Clupeidae — Herring

By Susan McDougall

With a classic fish shape and color, the Pacific Herring flashes its silvery sides in the company of hundreds of its kind, swimming towards a destination known only to the group, occasionally changing directions in an instant, rather like a congregation of shorebirds flying in formation over the sea. Then the rippling of bright scales attracts a predator — a diving bird opportunistically penetrates the swaying mass, while beneath the surface a trailing seal swerves in response. As a solitary fish, the herring's luminous body is an offering of a nutritious snack for birds and mammals alike. But cloistered within the great school, individuality disappears, and survival is enhanced. It is a tactic tuned by evolution, contributing to the success of the Pacific Herring in its cool marine home.

The herring family — the Clupeidae — is a large and ancient group composed of approximately 57 genera and 190 species, with a worldwide distribution that includes marine, estuarine, and freshwater habitats. There are two species in the Strait of Juan de Fuca, with the Pacific Herring (*Clupea pallasii*), the most numerous, plus the relatively uncommon, introduced American Shad (*Alosa sapidissima*). The shad is native to the Atlantic Ocean but was intentionally released in the Sacramento River in 1876. Other than these two, the closely related Northern Anchovy (*Engraulis mordax*), a member of the Engraulidae family, also makes its home in the Strait.

The herring's genus name, "Clupea", is derived from the Latin "clupeus," meaning "shield," in reference to the numerous scales, while the species designation, "pallasii," honors Peter Simon Pallas, an eighteenth-century German-born naturalist who spent much of his career in Russia.

Pacific Herring (*Clupea pallasii*)

The Clupeidae family is a member of the Clupeiformes, a large order composed of seven families and approximately 405 species. With origins dating to approximately 250 million years ago, many of the species are well known for their history as food for humans, with both meat and eggs providing sustenance; other uses include bait or fish meal. The majority of the Clupeiformes' species are small, tropical fish less than 12 inches (30 cm) in length, and slender, with silvery scales and often a substantial snout. Although most live in marine environments, two families are exclusively freshwater, primarily of tropical waters, and other families are composed of species that are diadromous, meaning they travel between fresh and saltwater habitats. Seasonally, most species tend to inhabit waters near the shore, where spawning takes place.

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Perhaps it is their size that contributes to their tendency to congregate in large numbers, a behavior that has attracted human attention and served seashore dwelling societies for thousands of years. With familiar common names such as “herring,” “sardine,” and “anchovy,” only three species of the Clupeiformes order are represented in the Strait. Yet here as elsewhere, their history as a commercial and recreational fish is huge; it is estimated that globally, nearly one-third of the fish taken for human use are Clupeiformes.

In many ways, the Pacific Herring is a typical member of its order. The body is slender and elongated, the head small, the eyes large, and the silvery scales numerous. The back is a deep metallic blue. A large, deeply forked caudal fin, and small dorsal and anal fins further distinguish this herring, and a maximum size of 18 inches (46 cm), but most often smaller, place it in an average category. Add to its appearance an oversized snout, long mouth, and a lower jaw that protrudes beyond the upper, and the herring’s unique form emerges.

Such a large mouth and over-sized snout is very useful to a fish that most often feeds on phytoplankton and zooplankton (small invertebrates). Swimming with a wide-open mouth and utilizing its many gill rakers to sift plankton, the Pacific Herring effectively sweeps in a meal. “Picking” at prey is also an option, and taking small fish and larvae rounds out the herring diet.

With a maximum age of 19 years, most Pacific Herring live to 12 or 13. The species ranges from the White Sea in northwest Russia, across to the Chukchi Sea, the Aleutians, south to Japan, to the west coast of Korea, east to the Bering Sea, and as far south as northern Baja California. There are a few landlocked populations in Japan and Russia. This is primarily a shallow water fish that is nevertheless known to range as deep as 820 feet (250 meters). Herring are migratory fish, typically moving in large schools west or east and returning to shallow nearshore waters in late winter and early spring. There they spawn, the females depositing their sticky eggs on vegetation such as eelgrass and kelp, and on rocks and other solid objects as well. The spawning area is typically cloudy with milt, and the number of eggs laid by one female can range from 9,000 to 38,000. The eggs hatch in about 10 days, and the larvae are prone to drifting out to sea. They are important prey for many animals, including salmon, marine mammals, birds, and, of course, humans. Nearly any creature larger than the herring seems to eat it.

The Pacific Herring family evolved approximately 56 million years ago. Fossils of Eocene age (56 to 34 million before the present) are particularly abundant at a few locations, and the family was present in the temperate Pacific by about 5.3 million years ago. What is most unusual about the order, and especially the Clupeidae family, is a lifestyle that for many species includes migrations back-and-forth between fresh and saltwater. Uncommon and most often related to spawning, such “diadromous” behavior has evolved more than once in the Clupeiformes. A subject of ongoing research, particularly as it applies to salmon — members of a different order — diadromy can reveal much about the influence of both physical and biological factors on fish evolution.

Diadromy — A Clupeiformes Speciality

There are three categories of diadromy — “anadromy,” “catadromy,” and “amphidromy.” The first two involve migration for the purpose of spawning, while amphidromy refers to forays to the sea for growth and then a return for more maturation in fresh water and, eventually, reproduction.

Best known for the spawning behavior of salmon that propels their journey to the rich waters of the sea and back to the freshwater home of their birth, anadromous fish die after spawning, never seeing the new generation that they work so hard to ensure. Other, less well-known local fish are also

anadromous; in particular, the Pacific Lamprey (*Entosphenus tridentatus*), a parasitic fish that resides in the Strait, matures in saltwater and returns to spawn in freshwater streams.

Catadromous fish reverse the process, hatching in saltwater and completing their maturation in freshwater, only to return to the sea where they spawn and die. “Catadromous” means “downward running.”

Worldwide, approximately 100 fish species are known to be anadromous: the less numerous catadromous fish include the eels, which number about 16 species. Where then do the Clupeiformes fit into this scheme, and what, if any application, is there to fish that live in the Strait?

While the Clupeiformes order includes exclusively marine and freshwater species and diadromous ones as well, the Pacific Herring’s family, the Clupeidae, counts more diadromous species among its members than any other family except Gobiidae (the gobies) and Salmonidae (the salmon). Thirty-one species are diadromous, with most of that number (26) anadromous, traveling to fresh water when mature, there to spawn and die.

Diadromous fish have long been a subject of human interest not only for their value as food but for the physiological changes they undergo in their transition between salt and fresh water. The alterations are considerable and must be made twice, as the fish migrate from their place of birth to a salty or freshwater environment and back again. Among other stresses that this transition requires, diadromous fish must adjust their cell chemistry. In freshwater the concentration of ion and salt are greater in the cells of the fish than the surrounding water; in this scenario the cell tends to gain water and lose ions. Thus, among other adjustments, freshwater fish must rid themselves of excess water. However, in saltwater the fish must gain water and excrete ions to maintain a balanced concentration.

Thus, when a diadromous fish migrates between saltwater and freshwater for either spawning or to access new food sources, the accumulated water in its cells must now be excreted once again; this transition is often undertaken in brackish waters where conditions are intermediate. But wherever the physiological changes occur, it is a stressful transition for the fish.

As it turns out, the evolutionary record of the Clupeiformes order reveals much about this life journey, one practiced by fewer than one percent of all fish species. Genetic research has revealed that catadromy evolved twice and anadromy five times in the Clupeiformes. The order itself is ancestrally a marine group that invaded continental freshwater 112 times, with only three reversals. Most of this evolution took place in waters lacking other diadromous fish, implying that once a species evolves in a particular site, others are excluded. Researchers also adhere to a “safe-site hypothesis,” which states that migration, at least to freshwater, may have been prompted by predator avoidance. It is also possible that diadromy may be an evolutionary “dead end,” as most lineages are species-poor.

If diadromy depletes numbers of species, what advantages are there for the return of a species to its birthplace to spawn? And what does the Herring order, the Clupeiformes, have to do with the evolution of diadromy?

Recent investigations have questioned at least one widely accepted explanation, the so-called “productivity” theory. This hypothesis proposes that anadromous lineages evolved in temperate areas from freshwater ancestors, while catadromous species began their transition in tropical saltwater. There appear to be many exceptions to this proposition.

Although the three species of the *Clupea* genus, including the Pacific Herring, are not diadromous, the related shads are anadromous, migrating from salt to freshwater in late winter and early spring to spawn. After the establishment of this species in the Sacramento River and its introduction to the

Columbia River in 1885, the American Shad began its move northward, becoming numerous throughout the Salish Sea, where it spawns in large rivers.

The success of the shads worldwide would seem to imply minimal risk to their continued existence. Yet as with all diadromous fish there is the ongoing possibility of human impact to both the waters of their birth and their adulthood. Freshwater habitats are subjected to many degradations, including erosion, pollution, and warming. No less worrisome is the saltwater regime, which may seem vast by comparison, but has revealed over the years a sensitivity to anthropogenic alterations that would surprise even the most visionary naturalists. Population growth implies shoreline expansion, risk of toxic chemicals, bulkheads for "protection," and many more changes. And species such as the Pacific Herring, spawning near the shore and typically returning to the same location each year, as well as their cousins that travel from that nearshore environment to streams and rivers, must deal with alterations that their evolutionary history has not prepared them to deal with.

Add the long history of fishing a species such as Pacific Herring, whose population dynamics is poorly understood, and the worry deepens.

Fishing the Herring — A Downward Spiral

Pacific Herring has long been fished in the Salish Sea, often for its roe but also for the oily flesh that is both nutritious and dries very well. In the past, indigenous peoples would gather the eggs by placing hemlock branches in shallow waters, attracting the females which spawned on the vegetation. Archeological research at many sites in Alaska, British Columbia, and Washington reveal the importance of herring to local diets. In one study 171 sites were surveyed, and of these only two lacked herring bones. Oral history and physical evidence reveal the importance of Pacific Herring and the expectation of the annual return of the fish; several place names refer to the herring's presence, either during spawning or when present offshore in immense fish schools. Harvest was sufficient to enable trading, and kelp "gardens" were often augmented. Rights and responsibilities included the management of herring spawning sites. Such practices imply a consistent and expected return of the Pacific Herring to pre-contact locations.

In the late 19th century, commercial fishing commenced in the Salish Sea, with seines providing a means for catching thousands of fish that were then rendered for their oil and as fish meal. By 1910, restrictions were already in place in the Vancouver Island commercial industry and by the 1930s concern was expressed over the reduction in the herring population. Meanwhile, herring ecology was not a research subject, but rather was limited to observations that fish both returned to the same spawning sites and were consistently present in open waters.

Heavy fishing pressure inevitably led to a crash, not only in the Pacific Northwest, but in Japan as well. The Asian loss put more pressure on demand for herring roe, and thus a "shift" to a roe fishery began, with females collected for their eggs. Not surprisingly, this fishery also declined. Today, at least in specific sites in south Puget Sound the Pacific Herring fishery is for "sport bait" only. As a last holdout for herring fishing, concern has been raised about the lack of spawning in this region where they were historically present.

Sadly, the ups-and-downs of the herring fishery seem to be a once-a-decade news item. Fishery in the 1950s phased out, in concert with the rise of targeting roe, halted again in the 1980s, only to restart but decline again in the 1990s. Closure, reduction to bait fishing — a strange end for an edible fish that has provided so much for humanity in the past.

It seems like the ultimate in human hubris, particularly given that fish declines are not new, to fish and fish with little thought for the fact that no species can sustain such a continuous exploitation. We ourselves, Homo sapiens, *could not survive such a concentrated hunting effort as has been placed on fish.*

Perhaps the Pacific Herring is rather like the Passenger Pigeon or the Great Auk; they reach a critical number or density at which extinction is inevitable.

Where Did the Cherry Point Population Go?

In the past, attempts to list various groups, such as those of Cherry Point and south Puget Sound, have been unsuccessful, and Pacific Herring is termed "data deficient" by the IUCN (International Union for Conservation of Nature), a ruling that impedes attempts to implement protection that may be necessary to sustain the species. Thus, while the IUCN seems to have "punted" in its regulations concerning Pacific Herring, the Cherry Point stock, which spawns much later than other herring populations, has declined an incredible 97% since 1979, from 14,000 tons to about 300. This stock was once the most abundant in Washington State.

What happened? Certainly, it did not help that fishing of the Cherry Point herring was not permanently banned until 1996. By that time, the population was at approximately 1,000 tons, and commercial fishing was for sport bait only. The fishery had been closed in 1981, in response to the declining roe harvest which had gone from a high of 4,000 tons in 1973 to approximately 1,200 tons in 1980. Yet in spite of the impact on herring populations near Cherry Point, the fishery was reopened in 1988, only to be closed permanently in 1996. Too late. By this time, the herring numbers at Cherry Point were in freefall, a precipitous decline that continued unchecked.

Historically the Cherry Point stock included spawning sites as far north as the U.S./Canadian border and south throughout Bellingham Bay. This stretch of more than 37 miles (60 km) is now reduced to only 14 miles (22 km). And although there is a 3,050-acre reserve at the Point, the low numbers of spawning fish implies that the population remains in a tenuous state.

Although many factors have been proposed to explain the decline, it seems inevitable that intensive harvesting of herring eggs — continuously removing generations — would impact the population. This was a boom-and-bust industry, one that continues in waters north of the Washington state line, but not without controversy.

As a forage fish, Pacific Herring plays an important role in the marine ecosystem, but when intensive fishing began, understanding of population dynamics was in its infancy. Even today knowledge is insufficient to forecast the impacts of physical and biological pressures on this vital fish. Herring are a resource for many predators, including the Surf Scoter, a marine diving duck known to alter its preferred prey in response to herring availability. Bigger fish consume adult herring while smaller fish, such as young salmon, eat the tiny larvae. Jellyfish also consume larvae; as jellyfish numbers have increased, they have become a particularly worrisome predator. Mammals prey on herring as well, and whereas seabirds have declined in numbers, pinnipeds, particularly Harbor Seals, have increased their presence in recent decades.

Physical factors also play a role in fluctuating herring numbers. Heat stress from warming waters, pollution from shoreline industries, urbanization, and stormwater runoff all contribute. Other less well-known impacts range from noise, increased light pollution, and the presence of both recreational and

commercial vessels. All of these can affect the Pacific Herring; what is not always clear is the severity of the stress.

Cherry Point herring may be especially vulnerable, as this group spawns much later in the spring than other populations. And with knowledge of herring population dynamics incomplete, questions such as where the adults go after spawning — i.e., do they join up with other stocks, and if so, which ones — is only marginally assessed. It is difficult to track migratory fish, and in Washington State herring surveys are limited to estimating spawning mass.

Meanwhile, while conservationist groups, in concert with the local tribes and concerned citizens work to improve and restore habitat for species such as the Pacific Herring, the stress of the second largest greenhouse emitting facility in the state, the Cherry Point refinery, ranks as the state's largest oil refinery. With rulings demanding a reduction in emissions, improvements to the various fossil fuels processing machines are apparently being implemented. Not far away the Intalco Works Aluminum Smelter, a Cherry Point refinery customer, closed in 2020, but plans to reopen it have garnered state as well as local support. In the past, pollution violations from the plant included excess emission of sulfur dioxide.

Studies and Suggestions

Research into the biological and physical factors affecting Pacific Herring has increased in recent years, and genetic studies are beginning to offer more insight into the relationship between the Pacific Herring spawning populations of the Salish Sea. And at least one comprehensive study both summarizes impacts and examines possible responses to concerns. It is an important effort to both understand and to take a pro-active approach, with the premise that as consumers of a fish so fundamental to the marine food chain, society must consider the future of the herring to be as of equal concern (or perhaps more) as immediate demands.

As an important forage fish, Pacific Herring contribute carbon on an annual basis to the Salish Sea, enriching members of the marine food chain; in fact, herring are considered to be more economically valuable when populations are healthy and left in the water than when fished. Thinking of the many herring predators, juvenile salmon immediately come to mind, but other commercially and recreationally important species also benefit from a large herring biomass. Pacific Hake are known to prey on herring; unfortunately, although formerly both numerous and an important fisheries resource, this species declined 89% in the 1980s. Although Orcas prefer salmon, they will consume herring, and Humpback Whales feast on them when the fish are available. Bird species such as grebes, cormorants, and ducks consume them — the decrease of piscivorous seabirds in recent years has been a particular concern to wildlife scientists and the birding public as well. It seems possible that this decline is in part an outcome of reduced forage fish numbers.

Some herring consumers, however, pose a concern. Over the past 40 years a threefold to ninefold increase in large jellyfish blooms in Puget Sound, coupled with a decline in herring and other forage fish has drawn attention to jellyfish predation on herring larvae. These ancient creatures also compete with herring for planktonic prey. Unfortunately, human alterations to the seashore promote jellyfish populations; as opportunistic invertebrates they do well with seawalls, jetties, and other marine constructs. In certain areas of Puget Sound, a stunning 90% of the biomass can be jellyfish. Less of a concern in the Strait of Juan de Fuca, wariness about their increase seems advisable.

Still other factors that can impact herring populations include ocean acidification which can weaken crustacean shells; these are important prey for both herring larvae and adults. Increased temperatures reduce the survival rate for herring larvae. Disappearance of eelgrass is also a concern; Pacific Herring lay their eggs on eelgrass and other aquatic vegetation such as kelp.

The list of impacts on Pacific Herring from physical and biological alterations in the Salish Sea is long; coupled with the limited knowledge of the reasons for growth or decline of herring populations, the answers are complex, and possible solutions often very difficult to implement. Attempts at restoration are in their infancy, and preservation is achingly slow. To preserve is to withhold from development, and if one thing is evident, it is the growth of the human population along the shores of the Salish sea.

Understanding herring dynamics, even given the knowledge of factors that influence the species' abundance, is difficult. Gathering in schools numbering in the thousands, Pacific Herring do not conveniently stay in one place, and the composition of these great masses varies, perhaps on a seasonal basis. Migration between Salish Sea spawning populations, such as those of Cherry Point, can cover distances as far as the west coast of Vancouver Island, the Strait of Georgia, and other saltwater locations. Spawning is not always predictable and may be affected by tides, presence of predators, and other factors. The tendency to form large schools is beneficial for commercial fisheries, but the dispersal dynamics on the remaining members of a numerically decreased group is poorly known. It has proven difficult to define a specific group, and, most worrisome, the disappearance of spawning at a location is poorly understood.

Attempts to mathematically model Pacific Herring populations have been implemented in recent years; these studies are difficult to assess owing to a paucity of data, but ongoing efforts provide some insight to this "data deficient" species. Qualitative modeling includes some of the many factors that impact Pacific Herring populations. Mathematically rigorous, this approach involves perturbing a factor and evaluating the outcome of the four herring life stages. Although limited in its accuracy, improvements to this type of modeling as well as other approaches are being made and it can be hoped that quantification will provide more insight into Pacific Herring dynamics.

Suggestions for stabilizing the herring stock are reasonable, if somewhat obvious. Improve water quality, reduce light pollution, limit development, transplant herring eggs, reduce vessel impacts, prevent oil spills, limit fishing – the list is a litany for the herring and so many other species. The question is — what has been implemented? And, of equal importance, where does public education and involvement fit into the efforts to understand and preserve Pacific Herring? What is the impact of such attention, if any, on fisheries management? What guidelines should be in place?

In the Strait — Eastern Bays

Documented Pacific Herring spawning sites in the eastern waters of the Strait includes Dungeness, Sequim, and Discovery Bays. Other sites, such as McCurdy Point located north and east of Discovery Bay have been successful spawning locations for the herring as well.

Discovery Bay is considered prime herring spawning habitat in the Strait, but it is also unfortunately noted for its fairly severe ups-and-downs, rather than a consistently productive location. Once extensively fished, since 1990 the stock, with the exception of a good year in 2006 (the causes of such a bonanza year are not well understood) and possibly 2020, has been in decline, with spawning entirely

absent in some years. The cause of the depressed numbers is unknown; although Discovery Bay is a good spawning site, it is possible the herring have moved to a different location.

Dungeness Bay has been documented as the furthest west of any spawning Pacific Herring stock. With excellent vegetation beds, the bay is considered good for herring, yet no spawning has been recorded since 1994; the stock is considered "Declining." Overall, the Pacific Herring stocks of the Strait of Juan de Fuca are labeled as "Critical."

Yet, compared to many sites in the Salish Sea, the Strait of Juan de Fuca seems pristine, a haven where population impacts resulting from anthropogenic activities are not as severe as at locations to the east and south. But no region is without its list of concerns, and as shoreline development proceeds, forests are cut, and the concerns of global warming press closer to the public consciousness, in spite of plans and hopes, work and dedication, it seems that the struggle to ensure healthy marine waters, as well as the rivers that feed them, and all the creatures that dwell there is both deadly serious and unending.

A Good Year, and a Decline

In 2020, Pacific Herring spawning surveys in Washington State included full coverage of six stocks and partial study of another six before closure due to the Covid pandemic. The results were the most encouraging in years; estimated numbers were 17,635 tons, as opposed to an average over the previous ten years of 9,350 tons. Of particular interest were the Purdy, Quilcene, and Port Orchard/Port Madison stocks which reported the highest numbers since surveying began. It was indeed great news, even if the reasons for the excellent spawning season were somewhat perplexing.

However, in 2021, the estimated herring biomass declined by approximately 43%, putting it at 2.5% below the ten-year average. The 2021 surveys included 21 spawning areas in Puget Sound; two areas in particular, declined, including Discovery Bay. Herring were absent from southern Hood Canal for the first time since surveying began. Clearly, the dynamics of Pacific Herring stocks remain only partially understood.

Discovery Bay – Critical habitat

In 2020, the Jamestown S'Klallam tribe reported an addition of 1.5 miles of armored shoreline to their Area of Interest. Noting that shoreline armoring is increasing, the impact of such structures is known on forage fish, including the Pacific Herring. It is reported in the bay that 19.1% of spawning grounds for forage fish are armored, a number most likely to increase. In particular, Clallam County shoreline permitting does not consider impact of armoring off-site. Issues such as water quality, climate change, and declining forest quality are as always of increasing rather than decreasing concern.

Yet in this region encouragement is found in the restoration and recovery efforts that involve many citizens. Coupled with an ongoing commitment of conservation organizations to protecting what remains and embracing positive change for the marine waters of the Strait, much effort is devoted to improving salmon habitat. Acknowledging the importance of the smaller fish that provide food for marine and terrestrial life alike, attention is directed towards species such as Pacific Herring, as well as the plankton that ultimately all marine life depends on. The evident decline of so many species in the Strait will remain a concern for the foreseeable future, but it can be hoped that through awareness and prioritization one day the telltale spawning of the Pacific Herring will year after year will cloud the clear marine waters that are home.

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Declarations of the apparent health of Pacific Herring stocks can be taken as encouraging news. Lack of understanding remains worrisome. And the tendency to permit an increased take when fish stocks increase, however temporarily, is always a concern. It seems that the pressure to fish is always on.

Perhaps in this case it would be good to declare a reprieve for a fish that is so important at so many levels to the health of the sea. Maybe the Pacific Herring shouldn't be fished to a specified level of "unfished biomass." Perhaps one hundred percent would provide not only a fighting chance for the fish but an educational opportunity unlike any other. It seems logical that the best management practices should involve looking towards the future of the Salish Sea for more than a season or two. The goal is simple — the health of its waters, the continuance of the creatures that reside there, and the humans that ultimately depend upon them.