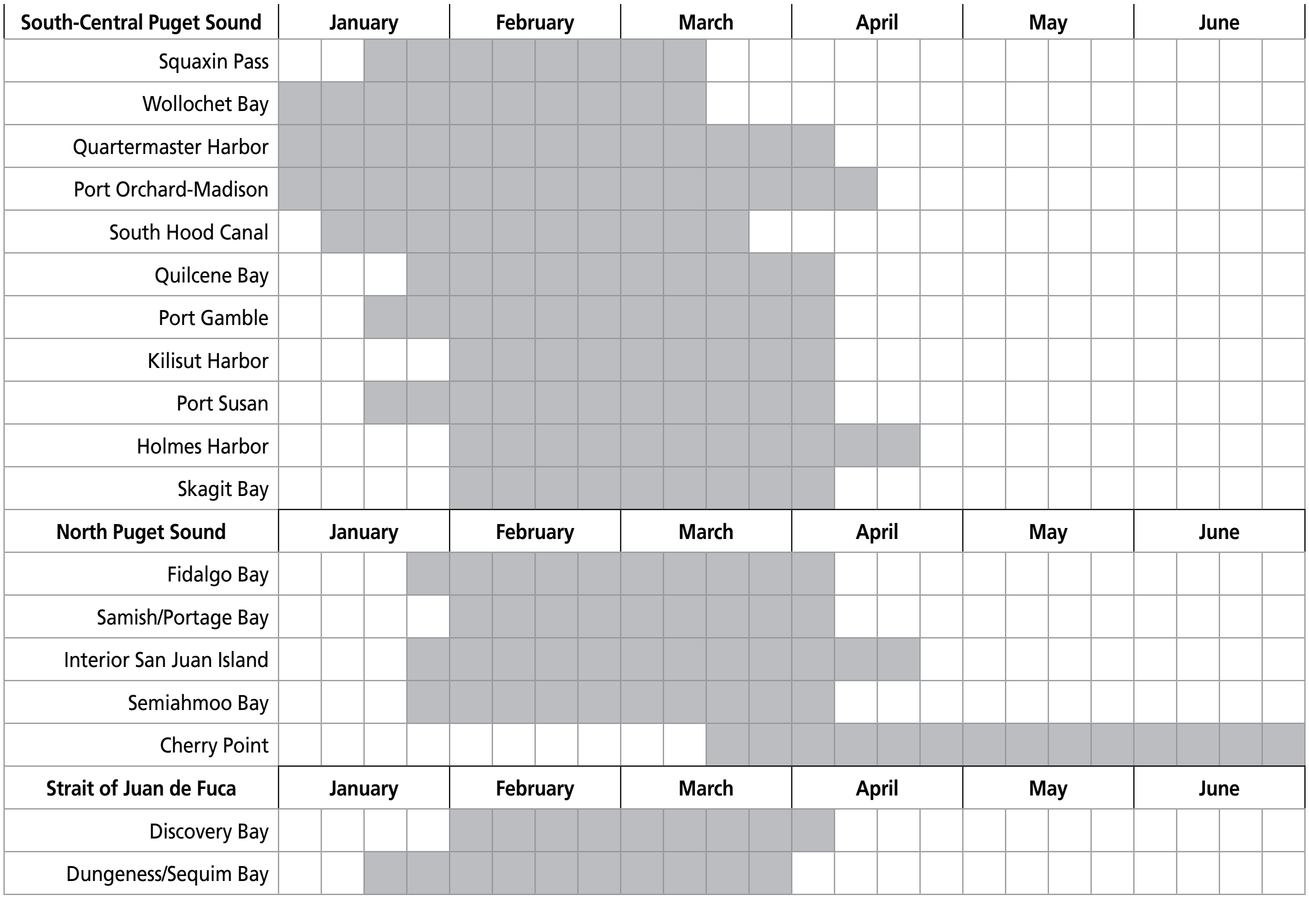

Figure 3. Documented spawning times for Puget Sound herring stocks.

biological data are available (Field 1988).

Sand lance spawning habitat has been documented in the Puget Sound Basin only since late 1989, when a protocol for detecting eggs in suitable substrate was developed (Penttila 1995a, b). Currently, about 10 percent of the basin's shoreline has been documented as sand lance spawning habitat (Figure 6). Additional sand lance spawning beaches continue to be found during ongoing habitat survey projects (WDFW unpub. data). In many instances, the spawning beaches of fall-winter surf smelt and sand lance populations overlap geographically.

WDFW does not attempt to assess the annual status of sand lance spawning populations in the Puget Sound Basin. In addition to dwelling very near shore, sand lances spend part of their diurnal cycle buried in the bottom substrates. They lack an acoustically-reflective air bladder, and they are extremely difficult to capture quantitatively in nets. They deposit their eggs in many tiny individual events scattered over broad reaches of shoreline. Thus, like surf smelt, they are not amenable to the assessment techniques commonly applied by WDFW to herring stock assessment in Puget Sound. Up to the present time, the absence of significant harvest fisheries has not allowed WDFW to assign any priority to sand lance stock assessment.

Longfin Smelt

The only well-documented marine/anadromous spawning population of longfin smelt in the Puget Sound Basin occurs in the Nooksack River and the adjacent marine waters of Bellingham Bay and neighboring Skagit and San Juan counties. A population of longfin smelt is also thought to occur in the Duwamish River. The longfin smelt was identified as a locally common nearshore fish species along the Strait of Juan de Fuca during the University of Washington-Marine Ecosystem Analysis (UW-MESA) surveys of the 1970s, but no adjacent spawning streams have been identified in that area (Simenstad, et al. 1977). The landlocked longfin smelt population inhabiting Lake Washington (King County, WA) has been the target of biological studies (Moulton 1974, Wydoski and Whitney 1979).

No biological data, stock assessment, or spawning habitat survey data exist for any known marine population of longfin smelt. The species has been an incidental catch during winter hydroacoustic/midwater trawl herring assessment surveys in the Bellingham Bay region (WDFW unpub. data). Longfin smelt may have the most geographically-restricted and vulnerable spawning habitat of any marine/anadromous forage fish species in the Puget Sound Basin.

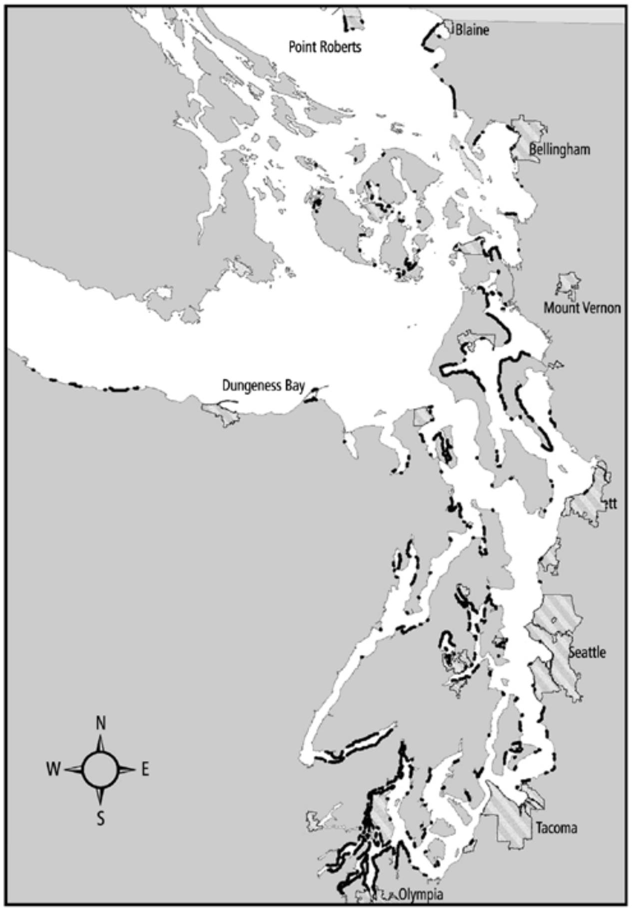

Figure 4. Documented Puget Sound surf smelt spawning beaches as of October 2005.

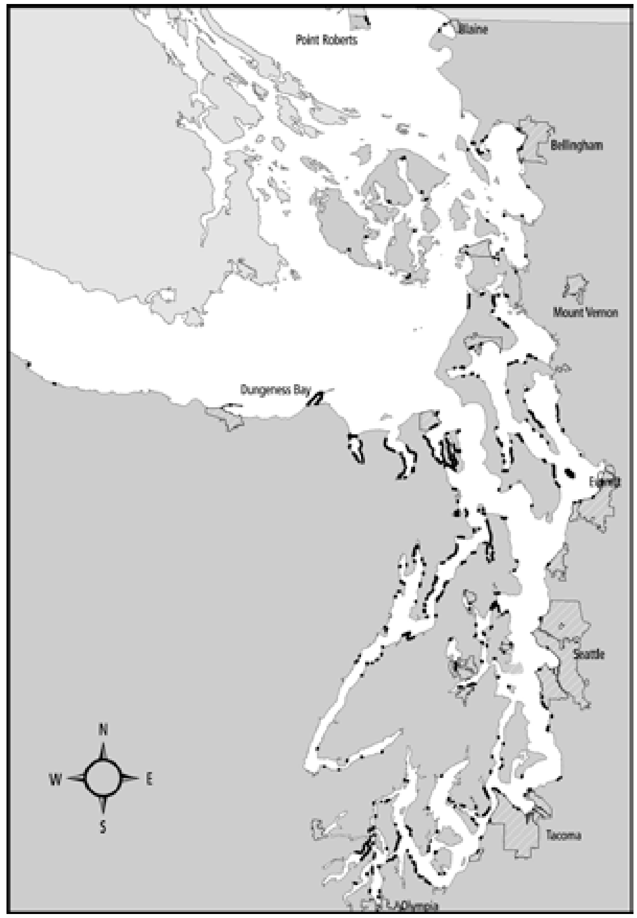

Figure 6. Documented Puget Sound sand lance spawning beaches as of October 2005.

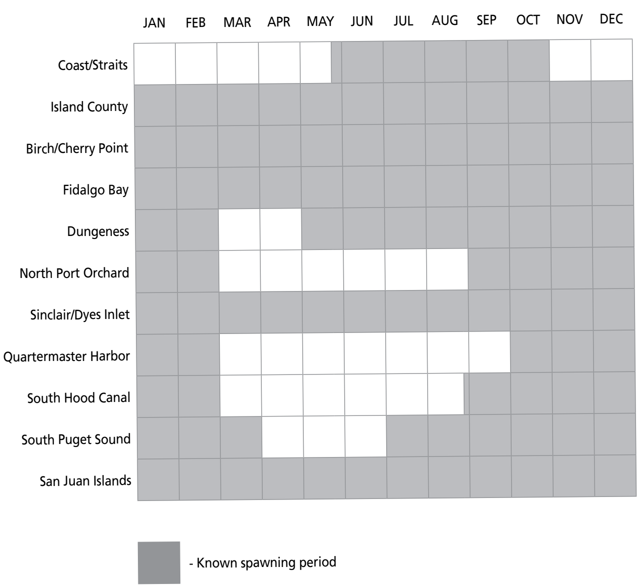

Figure 5. Spawning seasons for Puget Sound surf smelt stocks.

Nearshore Habitat Requirements

Pacific Herring

Pacific herring congregate in the general area of their spawning grounds several weeks prior to the beginning of spawning activity. Groups of herring will become ready to spawn at intervals over a two-month period, at which time they move from deep water into the shallow nearshore zone for spawn deposition. In Washington, Pacific herring deposit their adhesive eggs almost exclusively on benthic marine macro-vegetation.

The herring spawning seasons vary by area within Washington, but most spawning takes place in February and March (Lemberg et al. 1997, Stick 2005). Spawning may occur as early as late January in some areas and commonly ends in nearly all areas by early April (Figure 3). The Cherry Point herring stock of western Whatcom County is unusual among Washington herring populations because of its mid-April to early June spawning season. The spawning season on any individual spawning ground may last six to eight weeks, during which a number of individual spawning events of varying magnitudes and varying degrees of geographical and timing overlap may occur.

Within herring spawning areas, the depth zone of spawn deposition is largely controlled by the perennial clarity of the water, which in turn controls the amount of ambient light and the maximum depths at which vegetation will grow (Druehl 2000). In some areas with relatively clear water, herring spawn deposition may occur as deep as -10 meters in tidal elevation. In many cases, composition of the substrate will also control the character of the marine vegetation that is present. Most vegetation used by herring for spawning is confined to the shallow subtidal and lower half of the intertidal zone.

Across the Puget Sound region, the native eelgrass *Zostera marina* is of primary importance as a herring spawning substrate (Figure 7). In certain parts of the Puget Sound Basin, especially western Whatcom County, the intertidal and shallow subtidal marine algal turf, often comprising dozens of species of red, green and brown algae, is used by spawning herring (Millikan and Penttila 1973) (Figure 8). In somewhat deeper water, and in areas where native eelgrass beds do not predominate, the mud-bottom-dwelling red alga *Gracilariopsis* sp. (referred to as *Gracilaria* in some sources) may be the dominant substrate plant (Figure 9).

In a small proportion of the known herring spawning areas, more atypical spawning substrates are used. For example, within Port Susan (Island-Snohomish counties), herring commonly spawn on middle intertidal boulder/cobble rock surfaces with little or no macroalgae (WDFW unpub. data). In the east Hammersley Inlet area (Mason County), herring will occasionally deposit very thick layers of eggs on current-swept subtidal gravel beds in the near absence of macro-vegetation (WDFW unpub. data). In northern Port

Figure 7. Eelgrass meadow used as herring spawning habitat, N.W. Hale Passage, Whatcom Co.

Orchard (Kitsap County), herring will also deposit their eggs in relatively deep water on the amassed beds of tubes of the polychaete worm *Phyllochaetopterus* sp.

In Grays Harbor (Grays Harbor County), the primary herring spawning habitat is the outer edges of native salt-marsh beds, where a turf of rockweed (*Fucus*), sea-lettuce (*Ulva*), pickleweed (*Salicornia*) and salt-grass (*Distichlis*) in the uppermost intertidal zone serves as spawn deposition substrate. Herring spawning behavior using salt marshes has not been observed inside Puget Sound. Spawning herring also use salt-marsh vegetation, along with beds of over-wintering cordgrass (*Spartina*) stubble and native eelgrass beds, in Willapa Bay (Pacific County) (WDFW unpub. data). Finally, herring spawning has been observed on dock pilings in Puget Sound and coastal bays (WDFW unpub. data).

Within herring spawning stocks, there are large natural annual and decadal variations in relative abundance (Lemberg et al. 1997, Brett 1985, Stick 2005). These fluctuations are reflected in the geographic distribution of spawn deposition along a shoreline. Most spawning areas appear to have "outlier" areas, used only during periods of high abundance, and "core" areas, into which spawning activity withdraws during periods of low abundance.

Herring spawning habitat is the critical life history element that can be identified and managed. An essential element of herring spawning habitat appears to be the presence of perennial marine vegetation beds at rather specific locations. A natural selection of spawning sites has probably been taking place in the Puget Sound Basin over the last few thousand years, since the last retreat of Ice Age glaciers, the stabilization of sea level and shoreline location, and re-establishment of marine vegetation beds.

It is not known how groups of fish have selected present-day

Figure 8. Intertidal algae bed with heavy herring spawn, S. Cherry Point, Whatcom Co.

herring spawning areas in such a short geologic time. Judging from the distribution of the existing herring spawning sites within Puget Sound, it is obvious that not all vegetated shorelines within the basin have been equally attractive to ripening herring. About 10 percent of the shoreline has been selected by the spawning fish, generally in sheltered bays (Figure 2). Marine vegetation beds within the selected sites are not of discernibly higher quality than vegetation on adjacent shorelines that are never used by the spawning fish. Thus, it appears that location is rather more important as a selection criterion than the mere presence of marine vegetation beds, which are virtually ubiquitous along the Puget Sound shoreline, regardless of aspect and exposure regime.

Within the geographical limits of the various known herring spawning areas, factors affecting the distribution and abundance of marine vegetation over time and space are critical to herring stock maintenance. An unintentional experiment on the impacts of a gross and abrupt change in the abundance of a herring stock's preferred spawning substrate is currently under way in Westcott-Garrison Bays, San Juan County (Wyllie-Echeverria et al. 2005). For unknown reasons, vast beds of native eelgrass almost completely disappeared from these bays during 2000-2004. These eelgrass beds had supported annual herring spawning activity since the mid-1970s (Stick 2005). Coincident with the disappearance, herring spawn has not been detectable by WDFW surveys during 2004-2006, and the current status and fate of this small herring stock is unknown.

Individual herring egg broods take up to two weeks to hatch, at which time the yolk-sac larvae inhabit the nearshore plankton around the spawning areas (Millikan and Penttila 1974). The planktonic larvae drift in the water column for some weeks after hatching. After the first week of drift, the larvae exhaust their yolk sac nutritional reserves and must be in the presence of microplankton of appropriate type and density to begin feeding successfully on their own. This circumstance, along with the varying character of potential predators upon the larvae, is thought to characterize an annual critical period in the larval-herring life history that may have great impact on future abundance of the year-class (Alderdice and Hourston 1985). The late-winter/early-spring herring spawning/hatching season might have evolved to take best advantage of the spring increase in planktonic productivity, which may be triggered earlier, more densely and more consistently in sheltered bays. Part of the spawning site-selection process might have been a higher survival rate among fish that spawned in the vicinity of potentially more suitable larval nursery grounds or at sites where the early larvae would most consistently be transported to such grounds by tidal currents. In Puget Sound, juvenile herring inhabit nearshore waters through their first several months of life, and then move into deeper water during September-October. They appear to remain inside Puget Sound until their second year of life, when some of the year-class may mature and spawn.

While herring spawning sites are remarkably consistent and predictable in their annual usage, it appears that neither post-spawning adult herring nor pre-recruit herring persist in numbers in the immediate vicinity of any spawning ground during non-spawning times of year. Puget Sound herring are thought to be a mix of "resident" and "migratory" stocks, with the migratory populations cycling between winter spawning grounds in the inside waters and the conti-

Figure 9. Sample of *Gracilariopsis* with herring spawn, Quartermaster Harbor, King Co.

nental shelf off the mouth of the Strait of Juan de Fuca in the summer months. The consistency of spawning site usage is coupled by an apparent consistency in the usage of certain pre-spawning holding areas, where ripening fish assemble adjacent to spawning sites some months before the onset of spawning activity. Presumably, this life-history phase has also been under selective pressure. The specificity and predictability of spawn deposition in time and space suggests that herring stocks "home," and thus may be genetically distinct. It has been hypothesized that while the bulk of herring migration and spawning actions are under genetic control, the fish may also have the capacity to explore for additional spawning habitats. Intuitively, herring must have this capacity, enabling them to rapidly recolonize the glaciated coastlines of the northeast Pacific Ocean following the most recent glacial retreat.

Given that herring may have the ability or tendency to colonize new shores and spawning grounds, what constitutes a fully-colonized nearshore ecosystem is not known. The shores of the Puget Sound Basin have not been monitored completely or continuously enough over time to detect, with any certainty, possible efforts by herring to establish wholly new spawning areas. Within their extended geographical range, from northern Baja California to northern Honshu Island, Japan, Pacific herring are quite flexible in the oceanographic contexts in which they are known to spawn.

Even when dwelling near shore, herring feed upon planktonic organisms. Calanoid copepods made up the bulk of the diet of juvenile herring in the Strait of Juan de Fuca nearshore zone (Simenstad et al. 1977). Midwater trawl-caught, post-spawning adult herring have been observed to have fed heavily on both calanoid copepods and euphausiids (WDFW unpub. data).

Surf Smelt

Little is known about the life history of surf smelt away from their spawning grounds. Stocks that have been studied include one- and two-year-old fish, with few fish surviving beyond age four (Penttila 1978). They do not generally form large open-water pelagic schools. They may reside near the shoreline in the general area of their spawning sites for their entire lives. There is no evidence of surf smelt making annual migrations from their spawning sites to the open ocean. Nearshore-dwelling surf smelt in the Strait of Juan de Fuca feed primarily on calanoid copepods, with a small proportion of their diet consisting of small epibenthic crustaceans (Simenstad et al. 1977, Simenstad et al. 1979).

The life history of the surf smelt is intimately linked to nearshore geophysical processes. The critical element of surf smelt spawning habitat is the availability of a suitable amount of appropriately textured spawning substrate at a certain tidal elevation along the shoreline. Their potential spawning/spawn incubation zone spans the uppermost one-third of the tidal range, from approximately +7 feet up to extreme high water (EHW) in central Puget Sound or the local equivalent. Spawning substrate grain size is generally a sand-gravel mix, with the bulk of the material in the 1-7 mm diameter range (Schaefer 1936, Penttila 1978) (Figure 10). The thickness of the spawn-bearing substrate layer on the upper beach will vary with local wave-action and sediment-supply regimes, ranging from 1-10 cm. The physical area of spawning substrate can vary from a discontinuous array of small patches around the high tide line to nearly continuous bands of material several meters wide and several kilometers long.

Within a typical sediment drift cell, surf smelt spawning habitat may be limited at the erosional beginning of the drift cell, where beaches tend to be overly coarse in sediment texture. Surf smelt may also be limited at the depositional end of a drift cell, where the upper beach may be overly sandy in character. Approximately 10 percent of the shoreline of the Puget Sound Basin is used by surf smelt for spawning habitat (Figure 4). Most of beaches on the Puget Sound shoreline that appear outwardly suitable for surf smelt spawning habitat are apparently not used by the fish, at least to a degree where spawn can be detected by current forage fish spawning habitat survey protocols (Penttila 1995a, Moulton and Penttila 2001). Most spawning beaches are used on an annual basis, although there are "outlier" sites that may be used only during periods of high local stock abundance.

Surf smelt spawning may occur at irregular, short intervals at any particular site. Spawning takes place in just a few inches of water just below the waterline during high tides (Figures 11 and 12). Spawning events a few days apart are commonly superimposed on each other, and it is not uncommon for an area to contain two to five individual broods of eggs. Once a spawning season begins, the rate of new egg deposition coupled with hatchings will likely provide the site with a continuous deposit of eggs for several months.

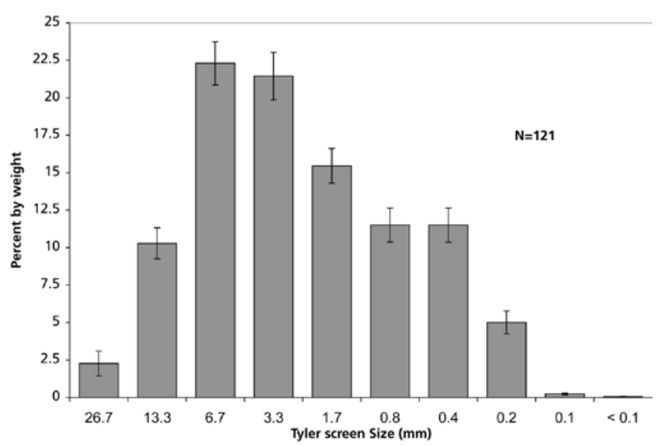

Figure 10. Puget Sound surf smelt spawning substrate grain-size spectrum.

Figure 11. Fresh surf smelt spawn patch, southern Dugualla Bay, Whidbey Island.

The surf smelt's spawning substrate is a rigorous environment, and the eggs appear to be resistant to some degree of thermal shock and desiccation stress. Typical surf smelt spawn substrate is rather sparsely inhabited by other macroscopic organisms. Epifaunal or infaunal predators on incubating surf smelt eggs have not been documented.

Surf smelt appear tolerant of the highly variable salinity regimes found on and around their spawning beaches; immersion in freshwater seeps during low tides is not uncommon (Penttila 1978). Thus there is little of the upper marine nearshore wetted perimeter anywhere in the Puget Sound Basin that these fish might be deterred from exploring, if suitable substrate is present at the appropriate tidal elevation. They appear not to be deterred by fallen trees, brush, or large woody debris. The maximum landward edge of the substrate zone accessible to the spawning fish will vary between spring and neap periods of the tidal month. During the higher high tides of a spring-tide period, the fish may spawn upon substrates that will not be wetted directly again until the next spring tide series. During the fall-winter periods' cool, moist weather conditions, this spawn can survive to hatching (WDFW unpub. data).

Some elements of surf smelt spawning habitat quality are intimately associated with the character of the bordering uplands. Natural erosion of the unconsolidated bluffs of

Figure 12. Fresh surf smelt spawn patch outlined, N.W. Bellingham Bay, Whatcom Co.

Quaternary sand/gravel is thought to contribute most of the sediments present on a Puget Sound beach (Johannessen and MacLennan 2007). Shade provided by the overhanging canopies of trees growing in the backshore zone is important during the summer incubation period (Penttila 2002, Rice 2006) (Figure 13).

During the summer, incubation times are about two weeks, while during cold winter weather, it may be four to eight weeks. Eggs on the surface are easily killed by sun or wind exposure during the summer. Overhanging shade trees above the upper beach greatly moderate this loss (Penttila 2002, Rice 2006) (Figure 13). Shade is unnecessary during the fall-winter season, when ambient temperatures result in much lower mortality rates.

Like the Pacific herring, surf smelt have managed to colonize the entire length and breadth of the Puget Sound Basin in the short time since the glaciers receded. Surf smelt may be similarly consistent with local herring stocks in their

Figure 13. Shaded summer surf smelt spawning habitat, eastern Camano Island.

predictable use of certain shorelines for spawning at certain seasons of the year. All spawning beaches first mapped by the Washington Department of Fisheries (WDF) in the 1930s are still being used at present, if they have survived detrimental human impacts in the interim (Schaefer 1936).

Surf smelt, however, differ significantly from herring in the relatively widespread occurrence of their spawning beaches along Puget Sound shorelines. While herring have geographically disjunct spawning grounds, surf smelt spawn over a much broader variety of shoreline aspects and exposures. Their mapped spawning sites are distributed rather evenly all across the landscape, and there are no obvious grounds for stock definition or isolation in geographical terms. Though the specificity of surf smelt spawning activity at certain sites and times suggests a degree of homing to their beaches of origin, this has not been proven. Mechanisms of surf smelt spawning site detection, selection, and the triggering of spawning activity are also unknown.

The potential for genetic interchange between spawning populations seems great: surf smelt larvae are planktonic drifters for a number of weeks after hatching; the spawning beaches are often at sites exposed to tidal currents; and the spawning beaches may produce larvae continuously for a season spanning many months. Young-of-the-year surf smelt are virtually ubiquitous along Puget Sound shorelines.

Pacific Sand Lance

Although the species are taxonomically unrelated, the spawning habitat of the Pacific sand lance generally resembles that of the surf smelt: upper intertidal beaches consisting of sand and gravel (Penttila 1995b). Their spawning sites are also similarly scattered evenly over the landscape of the Puget Sound Basin, to such a degree that hypothetical geographical stock boundaries are not apparent (Figure 6). Co-occurrence of eggs of the two species in the substrates is common during the winter, when the spawning seasons of Puget Sound sand lance and winter-spawning surf smelt populations overlap. The eggs of both species can be found incubating in the same substrate at the same time (Penttila 1995b).

Sand lance spawning habitat attributes derive from physical forces acting on sediment in the upper third of the intertidal zone, generally between mean higher high water (MHHW) and about +5 feet in tidal elevation in central Puget Sound or local equivalent. The grain-size spectrum of typical sand lance spawning substrate can be characterized as sand, finer-grained than that of surf smelt, with the bulk of the material in the range of .2-.4 mm in diameter (Penttila 1995b; WDFW unpub. data) (Figure 14). Beaches at the distal ends of drift-cells, where sandy spits, cuspate forelands and other accretionary shoreforms tend to occur, commonly support sand lance spawning (Figures 15 and 16).

Sand lance spawning occurs in fall-winter, between November and February in Puget Sound, mostly during the

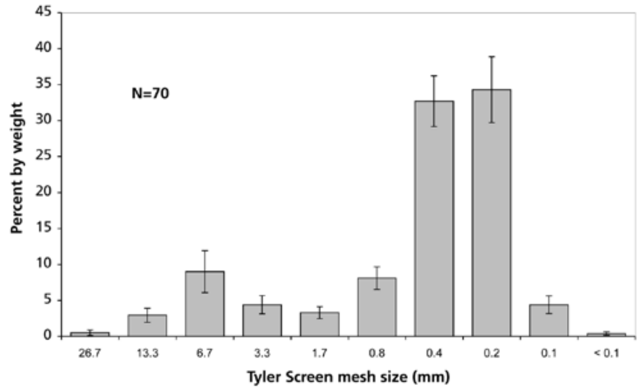

Figure 14. Puget Sound sand lance spawning substrate grain-size spectrum.

first half of that period (Penttila 1995b). Thus, the presence/absence of overhanging shade trees to moderate temperatures on their spawning beaches is not an important habitat attribute. Similar to surf smelt, incubating sand lance eggs appear to be resistant to wide variations in salinity and temperature. As with surf smelt, spawning occurs during high tides when the upper beach is shallowly covered by water. Sand lance eggs may be deposited slightly lower in the intertidal zone than those of surf smelt. Fresh, undispersed deposits of sand lance spawn often feature patches of eggs resting at the bottom of scattered, shallow pits, excavated in the beach surface by the spawning fish in some unknown manner (Penttila 1995b, Robards et al. 1999). Their incubation time is approximately one month, and repeated episodes of spawning activity may occur during the spawning season on any particular beach. Sand lance spawning sites appear to be used on a perennial basis.

Little is known about the life history or biology of the Pacific sand lance apart from its spawning sites. Sand lance from nearshore fish collections along the Strait of Juan de Fuca were found to feed primarily upon calanoid copepods (Simenstad et al. 1977). Postlarval/juvenile sand lances in the San Juan Islands were also found to feed primarily upon calanoid copepods, along with a variety of other planktonic organisms (Tribble 2000). Planktonic sand lance larvae are common in the nearshore waters of the Puget Sound Basin in the late winter. Juvenile sand lance are common in the nearshore zone through their first summer of life. Pursued and concentrated by alcid seabirds, they commonly attract a variety of predators to their dense surface schools, which salt-water anglers refer to as bait-balls. A broad array of marine bird, mammal and fish species are known to feed on Pacific sand lances, indicating their ecological importance to the marine food web (Field 1988).

Pacific sand lance are highly unusual among local forage fish species in their habit of actively burrowing into nearshore sand-gravel bottom sediments during parts of their diurnal and seasonal cycles of activity (Field 1988, Quinn 1999). Burrowing may occur mostly at night as a predator-avoidance mechanism. Pacific sand lances may also be found bur-

Figure 15. Sand lance spawning beach with spawn pits marked, S. Holmes Hbr., Whidbey Island.

Figure 16. Sand lance spawning beach with fresh spawn pits, S. Port Gamble Bay, Kitsap Co.

rowing at or below mean lower low water (MLLW) in the upper, oxygenated stratum of intertidal sediments on Puget Sound beaches (Quinn and Schneider 1991, Quinn 1999).

Northern Anchovy

Northern anchovies are entirely pelagic in their local life histories, releasing floating planktonic eggs that are not targeted to the nearshore zone. They are reported to frequently occur in estuaries throughout the Pacific coast of the mainland United States (Emmett et al. 1991). The narrow, complex, current-swept waterways of the Puget Sound Basin are such that the northern anchovy may be associated with the neritic portion of the nearshore environment, in spite of their pelagic habitat.

The distinctive oval eggs of the anchovy have been recovered from late spring and summer plankton-net catches from western Whatcom County and Carr Inlet in Pierce County (WDF unpub. data). Young-of-the-year anchovies occur in the nearshore zone of Puget Sound in the summer months as a species of lesser abundance than juvenile salmon, herring and squid in nighttime surface-tow net catches (Penttila et al. 1985, Penttila et al. 1986). Northern anchovies are also a species of lesser abundance in winter midwater trawl catches throughout the Puget Sound Basin and never rival Pacific herring in abundance (WDFW unpub. data).

Anchovies are reported to feed on a variety of planktonic organisms, both plants and animals. Depending on the character of the available prey, they may feed either by gill-raker filtering or by visual pursuit of individual larger prey items (Emmett et al. 1991).

Longfin Smelt

Longfin smelt are an anadromous species, depositing adhesive eggs on river-bottom sediments around the upper ranges of tidal influence of the Nooksack River and possibly other streams in the Puget Sound Basin. Although they do not have a marine nearshore spawning habitat requirement, they may occur in the neritic portion of the nearshore zone of shorelines in the vicinity of their spawning streams. They are reported to occur in many of the larger estuaries of the Pacific coast of the United States (Emmett et al. 1991).

Longfin smelt are a minor component of the pelagic fish community of the Bellingham Bay region during the winter months, comprising a mix of presumed young-of-the-year, maturing adults and recovering-spent females, as evidenced in midwater trawl surveys targeting Pacific herring (WDFW unpub. data). Apart from the south Whatcom/west Skagit/San Juan County region, they have been only rarely encountered elsewhere in Puget Sound during winter herring assessment surveys (WDFW unpub. data). Longfin smelt were found to be locally abundant in surface-townet catches in the nearshore zone on the Strait of Juan de Fuca (Simenstad et al. 1977). However, they were found to be virtually absent in WDFW nearshore night-time surface-townet catches in the south and central Puget Sound Basin during the 1977-1985 period (Penttila et al. 1985).

Longfin smelt collected along the shoreline of the Strait of Juan de Fuca consumed a variety of epipelagic and planktonic prey items, including calanoid copepods, mysids and amphipods (Simenstad et al. 1977). Midwater trawl-caught longfin smelt in the vicinity of the Nooksack River mouth in winter were occasionally observed to have consumed juvenile mud-shrimps, *Upogebia* sp. (WDFW unpub. data).

Status and Trends

Of the marine forage fishes reviewed in this document, only Pacific herring populations have been monitored by WDF/WDFW with sufficient detail, through annual estimates of relative abundance (annual spawning escapement biomass) for discrete spawning grounds. To provide evidence of trends in abundance over space and time, Stick (2005) offers the most recent summary of Puget Sound herring biomass data, 1975 to 2004, with a brief discussion of biomass estimation methodologies and trends. Over the past few years, the total spawning escapement biomass for pooled Puget Sound herring stocks has fluctuated between 10,000 and 15,000 metric tons annually (Figure 17). While two significant herring stocks, late-run Cherry Point and Discovery Bay, have suffered significant declines in biomass in recent years (for unknown reasons), their declines have been partially matched by increases in the estimated biomass of other Puget Sound stocks. This has resulted in a relatively flat trend in total Puget Sound spawner-herring abundance for about the last 20 years.

Populations of surf smelt, sand lance, northern anchovy and longfin smelt have never been monitored Puget Sound-wide by WDF/WDFW with an intent to establish annual abundance estimates or trends over time. The details of these species' life histories are such that they are not amendable to either the acoustic/trawl sampling of pelagic schools or the estimation of spawner biomass from the mapping of spawn densities and geographical distributions. Wildermuth (1993) summarized an initial attempt by WDFW to estimate spawner escapement biomass for a few hundred feet of surf smelt spawning habitat in Sinclair Inlet (Kitsap County) for a portion of the local spawning season. The necessary sampling process was very labor-intensive and not practical for large spatial or temporal scales. The number and distribution of suitable "spawn density index" sites needed to meaningfully monitor surf smelt populations over their hundreds of miles of spawning habitat within the Puget Sound Basin are not known.

Regulatory Environment

Prior to the early 1970s, the geographical distribution of herring, surf smelt and Pacific sand lance and their spawning beaches within the Puget Sound Basin were virtually unknown, and thus the cumulative impacts of human shoreline activities on these habitats were neither recognized nor assessed. The advent of a "Puget Sound Baitfish Project" in late 1971 represented the first dedication of staff and funding specifically to the investigation and management of Washington state forage fish populations by the WDF (Millikan and Penttila 1972). Herring and surf smelt spawning habitat mapping began immediately upon the inception of the Baitfish Project. The development and adoption of agency policies and regulations for the conservation

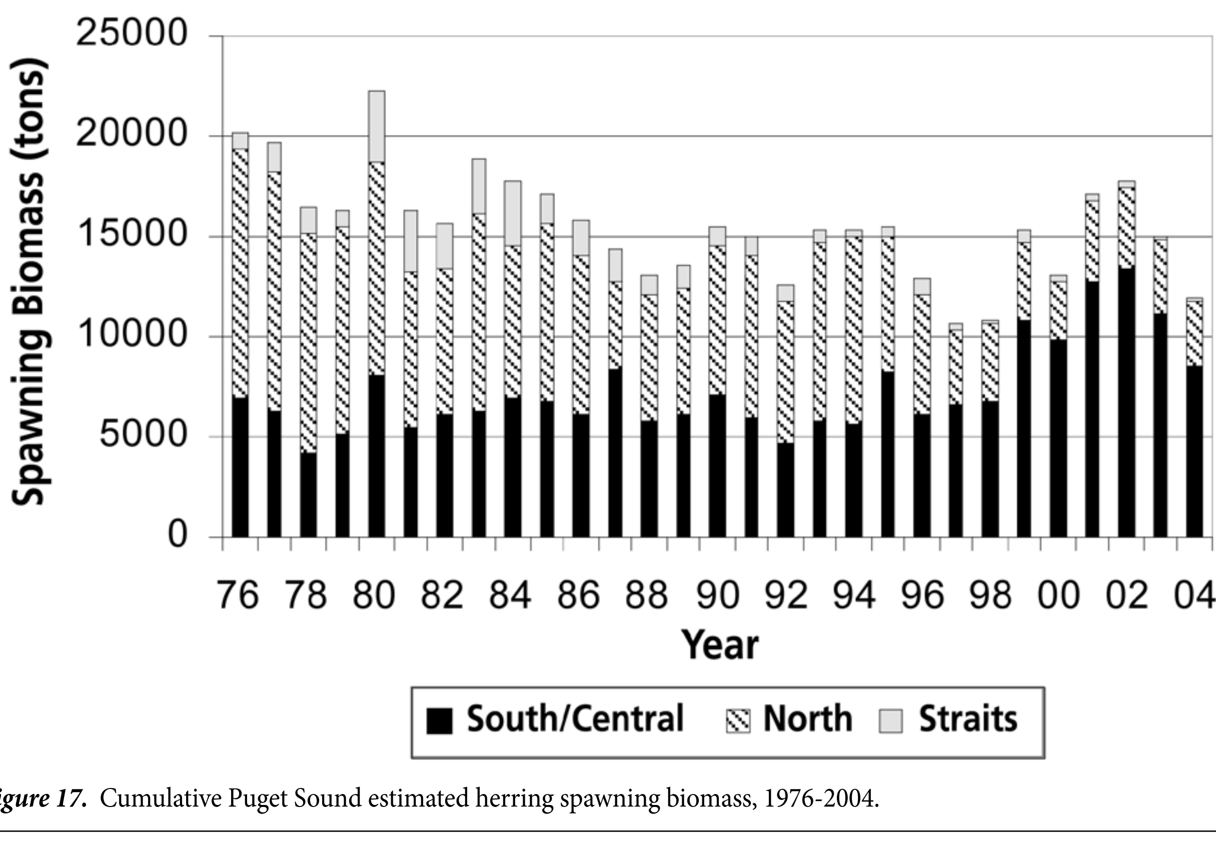

Figure 17. Cumulative Puget Sound estimated herring spawning biomass, 1976-2004.

of these forage fish spawning habitats soon followed, as the vulnerability of these habitats and their continued piecemeal destruction in the region became apparent.

Current WDF/WDFW stances on herring, surf smelt and sand lance spawning habitat protection measures have been generally accepted by other agencies and jurisdictions within the region. The WDFW Priority Habitats/Species (PHS) Program forage fish databases are considered "best available science", and jurisdictions are urged to adopt and reference them in their Growth Management Act (GMA)-mandated regulatory language.

While application of various regulatory measures has lessened activities destructive to forage fish spawning habitats along Puget Sound shorelines over the past 30 years, it has not eliminated them completely. Various present-day stressors on forage fish spawning habitats are reviewed in a following section. With continued human population growth predicted for the foreseeable future within the Puget Sound Basin, there will presumably be continued, if not increasing, requests for the placement of potentially damaging human infrastructure throughout the marine nearshore zone. These requested actions will continue to frequently involve assessments of potential impacts to known or potential forage fish spawning sites.

Ecosystem Support Processes, Habitat Attributes, and a Conceptual Model

Puget Sound forage fish populations do not, of course, exist in a biological/geological/physical vacuum. Figure 18 presents a simple conceptual model supporting forage fish occurrences, of all life history stages, within the Puget Sound Basin.

In the left column are items that may be "managed" or restored by human initiatives to allow at least some portion of the physical ecosystem to support forage fish populations. Support of physical aspects is emphasized, especially the presentation of suitable spawn deposition substrates at appropriate tidal elevations and sites. Note that there are important links with the functional responses of other valued ecosystem components: nearshore marine vegetation, sediment input/transport systems, and coastal forests. Note also that the human element is represented here by the role of existing regulatory actions whose enforcement may outweigh other factors in allowing forage fish stocks to persist. Public awareness is also important for the successful conservation of such biological resources.

Maintained or restored ecosystem processes further the establishment of perennial spawning habitats and appropriate

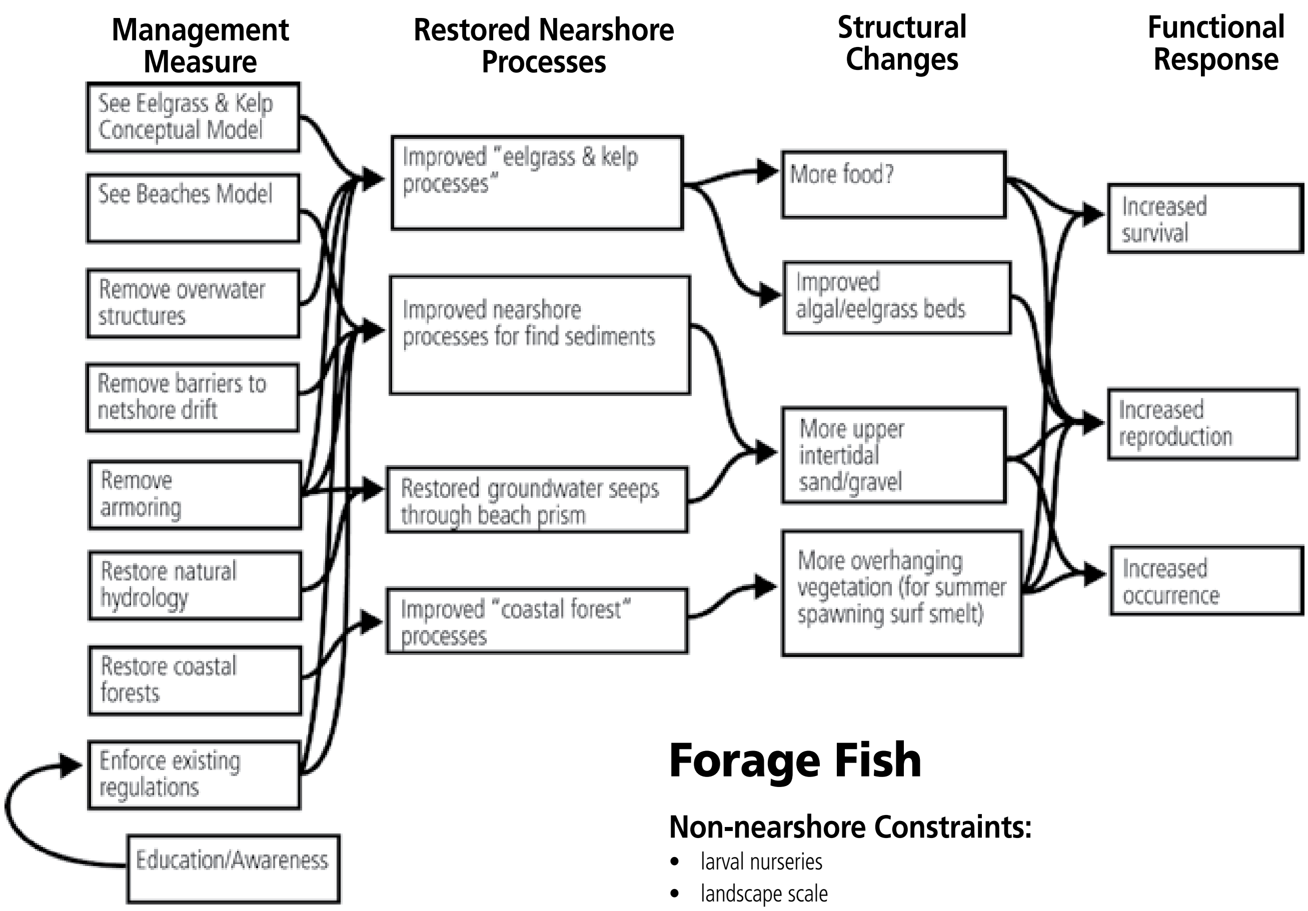

Figure 18. Puget Sound forage fish conceptual model.

food-item environments, represented in the second column. For forage fish spawning populations, it is critical to maintain or increase beach sediment inputs, drift cell functions, and marine vegetation communities and coastal forests. In addition, maintenance of properly functioning planktonic food webs allows non-spawning forage fishes to use a much more extensive segment of the nearshore zone and adjacent neritic waters as nursery grounds and seasonal residence sites.

There are functional and practical limits to how much of the Puget Sound Basin can be restored to its original condition for the sake of forage fish stock maintenance. In fact, the Puget Sound nearshore environment is probably still being actively degraded by the cumulative effects of both "grandfathered" illegal and permitted shoreline modifications. Restoration initiatives should perhaps be viewed as holding actions, pursued to maintain the status quo.

For all the management actions that might be applied to the Puget Sound ecosystem for the benefit of forage fishes and other nearshore resources, the primary positive functional response (i.e., increased abundance) may be difficult to detect. Abundances may still largely be due to environmental influences beyond human control. Environmental factors influencing forage fish larval survival, recruitment, or year-class strength are among the data gaps and uncertainties listed below.

Forage Fish Habitat Stressors And Protection/ Restoration Approaches

Shoreline modifications and development often negatively affect spawning sites of forage fish. A significant proportion of productive forage fish spawning habitat probably was lost in the Puget Sound basin prior to 1973 — a time when critical habitats of these species were ignored and shoreline armoring was largely unregulated. With the development and distribution of forage fish spawning habitat databases by WDFW during the last 30 years, the public and land-use managers have become aware of the critical habitat management and conservation needs of these species.

Shoreline Armoring

Williams and Thom (2001) reviewed the potential impacts of various forms of shoreline armoring on nearshore environmental factors and resources in the Puget Sound region. Shoreline armoring may be the primary threat to surf smelt and sand lance spawning habitat (Thom et al. 1994). Armoring affects spawning habitat by physical burial of the upper intertidal zone during the course of creating or protecting human infrastructure and activities. Prior to detailed studies of forage fish spawning habitat, it was presumed that the upper third of the intertidal zone could be sacrificed to development without concern. This high beach zone did not appear to support any biological resources. The sheltered bays of the inland waters so important to spawning forage fish have also been the shorelines of highest interest for commercial and residential development.

Armoring also blocks, delays or eliminates the natural erosion of material onto the beach and its subsequent transport (Johannessen and MacLennan 2007). These processes maintain forage fish spawning substrate on the upper beach (Williams and Thom 2001). Although beaches may appear to be stable, their sediment is in constant motion, driven by prevailing wind and waves. The sand and gravel making up forage fish spawning substrate moves along the shoreline and eventually off into deep water, and must be replaced by new material entering the shoreline sediment transport system. A lack of a constant supply of new sand and gravel, primarily derived from eroding shoreline bluffs, may lead to coarsening, lowering of the beach elevation, and thus long-term degradation of spawning habitat.

The WDFW Hydraulic Code Rules stipulate that the construction of bulkheads and other bank protection must not result in a permanent loss of forage fish spawning beds (WAC 220-110-280(4)). Permissible in-water development activities are also subject to seasonal work-closure periods during local forage fish spawning seasons (WAC 220-110-271(1)). WDFW hydraulic permits granted for in-water development actions may stipulate certain measures to mitigate unavoidable forage fish habitat losses and address interruptions to beach sediment sources and movements.

Dredging

Dredging is a primary activity that can destroy nearshore marine vegetation, to the detriment of herring spawning habitat. Dredging alters nearshore sea-bed topography to accommodate deep-draft vessel traffic and moorage. Nearshore bottomlands are commonly dredged too deep to allow sufficient light for marine vegetation beds to re-colonize and survive, resulting in a net loss of habitat. Dredging is prohibited in herring spawning beds by WDFW under WAC 220-110-320(8).

Overwater Structures

Nightingale and Simenstad (2001) reviewed the potential impacts of various forms of overwater structure (e.g., docks, ramps, floats, boathouses) on nearshore environmental factors and biological resources in the Puget Sound region. The impacts on forage fishes and their critical habitats vary with the species and the size and configuration of the structure. Surf smelt and sand lance spawning habitats may persist beneath overwater structures if the structures span the spawning habitat zone, and pilings have minimal displacement of beach area, so that upper intertidal sediment distribution and movement are not affected (WDFW unpub. data).

Herring spawning habitat, however, may be impacted by shading from overwater structures, grounding of floats, and accumulation of shell fragments that fall from the structure. There are few species of marine macro-vegetation that can tolerate the reduction in ambient light within the direct footprint of a typical overwater dock or pier, including plant species used by spawning herring (WDFW unpub. data). Introduction of fixed overwater structures invariably results in a die-off of vegetation directly beneath and may also show negative impacts on either side.

In addition, herring eggs deposited on wooden pilings associated with overwater structures may be impacted from uptake of contaminants, especially polycyclic aromatic hydrocarbons (PAH) from creosote (Vines et al. 2000). For unknown reasons, Puget Sound herring occasionally deposit their eggs in unusually high densities and high tidal elevations on nearshore pilings, much higher than on adjacent natural marine vegetation beds. For these eggs, the combined effects of possible chemical contamination from the substrate surfaces, smothering effects on multiple egg layers, and low-tide exposures to thermal shock and desiccation usually result in a nearly complete mortality (WDFW unpub. data).

Research is continuing on designs to promote light penetration beneath overwater structures (Diefenderfer et al. 2004, Blanton et al. 2002, Fresh et al. 2001). Design considerations include raising and narrowing the structure, using grating or translucent building materials instead of solid decking, installing reflective surfaces to angle light beneath the structures, orienting structures in a north-south direction, relocating structures to avoid marine vegetation beds, and using the minimum number of piles necessary (Shaffer 2002). At the present time, no technology exists to completely eliminate the impacts of a shading pier on marine vegetation beds (Fresh et al. 2001).

Grounding of floats and rafts is prohibited on surf smelt, Pacific herring, and sand lance spawning beds by WDFW per WAC 220-110-300 (1). Overwater structures and associated moorings must be designed and located to avoid adverse impacts to Pacific herring spawning beds (WAC 220-110-300 (6)). However, at the present time, forage fish habitat-related protective regulations apply only to the areas where spawn has been observed *in situ* by trained observers, there being no spawn detectable on most shorelines even with outwardly suitable-appearing habitat. Complete protection of forage fish spawning habitats of the Puget Sound Basin will depend on a continuing effort to detect and document all such sites.

Marine Riparian Vegetation

A significant attribute of surf smelt spawning habitat may be the overhead shading provided by the canopies of mature trees rooted in the backshore zone bordering the spawning beaches. Studies have strongly suggested that the presence of shading terrestrial vegetation in the marine riparian corridor has a positive effect on the survival of surf smelt spawn incubating in sand-gravel beaches in the upper intertidal zone during the summer months within the Puget Sound Basin (Penttila 2002). Such overhanging vegetation appears to serve the same function on marine beaches as it does along freshwater streams, moderating ambient temperature and humidity extremes in microhabitats occupied by early life history stages of spawning fishes otherwise adapted to cold climates (Brennan and Culverwell 2004, Rice 2006).

Marine riparian forest corridors and buffer zones lie landward of the jurisdictional reach of the WDFW Hydraulic Code Rules. However, riparian habitat zones bordering aquatic environments are included in the WDFW PHS Program as a priority for management and conservation (WDFW 1999). The ecological functions and values of riparian habitat bordering freshwater aquatic environments outlined by Knutson and Naef (1997), such as wildlife habitat, microclimate, run-off control, bank stabilization, etc., are now understood to apply to vegetated buffers bordering marine waters as well (Brennan 2007). Conservation of these riparian areas is expected during the drafting and updating of local Critical Areas Ordinances (CAO) by local jurisdictions as they seek to comply with the state GMA (WAC 365-190-080). Marine riparian vegetation buffers are also among the critical saltwater habitat classes listed for protection and restoration within the state Shoreline Master Program (SMP) Guidelines (WAC 173-26-221(iii)(A), (B)).

Aquaculture

Standard aquaculture practices may have profound effects on the benthic ecology of Washington state's tidelands and the conservation of forage fish spawning areas, especially for herring. In many areas, herring spawning grounds are now coincident with shellfish culture areas, particularly on tideflats occupied by beds of the native eelgrass. Pacific oyster (*Crassostrea gigas*) beds intended for the ground-culture and dredge harvest of oysters commonly become devoid of native eelgrass, either due to the cumulative effects of periodic dredging activities over time or by intentional destruction of the eelgrass beds before the start of culture activities (West 1997). Dredging operations routinely take place on or near tideflat areas containing herring spawn (WDFW unpub. data). Currently, the Washington Department of Agriculture (WDA) has regulatory authority over aquaculture activities that occur in intertidal areas of state waters. The Washington Department of Natural Resources (WDNR) has authority over state aquatic bottomlands and marine vegetation management. These agencies together with WDFW should seek a coordinated approach to the management of the growing aquaculture industry, with an eye toward modification of habitat-damaging culture practices and the mitigation of existing habitat degradation for which the industry has been responsible.

Forage Fish Data Gaps and Uncertainties

There are many gaps in our knowledge and understanding of the life histories, geographical distributions and ecological roles of the various species of marine forage fishes in the Puget Sound Basin. Up to the present time, governmental-agency forage fish-related activities have largely been centered on harvest management and the documentation and protection of spawning habitats, occasionally with the cooperation of nongovernmental organizations. Research institutions have carried out sporadic projects on certain aspects of local forage fish biology and ecology. The net result of these past efforts is a growing interest in forage fishes and their roles in the Puget Sound ecosystem region-wide, as new initiatives to restore the sound move forward. While some aspects of the life histories of Puget Sound forage fishes are relatively easy to approach, others are not. Remaining data-gaps may require significant investments of time, funds, staffing-power and technologies.

Herring

1. **Uncertainty of identity of resident versus migratory stocks.**

   Currently, it is uncertain whether or which Puget Sound herring stocks are migratory or resident. Investigation would require sampling of offshore summer herring populations and the discovery of genetic markers to identify individual spawning populations wherever they may be available for sampling.

2. **Location of additional undocumented herring spawning areas.**

   Unlike surf smelt and sand lance habitat survey programs, the vegetated shorelines of the Puget Sound Basin have never been systematically sampled for the presence of herring spawn during the regional spawning seasons. While known herring spawning sites are afforded no-net-loss regulatory protections from a number of existing regulations and policies, undocumented herring spawning sites are unprotected from damage caused by inappropriate land-use practices.

3. **Existence or location of perennial larval nursery grounds.**

   It is hypothesized that the evolution of herring spawning grounds derives from the existence of larval nursery areas in the vicinity. This hypothesis needs to be tested, perhaps with a herring larva sampling program to determine if there are perennial areas of seasonal concentration of larval abundance, and what the attributes of those areas might be.

4. **Location and ecological roles of herring in the Puget Sound Basin in the non-spawning months.**

   While WDFW routinely surveys certain herring pre-spawning holding areas throughout Puget Sound in the winter months, no attempt has been made to apply the same hydro-acoustic and mid-water trawl sampling methods to determine the distribution of herring and other pelagic organisms over broad areas of the Puget Sound Basin in the summer and fall. In the case of juvenile herring dwelling in the near-shore zone, other assessment and sampling technologies would have to be applied. This data gap would apply to all the other species of Puget Sound forage fishes as well.

5. **Unknown herring recruitment mechanisms.**

   The mechanism by which juvenile herring join a population of adult fish to begin to spawn is unknown, as is the degree to which Puget Sound herring might mix and stray prior to recruitment and during their adult years.

6. **Impacts of degraded water quality on larval survival in urbanized bays.**

   Forage fish spawning activity and potential nursery grounds may occur within bays subject to shoreline development and water quality degradation. No information is available as to whether various forms and levels of water quality degradation negatively impact the survival of larval herring and other forage fishes in their first few months of life.

7. **Causes of perennial herring spawn mass mortalities in certain Puget Sound bays.**

   Certain subareas of some Puget Sound herring spawning grounds have exhibited a tendency to suffer unusual mass mortalities of herring eggs during their incubation period. Causes have not been determined but may involve sediment toxicity or water quality issues of significance to other nearshore resources as well.

8. **Efficacy of certain herring spawning habitat restoration/mitigation measures to replace habitat for either stock maintenance or recovery.**

   There seems to be a growing sense of assurance that marine vegetation beds, including those used by spawning herring, are amenable to mitigation techniques to compensate for loss or damage due to shoreline development. However, there is high uncertainty of the true costs of such projects and the likelihood that they will succeed in replacing herring spawning habitat at a reasonable cost in perpetuity. Appropriate monitoring of permitted projects is extremely important. Any perception of apparent success in mitigating for herring spawning habitat may undermine current regulatory efforts to preserve natural spawning grounds intact.

9. **Causes of marine vegetation/herring spawning substrate disappearances in certain Puget Sound bays.**

   Striking declines in the geographical distribution and abundance of eelgrass, including known herring spawning habitats, have been documented in a number of small bays in northern Puget Sound. The causes of these abrupt, marked declines are currently unknown and should be investigated for the benefit of not only herring critical habitat conservation but also the soundwide ecosystem in general. Eelgrass stock status monitoring should continue throughout the Puget Sound Basin to detect declines should they occur elsewhere (Dowty et al. 2005).

10. **Population biology, ecology and status of stocks of the calanoid copepods and euphausiids that form the main diet of herring and other forage fishes.**

    The distribution, life history, ecology and potential stressors of the primary macro-zooplanktonic food items of herring, the next lower level of the Puget Sound neritic food web, are poorly known. Any such plankton investigations should perhaps be geared to also assess lower food-web levels, phytoplankton, and the micro-oceanographic processes and features at work within the Puget Sound Basin.

Surf Smelt and Sand Lance

1. **Location of all existing spawning sites in the Puget Sound Basin.**

   Spawning habitat survey programs continue to discover previously undocumented surf smelt and sand lance spawning sites on Puget Sound beaches. Support for such programs should continue, so that no-net-loss regulatory protection can be applied to all existing spawning sites in the event of nearby shoreline development proposals. The bulk of the Puget Sound Basin's shoreline is now in private ownership. The likelihood of continued financial and political pressure for shoreline modification by a landownership population largely ignorant of nearshore resource values and conservation risks is high.

2. **Biological parameters for a representative subset of local spawning populations.**

   Current data on the population biology of any surf smelt or sand lance spawning stock is lacking. Future fish stock and habitat management would benefit from better knowledge of the biology of these species' Puget Sound populations.

3. **Cost-effective methods for stock assessment.**

   Stock assessment, monitoring and trend analyses for Puget Sound surf smelt/sand lance populations will require the development of new methods of detection and sampling. As noted above, surf smelt/sand lance populations cannot be quantitatively assessed using techniques currently employed for herring assessment.

4. **Long-term impacts of shoreline armoring on spawning substrates/sediment budgets, smelt/sand lance spawning habitats and stock abundance.**

   The long-term impacts of shoreline armoring on Puget Sound forage fish spawning habitats and populations are still poorly documented. Research and monitoring should involve, at minimum, thorough investigation of historical records and photography of armored areas and careful stock assessment of remnant forage fish spawning habitats and populations within them.

5. **Analysis of efficacy of spawning habitat restoration/mitigation methods for stock maintenance.**

   There is a growing interest in "beach restoration" in the Puget Sound Basin, commonly couched in terms of maintenance and recovery of surf smelt/sand lance spawning habitats and populations, among other environmental gains. An effort should be made to make sure that forage fish habitat restoration is a meaningful and realistic goal of such projects. There should be assurances that the projects are properly monitored in both the short and long term to document their performances in increasing habitat and populations. Beach restoration projects should consider factors that caused the perceived degradation, with an effort to address them. Shoreline restoration should be recognized as possibly a commitment in perpetuity of funding and staffing resources.

6. **Effects of global warming/sea level rise on spawning habitats and their management.**

   Occurring as they do as narrow zones of fine-grained substrate high in the intertidal zone, surf smelt and sand lance spawning habitat zones may be vulnerable to "fore-shortening" and degradation in the face of a rapid rise in sea level (Johannessen and MacLennan 2007). The upper intertidal zone may not have sufficient time to advance upon the backshore zone and keep generating beaches of similar width and sediment character. Public perception of a rapid sea-level rise may also promote a heightened societal concern for erosion rates, negative impacts to the economy, land values, and other threats to public safety and institutions that could result in a promotion of hard-armoring practices, to the continued detriment of forage fish spawning habitats.

7. **Assessment of potential impacts of oil spills.**

   Surf smelt and sand lance spawning habitats will be extremely vulnerable to degradation from direct impacts of oil spills. Spawning substrates are very porous, and will entrain and retain oil and spill-breakdown products for long periods of time. Surf smelt and sand lance are short-lived fishes, and may not be able to tolerate widespread spawning habitat contamination without threat of local extinctions of spawning populations. The potential impacts of various forms of oil-spill remediation may also be damaging to beach-spawning forage fishes and their critical habitats. Data arising from the Exxon Valdez oil spill and its remediation effort should be gathered and analyzed for applicability in both planning and procedures for oil spill responses on sandy-gravel beaches in the Puget Sound Basin.

Northern Anchovy

1. **Assessment of northern anchovy populations.**

   Northern anchovy populations could be assessed in the same manner as are pre-spawning herring populations, by way of hydro-acoustic/mid-water trawl surveys. Such data on non-spawning populations would be obtained from current WDFW winter herring survey programs. Presumably, northern anchovy spawning populations could be similarly assessed during the summer months by the same technologies.

2. **Documentation of northern anchovy spawning ecology in Puget Sound.**

   Northern anchovies are now known to spawn throughout the Puget Sound Basin (WDFW unpub. data). Their pelagic eggs appear to be easily detectable by relatively simple plankton-sampling techniques. Knowledge of the distribution, densities and seasons of occurrence of anchovy eggs and larvae across the Puget Sound Basin could form a basis for critical-habitat conservation efforts for this species, much as it has for other local forage fish species.

Longfin smelt

1. **Documentation of the spawning ecology of longfin smelt in Puget Sound rivers.**

   The investigation of this species would necessarily involve linkages between the marine waters of Puget Sound and its tributary rivers. Longfin smelt spawning populations may be amenable to hydro-acoustic/mid-water trawl survey techniques in the general area of the mouths of their spawning rivers, judging from their occurrence during WDFW Bellingham Bay winter herring surveys (WDFW unpub. data). However, their occurrence elsewhere in the Puget Sound Basin is poorly known. Efforts could be made to sample river-bottom sediments and materials suspended in lower-river water columns during the winter/spring months to document other spawning streams. Incidental data could also be gathered in this manner on the occurrence of spawning stocks of the eulachon and American shad, other anadromous forage fishes for which there is virtually no life-history information within the Puget Sound Basin. More detailed information on the riverine spawning ecology of anadromous forage fishes is needed for rational management of these rivers and their benthic sediments.

Conclusion

Over the last 30 years, marine forage fish conservation has slowly gained a place along with societal concern for more charismatic or iconic species in Washington state. Data collection has gone beyond mere fishery harvest statistics into the realm of definition and mapping of critical habitats. Prior to this period, the shorelines of the Puget Sound Basin, their critical forage fish spawning habitats, and the natural processes forming and maintaining them, were manipulated and modified during the course of Euro-American economic development without regard for either site-specific or cumulative negative impacts. In many urbanized bays and waterways, the original characteristics of the nearshore marine environment are unknown. Today's "baseline" information is clearly of modified conditions.

Although most of the shoreline of the Puget Sound Basin is now privately owned, and a significant proportion is no longer in a natural condition, nearshore processes and ecosystems continue to function to various degrees to maintain marine resources. It is in this context that present-day land-use management, resource investigation, conservation, and restoration initiatives will operate. Our collective knowledge of shoreline processes and ecological functions continues to increase, as does the effort to educate the general public about these functions and resources. Resource conservation policies and regulations are also evolving.

Concern for forage fish stock status and critical-habitat conservation evolved in parallel with more rational management of the Puget Sound ecosystem. There are increasing efforts to disperse forage-fish-related information to the public and other agencies.

In summary, the following points could be emphasized, regarding forage fishes of the Puget Sound Basin:

- Seasonal forage fish spawning and rearing activity is an important ecological feature of a significant proportion of the shoreline and nearshore zone of the Puget Sound Basin.
- Preservation of spawning, rearing, and seasonal/migratory habitats is critical for forage fish stock maintenance.
- Located in the nearshore zone, forage fish spawning habitats are very vulnerable to the effects of shoreline development.
- Significant amounts of forage fish spawning habitat have been degraded or destroyed by the cumulative impacts of shoreline development in the Puget Sound Basin.
- All known forage fish spawning sites are currently protected from net loss by specific language within the state Hydraulic Code Rules, GMS, SMP Guidelines and local CAOs, if applied and enforced.
- Our knowledge of existing forage fish spawning and rearing sites is incomplete, and additional sites continue to be found during on-going survey programs.
- Forage fish habitat conservation cannot depend solely on public habitat acquisition, restoration or mitigation.
- Forage fish habitat conservation will continue to depend on the application of regulations to private property, given the widespread privatization of marine tidelands in Puget Sound.
- Adherence to "private property rights" must be balanced with a new attitude of meaningful stewardship and preservation of the public's forage fishes and their critical habitats.
- The citizens of the Puget Sound Basin are largely unaware of forage fishes and their critical habitats, thus there is a great need for continued public education on these matters.

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PSNERP and the Nearshore Partnership

The **Puget Sound Nearshore Ecosystem Restoration Project** (PSNERP) was formally initiated as a General Investigation (GI) Feasibility Study in September 2001 through a cost-share agreement between the U.S. Army Corps of Engineers and the State of Washington, represented by the Washington Department of Fish and Wildlife. This agreement describes our joint interests and responsibilities to complete a feasibility study to "… *evaluate significant ecosystem degradation in the Puget Sound Basin; to formulate, evaluate, and screen potential solutions to these problems; and to recommend a series of actions and projects that have a federal interest and are supported by a local entity willing to provide the necessary items of local cooperation.*"

Since that time, PSNERP has attracted considerable attention and support from a diverse group of individuals and organizations interested and involved in improving the health of Puget Sound nearshore ecosystems and the biological, cultural, and economic resources they support. The **Puget Sound Nearshore Partnership** is the name we have chosen to describe this growing and diverse group and the work we will collectively undertake, which ultimately supports the goals of PSNERP but is beyond the scope of the GI Study. We understand that the mission of PSNERP remains at the core of the Nearshore Partnership. However, restoration projects, information transfer, scientific studies and other activities can and should occur to advance our understanding and, ultimately, the health of the Puget Sound nearshore beyond the original focus and scope of the ongoing GI Study. As of the date of publication for this Technical Report, the Nearshore Partnership enjoys support and participation from the following entities:

King Conservation District

King County

Lead Entities

National Wildlife Federation

NOAA Fisheries

Northwest Indian Fisheries Commission

Northwest Straits Commission

People for Puget Sound

Pierce County

Puget Sound Partnership

Recreation and Conservation Office

Salmon Recovery Funding Board

Taylor Shellfish Company

The Nature Conservancy

U.S. Army Corps of Engineers

U.S. Department of Energy – Pacific Northwest National Laboratory

U.S. Environmental Protection Agency

U.S. Geological Survey

U.S. Fish and Wildlife Service

U.S. Navy

University of Washington

Washington Department of Ecology

Washington Department of Fish and Wildlife

Washington Department of Natural Resources

Washington Public Ports Association

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Information about the Nearshore Partnership, including the PSNERP work plan, technical reports, the Estuary and Salmon Restoration Program, and other activities, can be found on our Web site at: *www.pugetsoundnearshore.org*.

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