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2016 Washington State Herring Stock Status Report

by Todd Sandell, Adam Lindquist, Phill Dionne, and Dayv Lowry

Washington Department of
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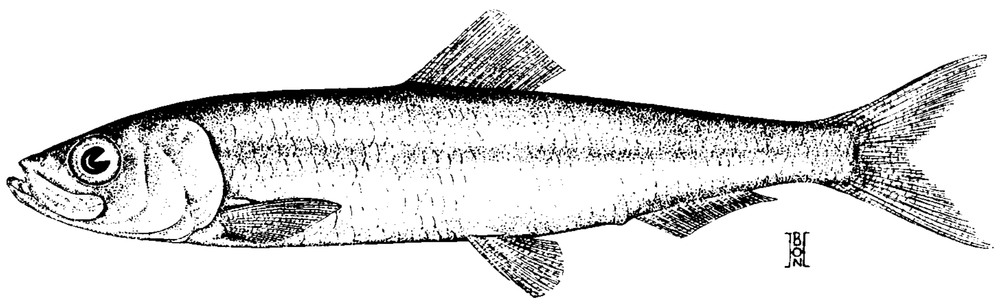

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Executive Summary

This is the sixth edition of the Washington Department of Fish and Wildlife's report on Pacific herring stock status. As in the 2012 edition, data collected from spawning ground surveys were used and geographic coverage is limited to greater Puget Sound (also referred to as the southern Salish Sea; SSS). In this report we revised our traditional stock status review method to reduce the influence of extreme values in any particular survey year and end the practice of using inputed values for years with missing data.

In the current report stock status was determined by comparing the four-year mean, rather than the two year mean, of estimated abundance with the previous 25-year mean abundance. (This reduces the influence of an abundance estimate from any single year on our understanding of recent stock status, minimizing status volatility, and brings assessment in alignment with the periodicity of these reports). We also base the mean abundance estimates for each stock only on years for which data are available, rather than using mean imputation for years in which data are unavailable, as in past reports. This practice added apparent stability in abundance over periods for which, in reality, no assessment of stock status could be made. Furthermore, we apply consistent, numerical stock status evaluation criteria and revised categories to include an "Increasing" status to reflect the large increases of abundance observed for some stocks. The new status categories are decribed in the Stock Status section on page 19. In the table of historic stock status (Table ES1), the new evaluation and status assignment criteria are used for each four year period, establishing new status time trends.

Using the new evaluation and status assignment criteria, the status category of 7 stocks has worsened, 12 stocks have the same classification, and 2 stocks have improved in the four years since 2012. The number of stocks classified as Increasing or Healthy have decreased from 5 to 4 (Table ES1). Cumulative abundance of the Other Stocks Complex remained relatively stable (Figure ES1) over the past four years. For the 2013-16 period the aggregate of SSS herring stocks is considered Healthy (total estimated spawning biomass is 110% of the 25 year mean). While this metric is the traditional model of assessment, it obscures several important trends. Stability of the total herring spawning biomass is driven entirely by large increases in the Quilcene Bay (Hood Canal) stock, which has increased 224% over the past four years and now makes up over half of all the SSS spawning herring biomass. If Hood Canal stocks are excluded from the Other Stocks Complex, the aggregate biomass of the remaining stocks has decreased and would now be categorized as Declining.

By basin, South and Central Puget Sound stock aggregates (Table ES1, Figure ES3) have changed from Declining to Critical, with four individual stocks (Purdy, Wollochet Bay, Quartermaster Harbor, and Port Orchard-Port Madison) having no spawn detected in 2016. The Whidbey Basin stock aggregate has also been changed from Healthy to Depressed. The Strait of Juan de Fuca and Hood Canal stock aggregates continue with the same status from 2012, with Strait of Juan de Fuca being Critical and Hood Canal categorized as Increasing. Northern stocks have been changed from Depressed to Healthy, due mainly to robust years at Semiahmoo and Samish/Portage Bays.

The genetically distinct Squaxin Pass stock is considered Depressed at this time (51% below 25 year mean), due in part to changing the sampling methodology (see the Squaxin Pass section for more information). The Cherry Point stock also shows no signs of recovery from its low level of abundance; spawning biomass in 2016 was again an all-time low (the stock has now declined over 96% from the initial estimate made in 1973). However, by basin the northern stocks (excluding the Cherry Point stock) aggregate spawning biomass is classified as Healthy partially because the Cherry Point Stock has been Critical for so many years that the rolling 25-year mean now fails to capture historic biomass peaks.

Commercial herring fisheries in the SSS have experienced several major shifts since the start of the last century, as described in detail by Trumble (1983) and Williams (1959), and summarized in a previous Washington state stock status report (Stick and Lindquist 2009). At present, the "sport bait" herring fishery continues to be the only commercial herring fishery still operating in Puget Sound, providing bait for sport salmon and groundfish fisheries. The sport bait fishery mostly targets 1+ to 2+ year old (juvenile) herring assumed to be an aggregate of stocks within the region. Almost all harvest in recent years has been taken by non-tribal fishers using relatively small (maximum length of 200 feet) lampara seines, with a small portion of landings captured via dip bag net gear. This fishery has a harvest guideline of less than 10% of the cumulative adult herring spawning biomass (SB) estimate of stocks that spawn in South/Central Puget Sound, Hood Canal, and the Whidbey Basin (Bargmann, 1998; Day, 1998), but usually only achieves 2-6% of the SB because of market conditions and processing/holding capacities (Stick et al., 2014). Fishing activity is primarily in South/Central Puget Sound. Hood Canal has been closed to all commercial herring fishing since 2004 due to concerns about the impacts of low dissolved oxygen and elevated summer temperatures on fish health and abundance, and several other areas are closed year round or seasonally to minimize harvest of spawning adults (Figure 7). Since the commercial harvest seasons depicted in Figure 7 were developed, additional spawning areas have been identified. To protect the herring spawning in these newly documented areas, the Department may consider modifications to the commercial seasons.

Stock status throughout the SSS is influenced by a variety of natural and anthropic factors, including habitat availability, predation intensity, and water quality. Efforts to comprehensively assess and evaluate stressors that might be mitigated by management actions is currently underway. Ensuring long-term persistence of herring stocks is key to food web and ecosystem health, and is a primary goal of the Department's Marine Fish Science Unit.

Table ES1. Status of herring stocks in the southern Salish Sea based on recent 4-year mean abundance compared to rolling long-term (previous 25-year mean) abundance.

Increasing■- A stock with recent 4-year mean abundance more than 20% above the 25-year mean; **Healthy**■- A stock with recent 4-year mean abundance within 20% of the 25-year mean; **Declining**■- A stock with recent 4-year mean abundance 21-50% below the 25-year mean; **Depressed**■- A stock with recent abundance 51-80% below the 25-year mean; **Critical**■- A stock with recent 4-year mean abundance 81-99% below the 25-year mean; **Undetected**■- A stock that can no longer be found in a formerly consistently utilized spawning ground for four consecutive years; **Unknown**□- Insufficient assessment data to identify stock status with confidence. Individual stocks in **BOLD** font are considered genetically distinct. The number to the right of each stock name indicates the number of years with biomass estimates available for the 25 year average (1988 through 2012).

SOUTHERN SALISH SEA HERRING STOCK STATUS BY BASIN AND STOCK, 1988-2016 (4 year average Vs. 25 year rolling average)

Basin	Stock - *# years w/ data 1988-2012*	1988	1992	1996	2000	2004	2008	2012	2016
South Puget Sound	**Squaxin Pass** - *23*	NO SAMPLE	UNKNOWN	DECLINING	DEPRESSED	INCREASING	HEALTHY	DECLINING	DEPRESSED
	Purdy - *5*	NO SAMPLE	NO SAMPLE	NO SAMPLE	NO SAMPLE	NO SAMPLE	UNKNOWN	UNKNOWN	UNKNOWN
	Wollochet Bay - *13*	NO SAMPLE	NO SAMPLE	NO SAMPLE	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	CRITICAL
	Quartermaster Harbor - *25*	UNKNOWN	DEPRESSED	HEALTHY	HEALTHY	DECLINING	DECLINING	DEPRESSED	CRITICAL
Central Puget Sound	Elliott Bay - *1*	NO SAMPLE	NO SAMPLE	NO SAMPLE	NO SAMPLE	NO SAMPLE	NO SAMPLE	UNKNOWN	UNKNOWN
	Port Orchard-Port Madison - *25*	UNKNOWN	DECLINING	DEPRESSED	HEALTHY	HEALTHY	INCREASING	DEPRESSED	CRITICAL
Hood Canal	South Hood Canal - *19*	NO SAMPLE	UNKNOWN	UNKNOWN	UNKNOWN	DECLINING	HEALTHY	HEALTHY	HEALTHY
	Quilcene Bay - *19*	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	INCREASING	INCREASING	INCREASING	INCREASING
	Port Gamble - *25*	UNKNOWN	INCREASING	HEALTHY	DECLINING	DECLINING	DEPRESSED	DEPRESSED	CRITICAL
Whidbey Basin	Holmes Harbor - *19*	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	INCREASING	INCREASING	INCREASING	DECLINING
	Skagit Bay - *19*	UNKNOWN	NO SAMPLE	UNKNOWN	UNKNOWN	INCREASING	INCREASING	DEPRESSED	DEPRESSED
	Port Susan - *25*	UNKNOWN	UNKNOWN	DECLINING	INCREASING	DECLINING	DEPRESSED	DEPRESSED	CRITICAL
Strait of Juan de Fuca	Kilisut Harbor - *21*	NO SAMPLE	UNKNOWN	UNKNOWN	HEALTHY	INCREASING	CRITICAL	UNDETECTED	CRITICAL
	Discovery Bay - *25*	UNKNOWN	DECLINING	DEPRESSED	CRITICAL	CRITICAL	DEPRESSED	CRITICAL	CRITICAL
	Dungeness/Sequim Bay - *20*	UNKNOWN	UNKNOWN	UNKNOWN	INCREASING	DECLINING	CRITICAL	DECLINING	DECLINING
San Juan Islands/ Strait of Georgia ("North")	Interior San Juan Islands - *21*	NO SAMPLE	UNKNOWN	UNKNOWN	UNKNOWN	DECLINING	DECLINING	CRITICAL	CRITICAL
	NW San Juan Islands - *18*	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNDETECTED	UNDETECTED	NO SAMPLE
	Fidalgo Bay - *22*	UNKNOWN	UNKNOWN	INCREASING	HEALTHY	HEALTHY	DEPRESSED	CRITICAL	CRITICAL
	Samish/Portage Bay - *22*	UNKNOWN	DECLINING	INCREASING	INCREASING	INCREASING	HEALTHY	INCREASING	INCREASING
	Semiahmoo Bay - *25*	UNKNOWN	INCREASING	HEALTHY	DECLINING	DECLINING	DECLINING	HEALTHY	INCREASING
	Cherry Point - *25*	DEPRESSED	DECLINING	DECLINING	CRITICAL	DEPRESSED	DEPRESSED	DEPRESSED	DEPRESSED

Regional Totals	1988	1992	1996	2000	2004	2008	2012	2016
South Puget Sound stocks	INCREASING	HEALTHY	INCREASING	HEALTHY	DECLINING	DECLINING	DECLINING	CRITICAL
Central Puget Sound stocks	INCREASING	INCREASING	DECLINING	HEALTHY	HEALTHY	INCREASING	DECLINING	CRITICAL
Hood Canal Stocks	INCREASING	INCREASING	INCREASING	INCREASING	INCREASING	HEALTHY	INCREASING	INCREASING
Strait of Juan de Fuca stocks	INCREASING	HEALTHY	INCREASING	INCREASING	INCREASING	INCREASING	HEALTHY	DEPRESSED
Whidbey Basin stocks	INCREASING	HEALTHY	DECLINING	DECLINING	DEPRESSED	DEPRESSED	CRITICAL	CRITICAL
Northern stocks	INCREASING	HEALTHY	HEALTHY	DEPRESSED	DEPRESSED	DECLINING	DEPRESSED	HEALTHY
All Stocks combined excluding Quilcene Bay (HC)	INCREASING	INCREASING	HEALTHY	DECLINING	DECLINING	DECLINING	DECLINING	DECLINING
All Stocks combined	INCREASING	INCREASING	HEALTHY	HEALTHY	HEALTHY	HEALTHY	DECLINING	HEALTHY

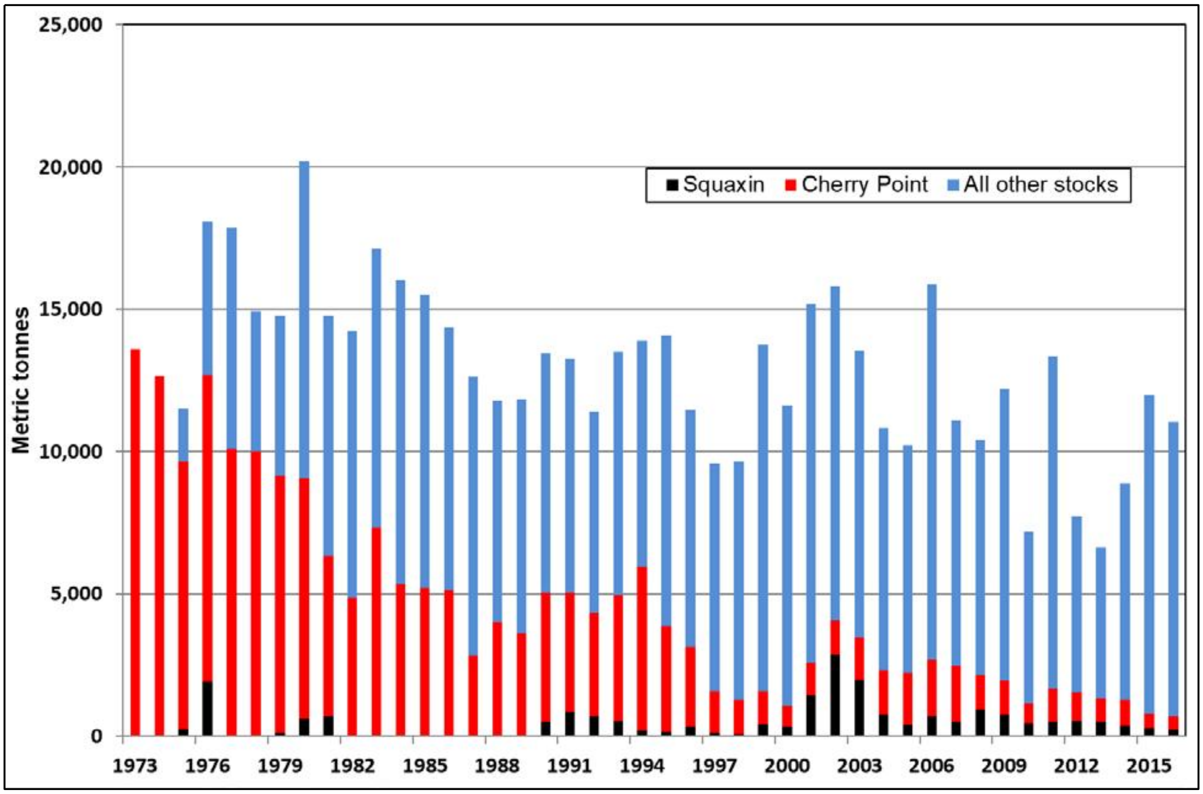


Figure ES1: Southern Salish Sea Herring Cumulative Spawning Biomass Estimates by Genetic Grouping, 1973-2016, in metric tonnes.

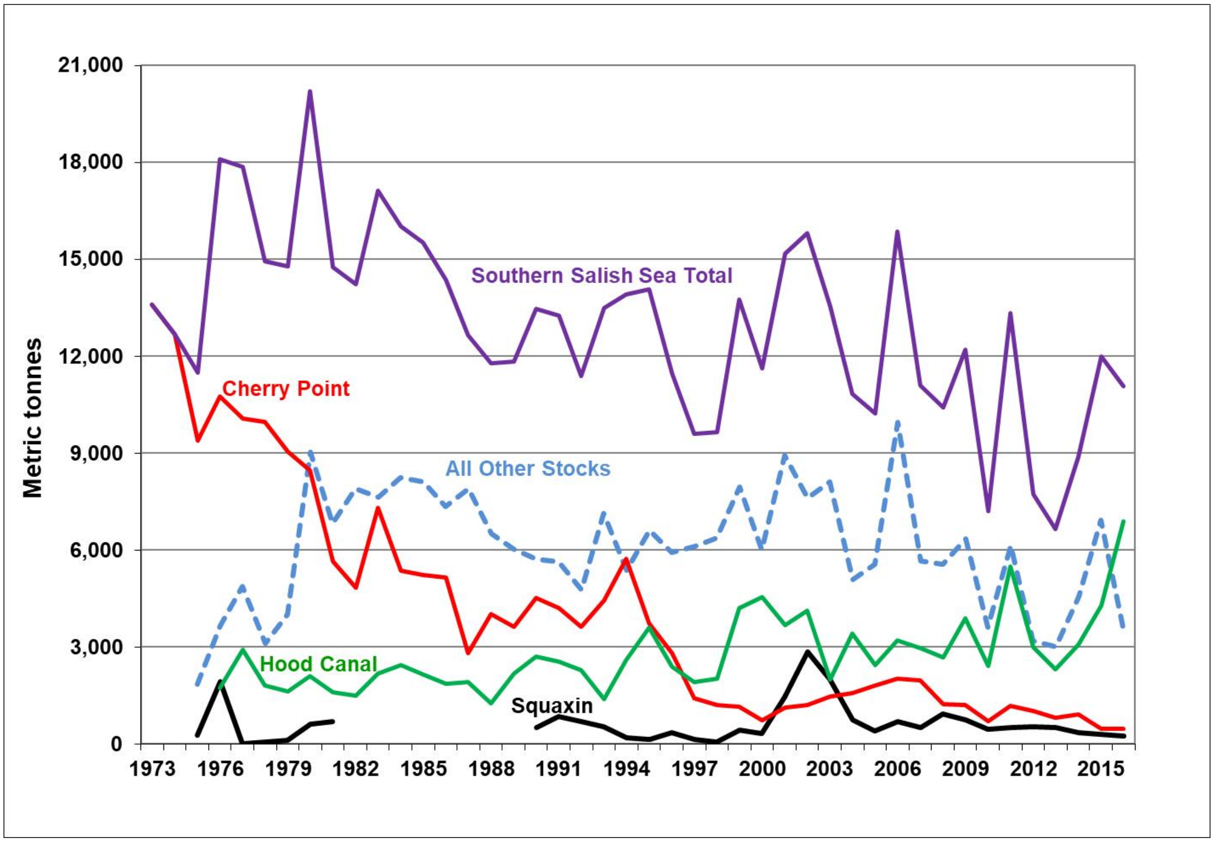


Figure ES2: Southern Salish Sea Herring Spawning Biomass Estimates, with Cherry Point, Squaxin, and Hood Canal stocks broken out, 1973-2016.

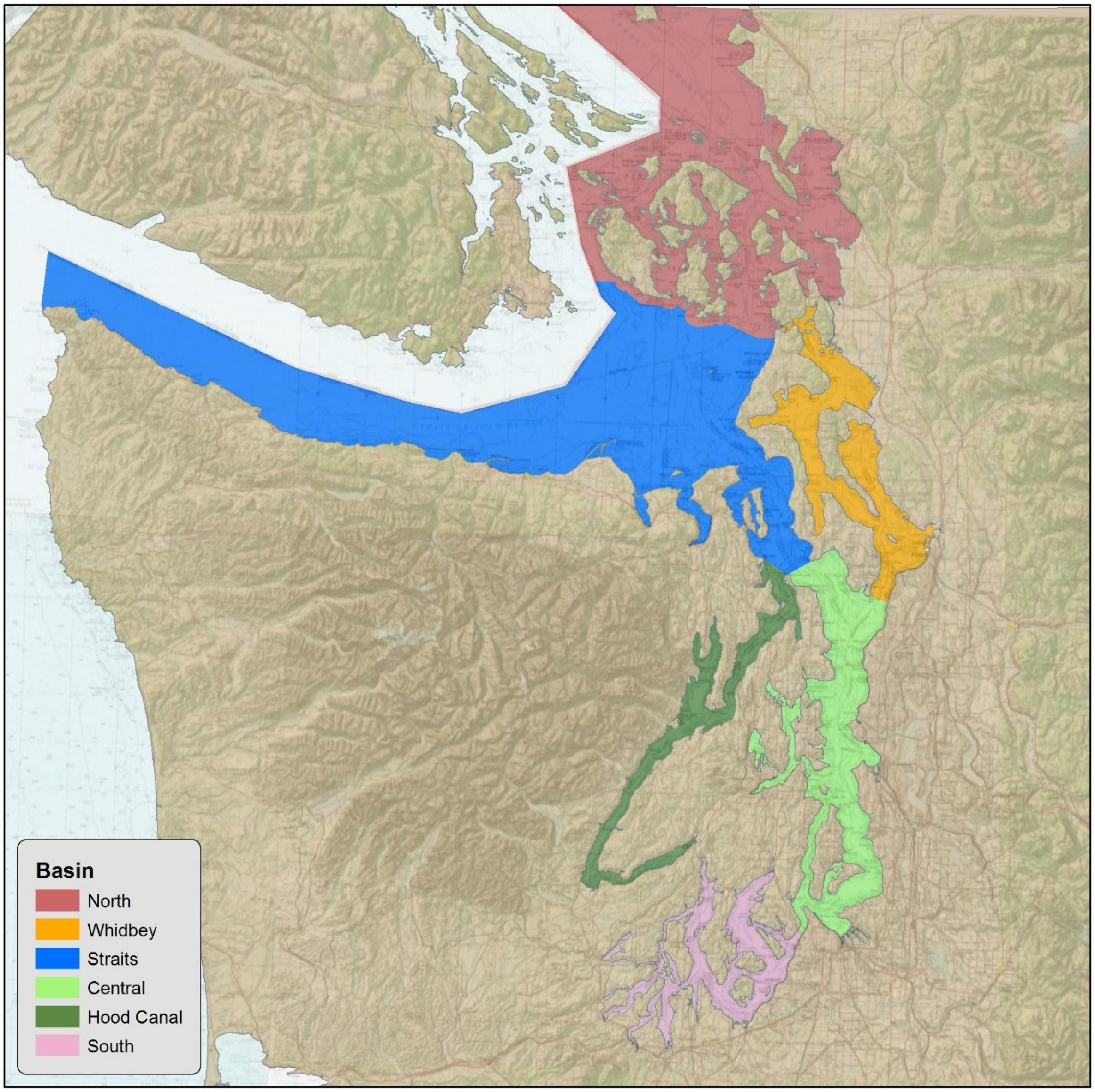


Figure ES3: Southern Salish Sea Basins referred to in this report.

Introduction

Forage fishes in general, and herring in particular, are vital components of the marine ecosystem of the Puget Sound (also referred to as the southern Salish Sea; SSS) and are a valuable indicator of the overall health of the marine environment. Many species of sea birds, marine mammals, and finfish, including lingcod (*Ophiodon elongatus*), Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon, depend on herring as an important prey item (DFO, 2001, Fresh et al., 1981; Beauchamp and Duffy, 2011; Kemp et al., 2013). Significant predation occurs at each stage of the herring life cycle, starting with consumption of deposited eggs by invertebrates, fish, gulls, and diving ducks. Reflecting the importance of herring in the SSS ecosystem, Washington Department of Fish and Wildlife (WDFW) has closely monitored abundance of key herring stocks since 1972, and the Puget Sound Partnership (PSP) selected the spawning biomass of SSS herring as an annual vital sign indicator of ecosystem health (PSP, 2010).

This report provides an evaluation of the current status of the Pacific herring (*Clupea pallasii* Valenciennes, 1847) resource in the SSS based on data available through 2016. This report is the sixth edition published by the WDFW that addresses the status of the herring resource in Washington waters. The previous editions are: *1994 Washington State Baitfish Stock Status Report* (WDFW and North Puget Sound Treaty Tribes, 1995); *1996 Forage Fish Stock Status Report* (Lemberg et al., 1997); *2004 Washington State Herring Stock Status Report* (Stick, 2005); *2008 Washington State Herring Stock Status Report* (Stick and Lindquist, 2009), and *2012 Washington State Herring Stock Status Report* (Stick et al., 2014).

Similar to previous reports in this series, this report is based on surveys of localized documented spawning grounds in Washington waters. Due to the consistent spatial and/or temporal separation of spawning events, these spawning grounds are used to define the 21 docuemented SSS herring stocks. Herring spawn for the first time at age two or three at specific locations throughout the SSS between early January and mid-June, depending on the stock. Adhesive eggs are deposited mainly on marine vegetation in the intertidal and shallow subtidal zone. While it is important to protect all documented herring spawning grounds, prior research has identified two genetically distinct stocks (Cherry Point and Squaxin Pass) and, as with past reports, abundance trends are reported for these stocks independently, as well as for the aggregate Other Stocks Complex. However, it may also be meaningful to examine abundance trends on a broader geographics scale (e.g., by basin) that acknowledges variations in habitat and population stressors, which is done for the first time in this report.

Information utilized for this report is obtained from an annual assessment of each known stock in the SSS in order to provide estimates of stock-specific spawning biomass. Historically, two methods were used to obtain these estimates: acoustic/trawl surveys; and rake spawn deposition surveys (see below). Due to budget reductions, acoustic/trawl assessment surveys, which had been conducted on selected SSS herring stocks by the WDFW since the early 1970s, were terminated after the 2009 season. Current assessment is based solely on rake spawn deposition surveys via inspection of macrovegetation. Due to the cessation of acoustic/trawling efforts, which brought adult fish to hand and allowed for scale ageing, assessment of sexual maturity, and length-weight regressions, we are no longer able to estimate the age structure of any stocks.

These data (through 2009) are available in Appendix A of the 2012 stock assessment report (Stick et al., 2014).

Stock profiles, which include spawning location and timing information, and annual run size estimates, are presented for each known Washington herring stock. The definitions for stock profile criteria follow this section. <u>The stock status assessment methods and criteria in this report deviate substantially from past reports</u>. Traditionally, current stock status was determined by comparing the average of abundance estimates for the two most recent years to the running 25-year average for each stock. Here, we expand this window to include the last four years, thus reducing the influence of an estimate from any single year on our understanding of recent stock status, minimizing volatility in status assignment, and bringing status evaluations into alignment with the periodicity of these reports. We also base the rolling 25-year mean abundance for each stock only on years for which data are available, rather than imputing means for years in which data are unavailable, as in past reports. This historic practice gave the impression that more data were available to assess stock status than actually existed, and introduced the appearance of hyperstability for some stocks (i.e., the same mean was used for several years in a row despite surveys not occurring during that period). Finally, past reports were not comprenesive in defining the quantitative bins used to assign stock status. To rectify this, we apply consistent, numerical stock status evaluation criteria and revise the category labels assigned to stocks based on these criteria, which allows us to better characterize recent increases in the abundance of some stocks.

Following the stock-specific status profiles, four-year stock status summaries based on the new evaluation criteria for 1988 through 2016 are provided for all stocks, followed by a discussion and graphs of cumulative herring spawning biomass estimates for the 1973-2016 period. <u>These summaries represent new status time trends that may deviate from assessments presented in past reports</u>.

An updated summary of SSS herring fisheries and landings through 2016 is provided in the next section. Herring were included in the 1974 "Boldt Decision" defining Native American Treaty Tribe fishing rights, and Washington stocks and fisheries are therefore jointly co-managed statewide by the WDFW and locally by area Tribal governments. Currently, the only active commercial herring fishery in Washington waters is the sport bait fishery, which provides product primarily for recreational salmon and bottomfish fisheries, and has taken less than 6% of the total estimated spawner biomass in recent years. For conservation reasons harvest in this fishery was capped at 10% of recent biomass in the late 1990s (Bargmann 1998). Fishing is also closed on Hood Canal south of the Hood Canal bridge.

Stock profiles for two coastal Washington stocks, Willapa Bay and Grays Harbor, were not included in this report as no assessment surveys have been conducted there since 2007; surveys in these areas will be renewed in 2017.

Southern Salish Sea Herring Stock Structure

The importance of stock structure throughout the range of Pacific herring has been recognized since the onset of directed management efforts, and the recognition of individual stocks within the Puget Sound herring resource has been utilized for management purposes for decades. Temporal and spatial specificity of observed spawn deposition, and differences in biological parameters, were the first characteristics used to support the independence of each spawning aggregation as a discrete stock.

Based largely on the fact that herring tend to return to spawn in approximately the same locations at about the same time year after year, Chapman et al. (1941) concluded that their hypothesis that each spawning population was independent from any other was strongly supported. Chapman et al. (1941) also suggested that the independence of spawning populations was demonstrated and that there was little, if any, intermixing among different spawning populations in Washington. This study formed the basis for considering each spawning aggregation as a discrete stock and was based primarily on mean vertebral counts, in addition to spawn timing and location. Williams (1959) reported that stocks of herring in greater Puget Sound were largely independent of each other, with respect to population dynamics, and that depleted stocks receive very little recruitment from other stocks.

Based on differences in spawn timing and location, growth rates, patterns of annulus formation, and incidence of internal parasites, Trumble (1983) determined that several major discrete spawning herring populations existed in the SSS, and that several smaller stocks may also exist. Cherry Point (Strait of Georgia) and Case Inlet (Squaxin Pass) herring exhibited the most distinct characteristics that separated them from herring in other areas. Trumble (1983) further stated that "spawning populations appear to maintain independence from other populations, and interbreeding between populations seems limited."

Early genetic work to assess stock structure based on allozyme variation (Grant & Utter, 1984), did not support the existence of discrete populations of herring within Puget Sound. This study, which included samples from South Puget Sound (Hale Passage) and the Strait of Georgia (Cherry Point stock) observed genetic differentiation only over relatively large geographic areas, such as between Asian and eastern Pacific regions, and perhaps between the Gulf of Alaska and California herring samples. Later studies, using mitochondrial DNA variation (Schweigert & Withler, 1990) and ribosomal DNA sequence variation (Domanico et al., 1996), also did not provide any evidence of local genetic differentiation of eastern Pacific herring, including those in the SSS.

The analysis of microsatellite DNA loci represented a landmark in the detection of systematic genetic variation among populations in localized areas of the eastern Pacific Ocean, such as Puget Sound and Canadian Strait of Georgia. Analyses completed by O'Connell et al. (1998) of Alaskan herring were the first to suggest that microsatellite DNA loci could be used to detect subtle genetic differentiation not previously distinguished via other techniques. The initial documentation of significant genetic differentiation for Washington state herring was reported by Beacham et al. (2001, 2002), who found that herring spawning at Cherry Point were distinct from sampled Canadian Strait of Georgia herring. This finding was considered consistent with estimated straying rates from tagging studies among stocks that are sufficient to homogenize allele frequencies over large geographic areas.

Tagging studies of herring in B.C. have indicated a high fidelity (i.e., repeat homing to a spawning location) rate of 75-96% of tagged fish at-large for one year, which also indicates a sizable straying rate of 4-25% (Ware et al., 2000). It should be noted that this is not a measure of natal homing but, rather, demonstration of a pattern of repeated use of a selected spawning area by an individual following first use of that site. Gustafson et al. (2006) concluded that the high fidelity rate provides the biological basis for existing herring stock management in B.C. because most of the adult herring return to the same region to spawn the following year, and that the observed straying rates reduce genetic divergence among the five major populations. In their analysis of the same tagging data, Hay et al. (2001) suggest a minimum area size of about 500 km^2 to support high fidelity. Ware et al. (2000) also concluded that their analysis suggests that the straying rate is density-dependent, appearing to increase linearly with increased population size as suitable spawning habitat becomes a limiting factor.

Potentially relevant to the discussion of stock structure and identification of Puget Sound herring is the fourth of a series of papers by Ware and Tovey (2004) outlining evidence that B.C. herring are spatially structured and interact as a metapopulation. They analyzed spawn time series between 1943 and 2002 for indications of “disappearance” and “recolonization” events at the spatial scale of “sections,” which on average contain about 250 km (155 miles) of shoreline. A disappearance event was assumed to have occurred in a section when five consecutive years of no spawn appeared in the time series. A recolonization event was assumed to have occurred when spawning was documented after a disappearance event. *The authors identified 82 spawn disappearance events for the sixty-year period examined and found that more than half (55%) of the sections had experienced one or more disappearance events.* They found that sections with larger amounts of spawning habitat experienced fewer disappearance events than smaller sections and stated that the high degree of straying between nearby sections explains why herring spawning aggregations at the section spatial-scale are so dynamic. The authors also note that their analysis may have overestimated the frequency of disappearance events in sections with very small spawn habitat indices (i.e., smaller spawning biomass) because it was not always known if a section had received survey effort.

A possible example of significant straying of adults to different spawning grounds in Puget Sound occurred in 2006 when a dramatic one-year increase in spawning biomass was observed for the Discovery Bay herring stock. The estimated spawning biomass for this stock in 2006 was 1,202 tonnes. The presumed 2 to 5 year old adults that would have comprised most of the 2006 spawning biomass were spawned in years that had a mean spawning biomass of only 169 tonnes, and spawning biomass for the two years following 2006 was less than 227 tonnes. If the majority of the 2006 spawning biomass documented for this area strayed from another stock, the identity of that stock is unknown.

Despite the potential for straying, when Small et al. (2005) examined temporal and spatial genetic variation for herring, including samples of prespawning adult herring from Cherry Point, Semiahmoo Bay, Fidalgo Bay, Port Gamble, and Squaxin Pass collected over intervals of two to four years. they demonstrated consistent genetic differentiation between the Cherry Point, Squaxin Pass, and the other three Washington samples. Given the small spatial scale involved, the degree of genetic differentiation for these two stocks (Cherry Point and Squaxin Pass) is considered to be "remarkable." Late spawn timing (Cherry Point) and geographic isolation (Squaxin Pass) were suggested as the primary causes for the observed levels of genetic distinctiveness.

The genetic differentiation of the Cherry Point herring stock was further demonstrated by Mitchell (2006). Microsatellite DNA loci were examined for samples from Cherry Point, Semiahmoo Bay, Port Gamble, Quartermaster Harbor, and Squaxin Pass herring with an increased temporal scale of six years. Genetic differentiation was consistent over six years for the Cherry Point stock (samples from 1999, 2004, and 2005), but the genetic differentiation of Squaxin Pass (Case Inlet) fish observed in 1999 was not observed in 2005 (though the 2005 samples may not have been active spawners and might have come from other nearby stocks). However, 2007 samples again demonstrated differentiation (Lorenz Hauser, University of Washington, unpublished data). There was a lack of biologically meaningful genetic differentiation among the other areas sampled in this study; as a result, these remain grouped into an Other Stocks Complex.

In the past decade, next generation sequencing has revolutionized evolutionary population genetics of non-model species (Seeb et al., 2011), such as herring. The great advantage of next generation sequencing technologies is that they combine a highly powerful survey of neutral genetic variation using thousands of genetic markers with the potential of detecting genes under selection, thus allowing unprecedented insight into population structure and connectivity as well as the molecular genetic basis of local adaptation. In Atlantic herring (*Clupea harengus*), this development has allowed two significant advances: first, it is now possible to assign individual herring to population of origin, with applications in the prosectution of illegal catches (Nielsen et al., 2012) and the management of mixed stock fisheries in the North Sea and Baltic Sea (Bekkevold et al., 2015). Second, it became possible to identify regions of the genome likely involved in adaptation to salinity and spawn timing, first by screening expressed genes (Lamichhaney et al., 2012; Limborg et al., 2012), but now also from whole genome sequences (Barrio et al., 2016; Lamichhaney et al. 2017). The latter studies identified a gene for a thyroid stimulating hormone receptor (TSHR) as having a particularly consistent association with spawn timing, which is intriguing because these genes are involved in photoperiod reception and reproductive biology (Lamichhaney et al., 2017). Importantly, these studies also supplied a fully assembled genome sequence for Atlantic herring (Barrio et al., 2016), which will be useful for analysis of Pacific herring in the SSS given the recent divergence between Atlantic and Pacific herring (Laakkonen et al., 2015). These recent genomics studies have therefore narrowed the gap between the phenotypic diversity first noted by Hjort (1914) and the population structure and adaptive genetic differentiation relevant to today's management.

Based on the available genetic data, WDFW manages Puget Sound herring in three aggregates: Squaxin Pass, Cherry Point, and the Other Stocks Complex (Stick et al., 2014). However, demographic structure and connectivity within the Other Stocks Complex is an issue of uncertainty, so WDFW typically assesses 21 spawning stocks of herring in the SSS (see Figure **1**, "Documented Southern Salish Sea Herring Spawning Grounds"). While tagging data from British Columbia suggested considerable straying on regional scales (Hay et al., 2001), population models based on WDFW data (Siple and Francis, 2016) and preliminary genetic data indicate distinct patterns of fluctuation in abundance and some reproductive isolation among sampled stocks in the SSS (personal communication, Lorenz Hauser, UW). The status of individual stocks is of considerable significance because isolated populations may be locally adapted and thus react independently, and possibly uniquely, to environmental perturbations and other stressors. Such adaptive population diversity may be a central component of the stability and perpetuation of SSS herring because asynchronous fluctuations in abundance dampen variation in total abundance in a so-called 'portfolio' effect (Schindler et al., 2010; Siple and Francis, 2016). In order to maintain the portfolio effect of stabilizing regional abundance, and thus the ecosystem function and evolutionary potential of SSS herring as a whole, it is crucial to identify adaptive genetic differences so that locally adapted populations and their spawning sites can be managed effectively. The geographic complexity of the SSS, with numerous long, isolated inlets means that loss of any single spawning stock can have considerable ecological effects for populations of resident marine predators and competitors.

Resident vs. Migratory stocks

The movement patterns of herring when not aggregated near their spawning grounds is of interest because the potential suite and magnitude of stressors that influence stock dynamics likely very across the range of habitats that the various stocks may occupy, and may account for some of the asynchronous abundance fluctuations observed between stocks that spawn in close proximity to one another. A microsatellite study by Beacham et al. (2008), involving summer mixed-stock samples of herring from B.C. and Washington, produced results showing the genetic differentiation of Cherry Point herring as well as four separate stocks in B.C. Also noteworthy from this work was the indication that herring from the east side of the Strait of Georgia (mainland inlet stocks) are predominantly "resident," while populations from more seaward locations along the central coast and Johnstone Strait were populations that migrated to offshore summer feeding grounds (West coast Vancouver Island and possibly other areas).

Potential differences in migratory behavior among SSS stocks has been indicated by tagging (O'Toole et al., 2000; Stick et al., 2014), otolith (Gao et al., 2001) and parasite (Hershberger et al., 2002) studies, with Cherry Point and Quilcene herring among the most migratory, and Squaxin Pass the most resident stock of the stocks that were assessed.

Coarser scale distribution of herring in onshore vs. offshore areas can be assessed by the analysis of stable isotopes (delta Carbon (ΔC) and delta Nitrogen (ΔN)) (an analogy would be the longitude of the areas where these fish are feeding when not on the spawning grounds). Stable isotope analysis indicates that the Cherry Point and Semiahmoo Bay stocks cluster more tightly with herring populations from the west coast of North America (e.g. Central Coast of B.C., West coast of Vancouver Island) whereas the inner Puget Sound herring stocks comprise a separate cluster (O'Neill, West [WDFW] and Ylitalo [NOAA], personal communication). The Port Orchard/Pt. Madison and Squaxin Pass populations have enriched isotopes indicative of residency in Puget Sound (O'Neill, West [WDFW] and Ylitalo [NOAA], personal communication). All the other SSS herring populations analyzed, except Quilcene Bay (Hood Canal), share a similar carbon isotope pattern that is indicative of a more coastal marine distribution, suggesting these fish migrate out of the SSS after spawning. The Quilcene Bay herring carbon signature is different, falling between the coastal and resident Puget Sound signatures, so at present it is unclear where they reside and feed when not spawning; they could remain in Hood Canal year-round.

The analysis of persistent organic pollutants (POPs) from herring tissue is another tool that provides a refined description of marine distribution and feeding patterns http://www.psp.wa.gov/vitalsigns/toxics_in_fish.php). Along the west coast of North America, DDTs are more elevated in prey from southern California, PCBs and PBDEs are more elevated in prey from Puget Sound, and HCBs more elevated in prey from the north coast (West Coast Vancouver Island and beyond) (O'Neill and West, WDFW). The POP "fingerprint" is thus correlated with latitude, providing a measure of the north to south marine distribution of herring feeding grounds. Collectively, both the stable isotopes (longitude) and the contaminant fingerprints (latitude) provide us with an understanding of where herring populations feed along the west coast of North America.

In their study of the geographic distribution and magnitude of three persistent organic pollutants (POPs) in herring, West et al. (2008) suggest strong environmental segregation of herring samples from inner Puget Sound (Squaxin Pass, Quartermaster Harbor, Port Orchard) compared to the Strait of Georgia (Cherry Point, Semiahmoo Bay, Hornby/Denman Island, B.C.). They conclude the observed segregation likely results from differential exposure to contaminants related to the locations where populations (two and three year old herring) reside and feed. All three "Strait of Georgia" samples were strongly isolated from the "inner Puget Sound" samples based on multidimensional scaling (MDS) mapping of POPs.

More recent work has also shown that herring from Quilcene Bay in Hood Canal have a unique toxics profile and confirms that that the herring from Cherry Point and Semiahmoo have a very different toxic fingerprint than those from Port Orchard and Squaxin Pass, indicating that these subpopulations feed in different marine locations. However, the POP data also suggest that the Cherry Point stock's contaminant profile is slightly different than that of Semiahmoo Bay, so it is unclear where they reside outside of spawning season; Cherry Point herring may remain in the Strait of Georgia year-round. On a broader scale, these data show that Puget Sound herring populations (collectively) have toxic fingerprints that are different than other herring populations sampled along the west coast of North America, indicative of the segregation of these populations into a discrete marine distribution and feeding area (personal communications, Jim West and Sandie O'Neill, T-BiOS group, WDFW).

If SSS herring stocks, with the exceptions of Cherry Point and Squaxin Pass, interact as a metapopulation similar to that attributed to B.C. herring, observed "disappearance" and/or dramatic decreases in abundance (e.g., N.W. San Juan Island, Kilisut Harbor, and Wollochet Bay) of individual stocks may not be cause for major concern. However, if these subpopulations are distinct – a topic of ongoing research in a collaboration between WDFW and UW – then we may need to reevaluate the current management strategy. Additional collection of genetic samples is being addressed by WDFW's 2016-17 Midwater Acoustic Trawl study, which is designed to sample the pelagic fish community at eighteen sites throughout the Southern Salish Sea. Results of this study will be incorporated into the next installment of the herring stock status report series, which will include data through 2020.

Stock Profile Parameters

The parameters used to develop each stock-specific profile are described below. Status ratings for each stock are based on spawning biomass estimates. Biomass and harvest estimates are presented in metric tonnes unless otherwise noted.

Stock Definition

Documented Puget Sound spawning areas through the 2016 spawning season are shown in Figure 1. Continuing with historical practice, for this report localized spawning grounds are considered distinct stocks. For fishery and ecosystem management purposes the total spawning biomass for all SSS stocks, excluding the Cherry Point and Squaxin Pass stocks, are aggregated under the title Other Stocks Complex. Stock-based assessment data are very useful for localized fisheries management issues and plans. However, if straying rates among SSS herring stocks are comparable to reported British Columbia herring behavior based on tagging results (Ware et al., 2000; Hay et al., 2001), it may be necessary to reconsider what represents a "stock" for SSS herring. Further discussion of this topic is presented later in this document.

Overview

Overview provides any unique information about, or characteristics of, the stock.

Spawning Grounds

The **Spawning Grounds** map depicts the cumulative documented spawning grounds (red hatching on the map) for each stock and the area where spawn deposition has been detected in the last four years (2013-2016; green areas). Herring deposit transparent, adhesive eggs primarily on lower intertidal and shallow subtidal eelgrass and marine algae. In Washington, most spawning activity takes place between 0 and -20 feet (0 to 6.1 meters) MLLW in tidal elevation, although spawn has been reported as deep as 40 feet (12.2 meters) in some areas (rarely).

Prespawner Holding Area

Where known from past acoustic/trawl surveys or other information, the **Prespawner Holding Area** depicts the location (yellow), usually adjacent to the spawning ground in deeper waters, where ripening adult herring congregate and hold prior to spawning. Schools of prespawning adults typically begin concentrating three to four weeks, or more, before the first spawning event (Trumble et al., 1982).

Spawning Timing

Spawning Timing for herring in Washington typically lasts from early January through mid-June, with each stock generally spawning for approximately a six- to eight-week period. The spawn timing figure (Figure 2) indicates the occurrence of any documented spawning activity within the first or second half of a month. Observed peak spawning, based on the observed quantity of egg deposition, is indicated by red cross-hatched cells. <u>Plots of mean spawn timing are presented for individual stocks only if spawn timing changed over the previous four years</u>.

Spawning Biomass

Spawning Biomass is the term used to quantify the tonnage of herring estimated to have engaged in spawning during a given year. Two methods have traditionally been used to provide quantitative estimates of herring abundance: acoustic/trawl surveys (Burton, 1991) and spawn deposition surveys (Stick, 1994). Prior to 1996, the spawning biomass for the 10-12 larger SSS stocks typically was assessed by both methods each year, while the remaining stocks were surveyed by spawn deposition surveys on a 3-year rotational basis (Stick, 1994). The two assessment techniques have generally shown good correspondence for most stocks (Burton, 1991), though the acoustic/trawl surveys estimate pre-spawner biomass while the spawn deposition surveys only account for fish that survive to spawn. The years when significant variance occurred were usually associated with sampling-related problems such as survey timing, adverse weather, equipment malfunctions, etc. From 1996 to 2009, duplicate assessment coverage was reduced and assessment for all known herring stocks was attempted each year by either one or both methods (Stick and Lindquist, 2009). If both methods were utilized, the spawn deposition estimate, combined with any relevant fishery harvest, were used as the final run size estimate if survey coverage was considered adequate. Beginning in 2010, only spawn deposition, "rake," surveys have been conducted to assess Washington herring stocks; as a result, few adult fish are now available for the collection of biometrics, age, and other biological parameters.

The spawning biomass of the Cherry Point herring stock has been estimated annually since 1973 but very few other Puget Sound herring stocks were assessed prior to 1976. Between 1976 and 1996, the spawning biomass for only the 10-12 larger Puget Sound stocks was estimated annually, with the remaining smaller stocks surveyed on a rotational basis, as noted above. Beginning in 1996, annual estimates of all known herring stocks in Puget Sound have been attempted. In prior reports, "missing" sample years have been imputed using estimates from adjacent years if available, the average of the most recent available years' estimates, then five-year intervals or decadal averages if needed. While this accounted for a lack of consistent sampling effort prior to 1996, it introduced false certainty into assessments and lead to apparent hyperstability for some stocks, for which the same average was used for several years in a row. Acknowledging substantial interannual variability in spawning stock biomass that was not being accounted for by this method, imputed values are no longer included in any data series. In addition to the providing the full time series of biomass estimates for each stock, we also provide the 40 year mean (1977 through 2016), 25 year mean (1992 through 2016), 10 year mean (2007 through 2016), and 4 year mean (2013 through 2016) biomass estimates for each stock, when biomass estimates are available for at least 80% of the years in question, or 3 of 4 years for the 4 year mean.

Spawn Deposition Survey Estimates

Spawn Deposition Surveys provide an estimate of herring spawning biomass. Marine vegetation on spawning grounds is sampled via rake to determine the location and density of spawn deposition, and these data are converted to an estimate of spawning escapement based on assumed values for size-specific fecundity, sex ratio in spawning schools, and other parameters (details in Stick, 1994). These surveys are generally conducted weekly during a stock's spawning season to document cumulative spawn deposition, and egg deposition date is determined based on developmental stage.

Stock Status

Describes a stock's condition based on the most recent 4 year average of abundance (spawning biomass) compared to the previous long-term (25-year) mean abundance.

Increasing - A stock with recent 4-year mean abundance more than 20% above the 25-year mean;
Healthy - A stock with recent 4-year mean abundance is within 20% of the 25-year mean;
Declining - A stock with recent 4-year mean abundance 21-50% below the 25-year mean;
Depressed - A stock with recent abundance 51-80% below the 25-year mean;
Critical - A stock with recent 4-year mean abundance 81-99% below the 25-year mean;
Undetected - A stock that can no longer be found in a formerly consistently utilized spawning ground for four consecutive years;
Unknown - Insufficient assessment data to identify stock status with confidence (less than 10 years of abundance data available for the 25-mean, or no abunadance data available for the 4-year mean)

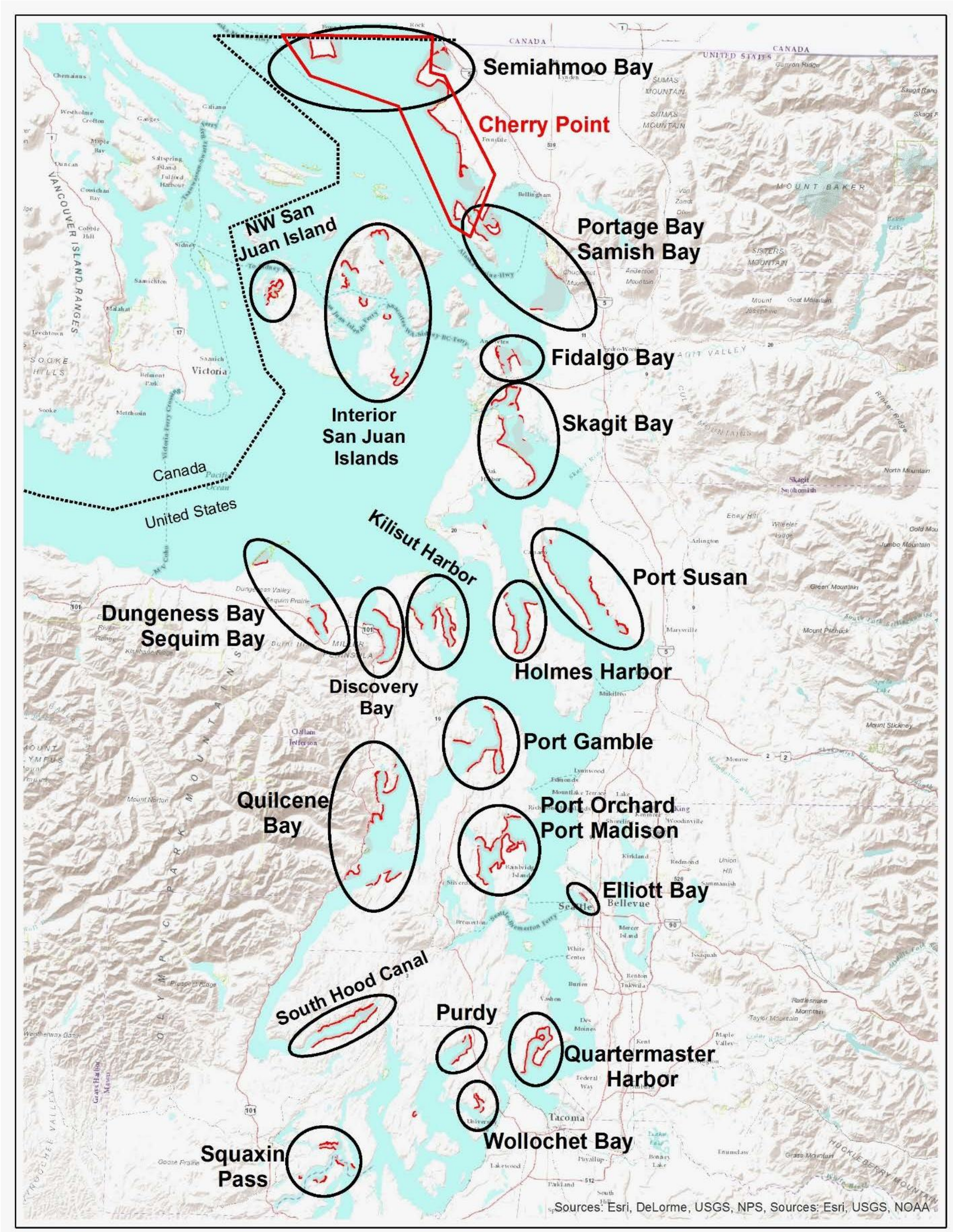


Figure 1: Documented Southern Salish Sea Herring Spawning Grounds

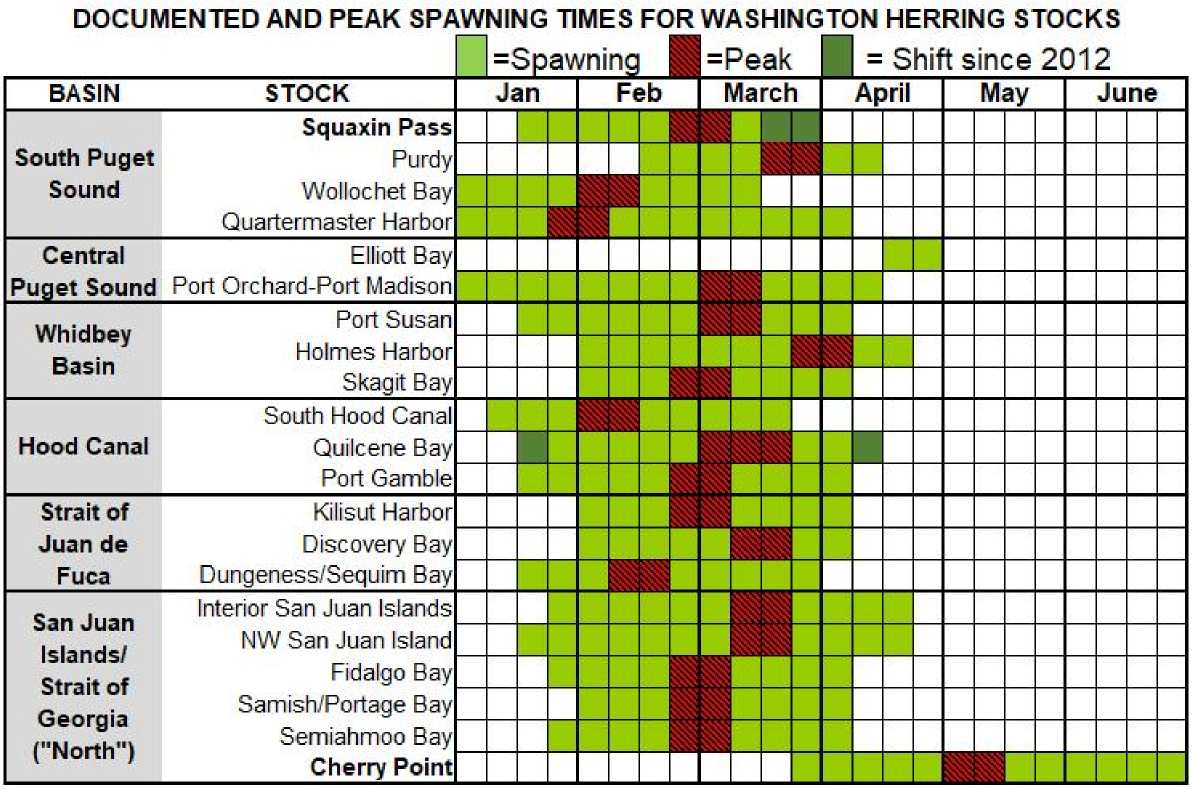
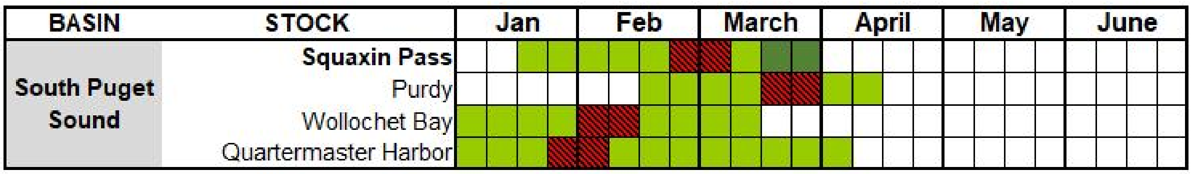


Figure 2: Documented and peak spawn times for SSS herring stocks (2016).

South Puget Sound Herring Stock Profiles

DOCUMENTED AND PEAK HERRING SPAWNING TIMES

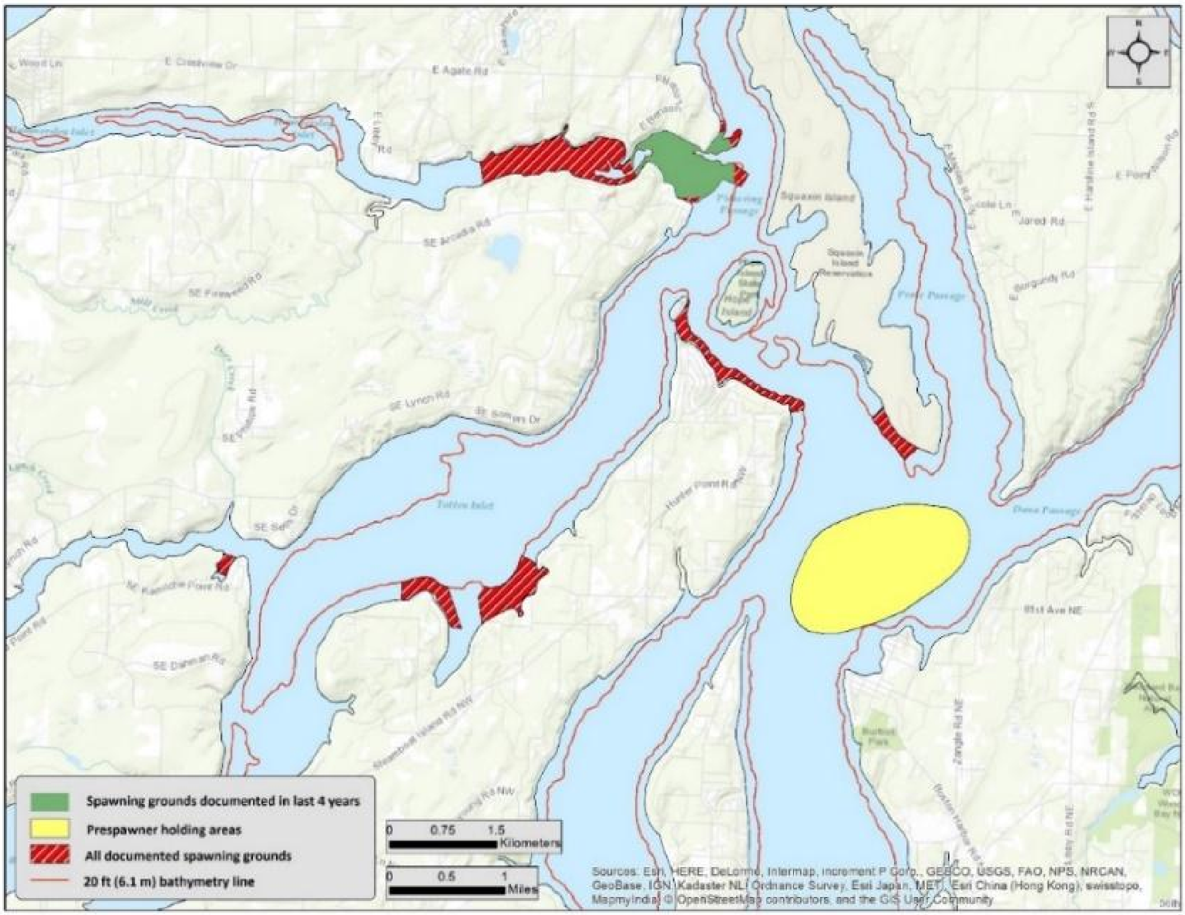


Squaxin Pass Herring Stock

<u>OVERVIEW</u>

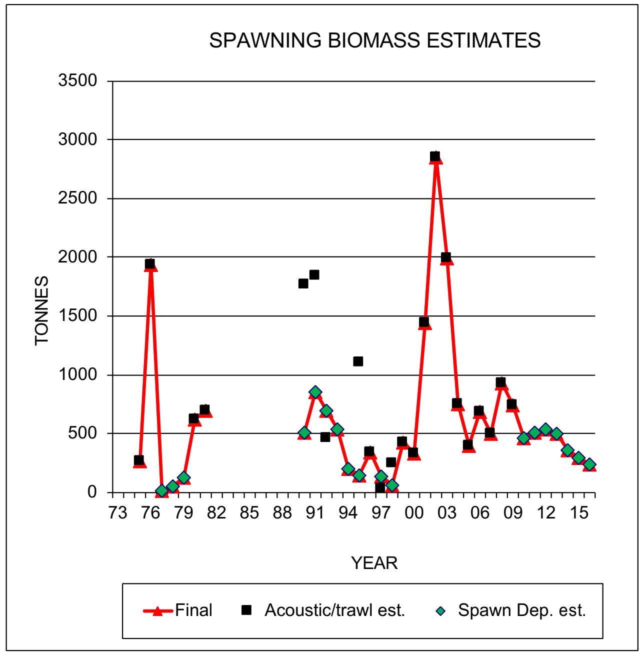
The southernmost stock within the Puget Sound basin, Squaxin Pass herring, exhibit unusual spawning behavior. Marine algae normally utilized for spawning substrate by herring are sparse in this area and spawn deposition often occurs on rocks and gravel, occasionally in relatively deep water (10-15 meters). Such behavior does not lend itself well to assessment from the spawn deposition survey method, which may explain the large disparity between previous spawn deposition and acoustic/trawl survey estimates for this stock. The area utilized for spawning (see figure below) contracted between 2008 and 2012 but has held relatively stable since that time, although the spawning season has extended from the middle to the end of March over the past four years (see below). This stock is currently Depressed (51% below the 25-year mean) and has been decreasing since 2012. Genetic analyses mentioned previously in this report have demonstrated differentiation of this stock from others in Puget Sound. Geographic isolation is suggested as the primary cause for the observed genetic divergence.

SQUAXIN PASS SPAWNING GROUNDS 2016 REPORT:



STOCK STATUS PROFILE FOR: Squaxin Pass Herring Stock

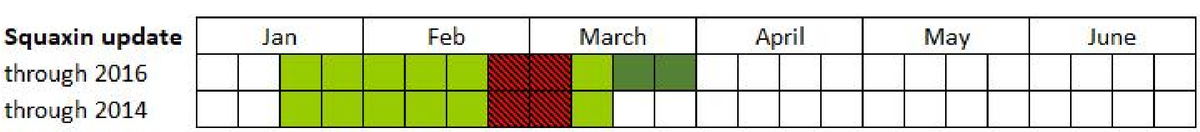
	SPAWNING BIOMASS ESTIMATES (tonnes)			
YEAR	SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975		270	270	
1976		1940	1940	
1977	18		18	
1978	53		53	
1979	124		124	
1980		620	620	
1981		700	700	
1982				
1983				
1984				
1985				
1986				
1987				
1988				
1989				
1990	513	1769	513	
1991	855	1846	855	761
1992	699	460	699	0
1993	541		541	
1994	204		204	
1995	142	1106	142	
1996		339	339	286
1997	135	32	135	128
1998	62	249	62	23
1999		430	430	401
2000		337	337	327
2001		1449	1449	1016
2002		2858	2858	1180
2003		1997	1997	1051
2004		751	751	386
2005		396	396	235
2006		685	685	393
2007		505	505	236
2008		930	930	930
2009		748	748	7
2010	463		463	NA
2011	513		513	NA
2012	534		534	NA
2013	503		503	NA
2014	357		357	NA
2015	294		294	NA
2016	236		236	NA



STOCK SUMMARY

40 year mean (tonnes): 593
25 year mean (tonnes): 644
10 year mean (tonnes): 508
4 year mean (tonnes): 348

Stock Status (4 year): Depressed



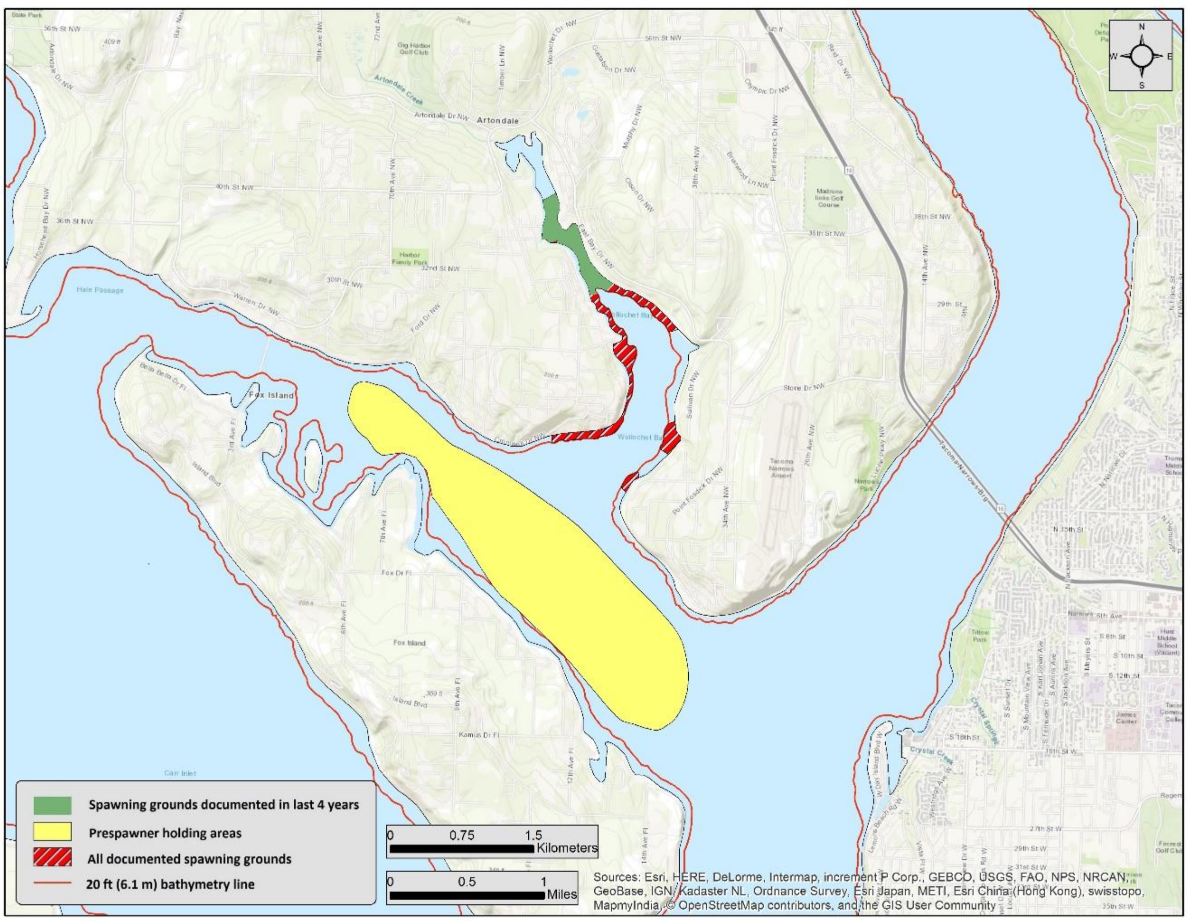
AR013457

Wollochet Bay Herring Stock

OVERVIEW

The Wollochet Bay stock's spawning grounds were initially documented during the 2000 season. This confirmed reported spawning activity from the late 1930s (Chapman et al., 1941) that had not been detected in the intervening years, so the return of spawning herring to Wollochet Bay may be a recolonization event. Stock size has been small and estimated spawning biomass has been quite variable, with a high of 138 tonnes estimated in 2003, followed by a steady decline, and has now been undetected for the past two years. Prespawning fish attributed to this spawning ground appear to congregate in Hale Passage; the area used for spawning contracted deeper into the Bay between 2008 and 2012, where much of the habitat has been modified by human activities. When spawning occurred, the timing was early relative to other stocks, peaking in early February. Timing of spawning activity here had been consistently earlier than observed since 2008 in Carr Inlet (Purdy/Henderson Bay), suggesting that these stocks may be discrete.

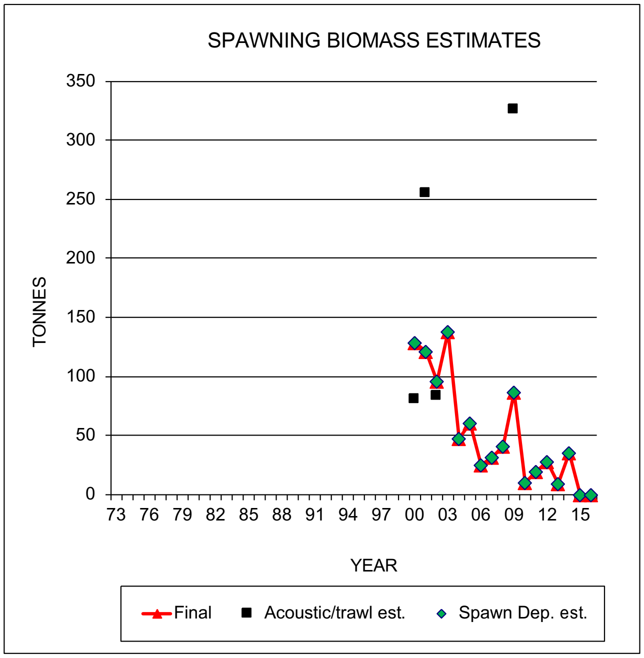
WOLLOCHET BAY SPAWNING GROUNDS 2016 REPORT:



AR013458

STOCK STATUS PROFILE FOR: Wollochet Bay Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976				
1977				
1978				
1979				
1980				
1981				
1982				
1983				
1984				
1985				
1986				
1987				
1988				
1989				
1990				
1991				
1992				
1993				
1994				
1995				
1996				
1997				
1998				
1999				
2000	129	81	129	
2001	121	256	121	92
2002	96	83	96	52
2003	138		138	
2004	47		47	
2005	61		61	
2006	24		24	
2007	32		32	
2008	41		41	
2009	86	327	86	
2010	10		10	NA
2011	19		19	NA
2012	28		28	NA
2013	9		9	NA
2014	35		35	NA
2015	0		0	NA
2016	0		0	NA



STOCK SUMMARY

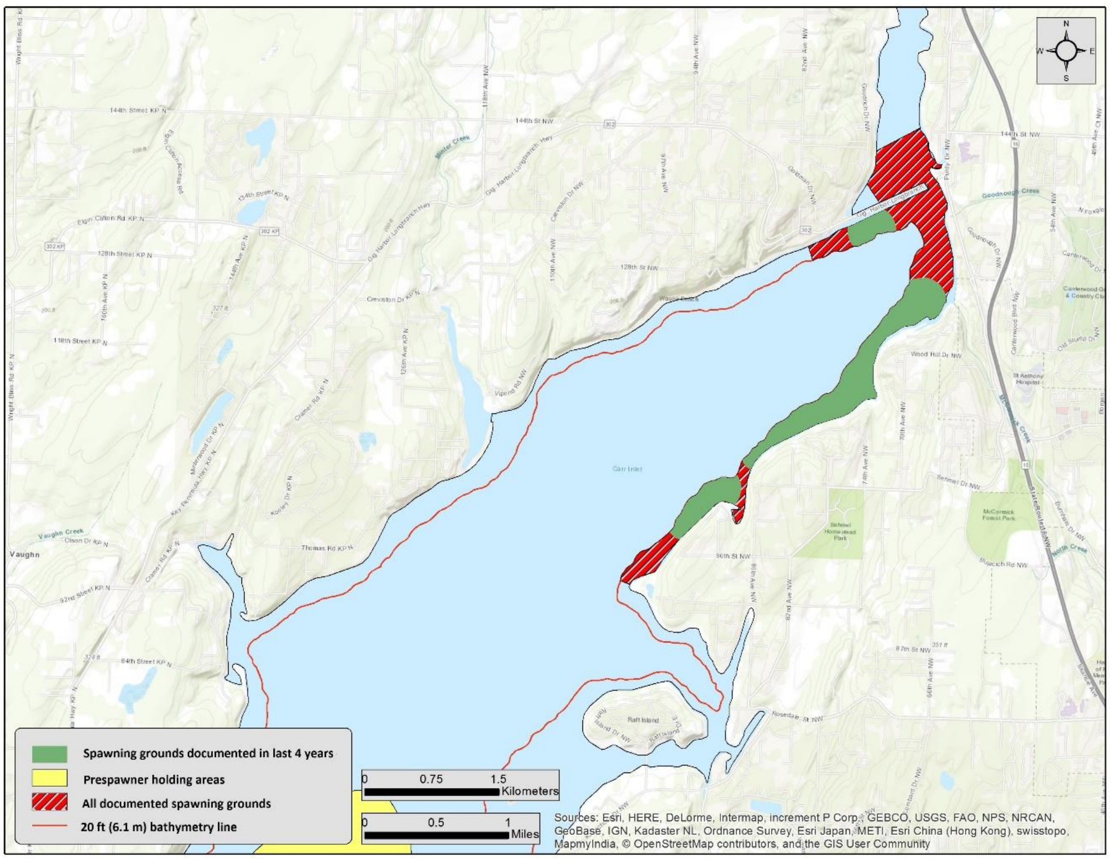
40 year mean (tonnes):	NA
25 year mean (tonnes):	NA
10 year mean (tonnes):	26
4 year mean (tonnes):	11
Stock Status (4 year):	Critical

Purdy Herring Stock

OVERVIEW

The Purdy stock's spawning grounds were first documented during the 2008 season. Spawning activity peaked in 2011 (645 tonnes) and was then variable until 2016, when no spawning was observed. Although unconfirmed, a prespawner holding area for this stock is assumed to be in lower Carr Inlet. Spawn timing is relatively late compared to other South Puget Sound stocks, with spawn dates as late as April 14. There is insufficient data at present to understand this stock's behavior, but the site will be continually monitored in coming years to see if spawning herring return.

PURDY SPAWNING GROUNDS 2016 REPORT:



AR013460

STOCK STATUS PROFILE FOR: Purdy Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes): SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976				
1977				
1978				
1979				
1980				
1981				
1982				
1983				
1984				
1985				
1986				
1987				
1988				
1989				
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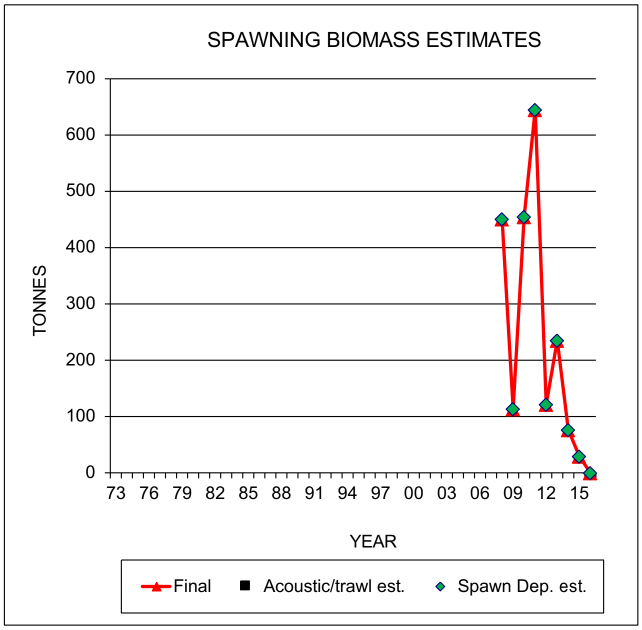
1994				
1995				
1996				
1997				
1998				
1999				
2000				
2001				
2002				
2003				
2004				
2005				
2006				
2007				
2008	450		450	
2009	113		113	
2010	454		454	NA
2011	645		645	NA
2012	122		122	NA
2013	236		236	NA
2014	76		76	NA
2015	29		29	NA
2016	0		0	NA



STOCK SUMMARY

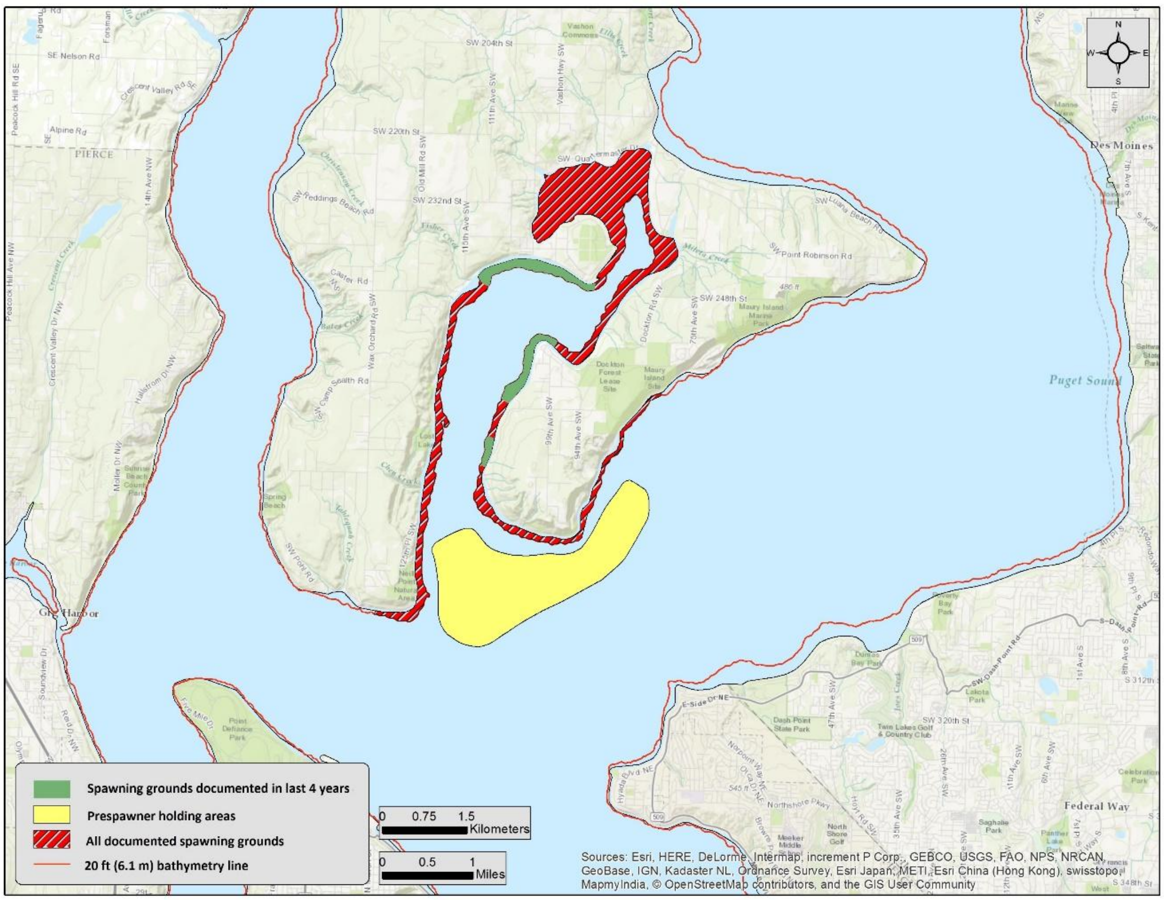
40 year mean (tonnes):	NA
25 year mean (tonnes):	NA
10 year mean (tonnes):	236
4 year mean (tonnes):	85
Stock Status (4 year):	Unknown

Quartermaster Harbor Herring Stock

OVERVIEW

The Quartermaster Harbor herring stock spawning activity occurs relatively early in the year, with spawning often beginning in early January and running as late as April. Spawn deposition is typically centered near Dockton on Maury Island. Spawning biomass peaked in 1995 at 1,815 tonnes, followed by a decreasing trend after 2006 and record low levels since 2010. The stock is now assessed to be Critical due to these declines, with a biomass 92% below the 25-year mean, and no spawn was detected in 2016. No spawn has been detected in the inner harbor, where shoreline habitat has been heavily modified by human activity, in recent years (see figure below). Given the long survey record at this site and relative stability of the spawning biomass through 2006, the decline of this stock is a concern and monitoring efforts will be increased in 2017-18.

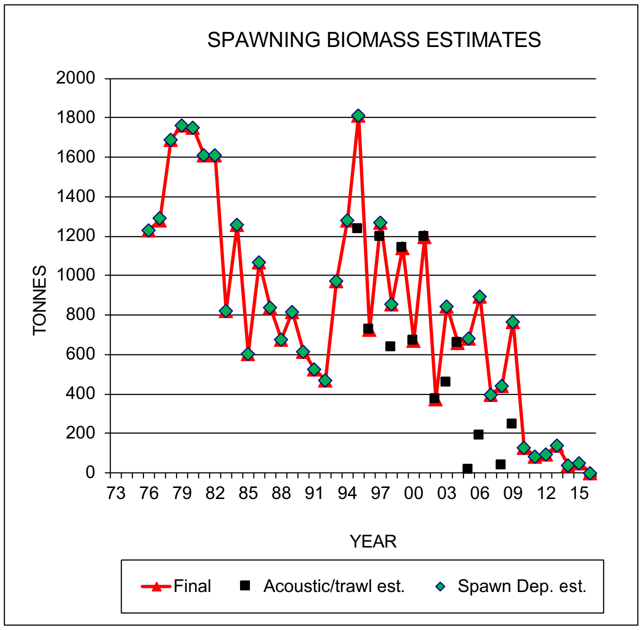
QUARTERMASTER HARBOR SPAWNING GROUNDS 2016 REPORT:



AR013462

STOCK STATUS PROFILE FOR: Quartermaster Harbor Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976	1231		1231	
1977	1291		1282	
1978	1687		1687	
1979	1761		1761	
1980	1751		1751	
1981	1612		1612	
1982	1613		1613	
1983	825		825	
1984	1257		1257	
1985	605		605	
1986	1071		1071	
1987	838		838	
1988	680		680	
1989	815		815	
1990	618		618	
1991	526		526	
1992	470		470	
1993	975		975	
1994	1281		1281	
1995	1815	1236	1815	
1996		730	730	687
1997	1272	1198	1272	397
1998	859	636	859	0
1999		1140	1140	1089
2000		674	674	510
2001		1197	1197	1110
2002		377	377	193
2003	844	459	844	594
2004		660	660	123
2005	686	16	686	484
2006	895	190	895	767
2007	400		400	
2008	445	42	445	
2009	765	247	765	400
2010	130		130	NA
2011	87		87	NA
2012	98		98	NA
2013	142		142	NA
2014	40		40	NA
2015	50		50	NA
2016	0		0	NA



STOCK SUMMARY

40 year mean (tonnes):	824
25 year mean (tonnes):	641
10 year mean (tonnes):	216
4 year mean (tonnes):	58
Stock Status (4 year):	Critical

AR013463

Central Puget Sound Herring Stock Profiles

DOCUMENTED AND PEAK HERRING SPAWNING TIMES

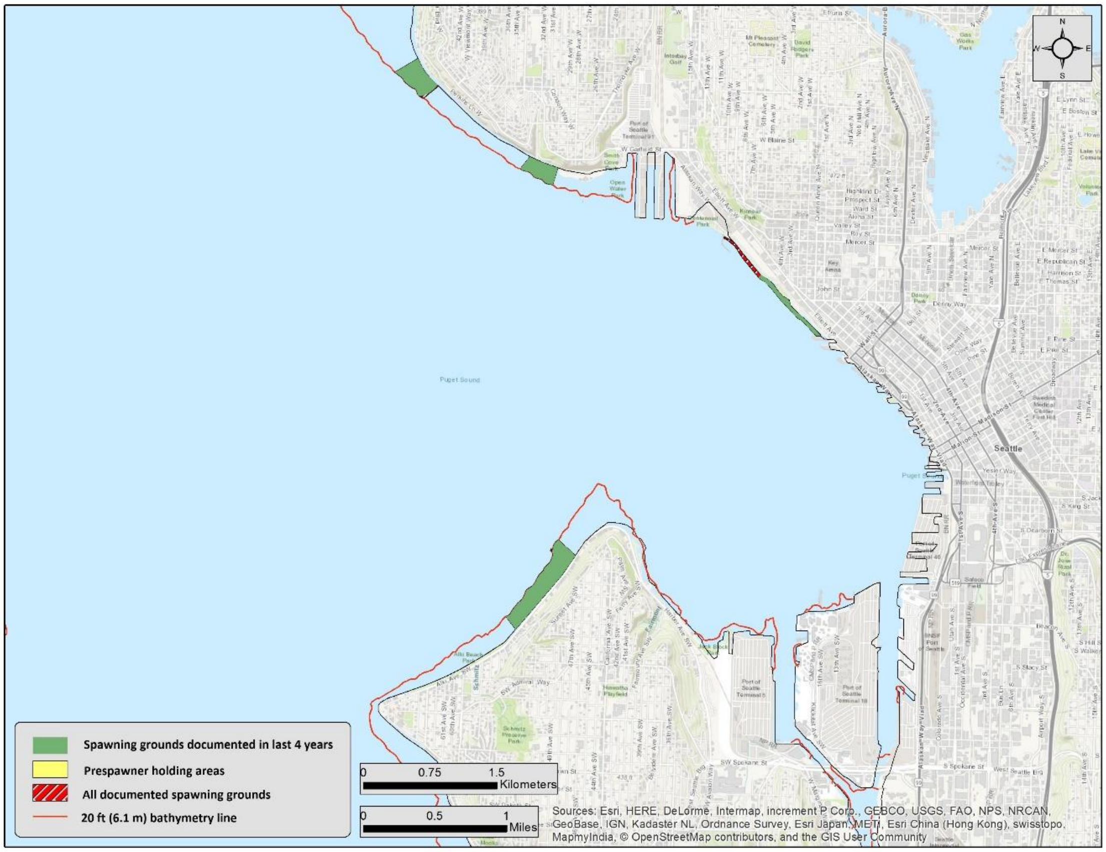
BASIN	STOCK	Jan	Feb	March	April	May	June
Central	Elliott Bay						
Puget Sound	Port Orchard-Port Madison						

Elliott Bay Herring Stock

OVERVIEW

Herring spawn deposition was documented for the first time in Elliott Bay in late April of 2012. The spawning location was primarily on restored/enhanced substrate created in 2008 to benefit the migration of juvenile salmonids (Olympic Sculpture Park Habitat Rehabilitation). Similar to the situation for the Purdy stock in 2008, this area had not been previously sampled for herring spawn deposition, so it is possible spawning activity in Elliott Bay could have been occurring but was undetected. Since the initial detection in 2012, estimated spawn biomass has averaged 141 tonnes annually and the area where eggs have been detected has expanded westward across Elliott Bay (limited spawning on eelgrass beds off Alki beach). Spawn timing is unusually late in the year (mid to late April) for the region and is most similar to the Cherry Point herring stock (although spawning in the Holmes Harbor and Interior San Juan Islands stocks can also occur into late April). Egg samples from Elliott Bay are included in ongoing research related to stock structure of Puget Sound herring and should provide information about the genetic composition of this stock.

ELLIOTT BAY SPAWNING GROUNDS 2016 REPORT:



AR013465

STOCK STATUS PROFILE FOR: Elliott Bay Herring Stock

	SPAWNING BIOMASS ESTIMATES (tonnes)			
YEAR	SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976				
1977				
1978				
1979				
1980				
1981				
1982				
1983				
1984				
1985				
1986				
1987				
1988				
1989				
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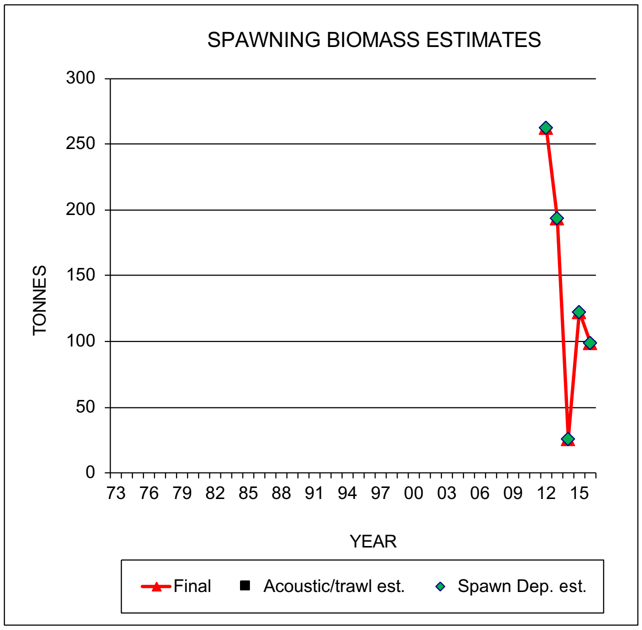
1997				
1998				
1999				
2000				
2001				
2002				
2003				
2004				
2005				
2006				
2007				
2008				
2009				
2010				
2011				
2012	263		263	NA
2013	194		194	NA
2014	26		26	NA
2015	122		122	NA
2016	99		99	NA



STOCK SUMMARY

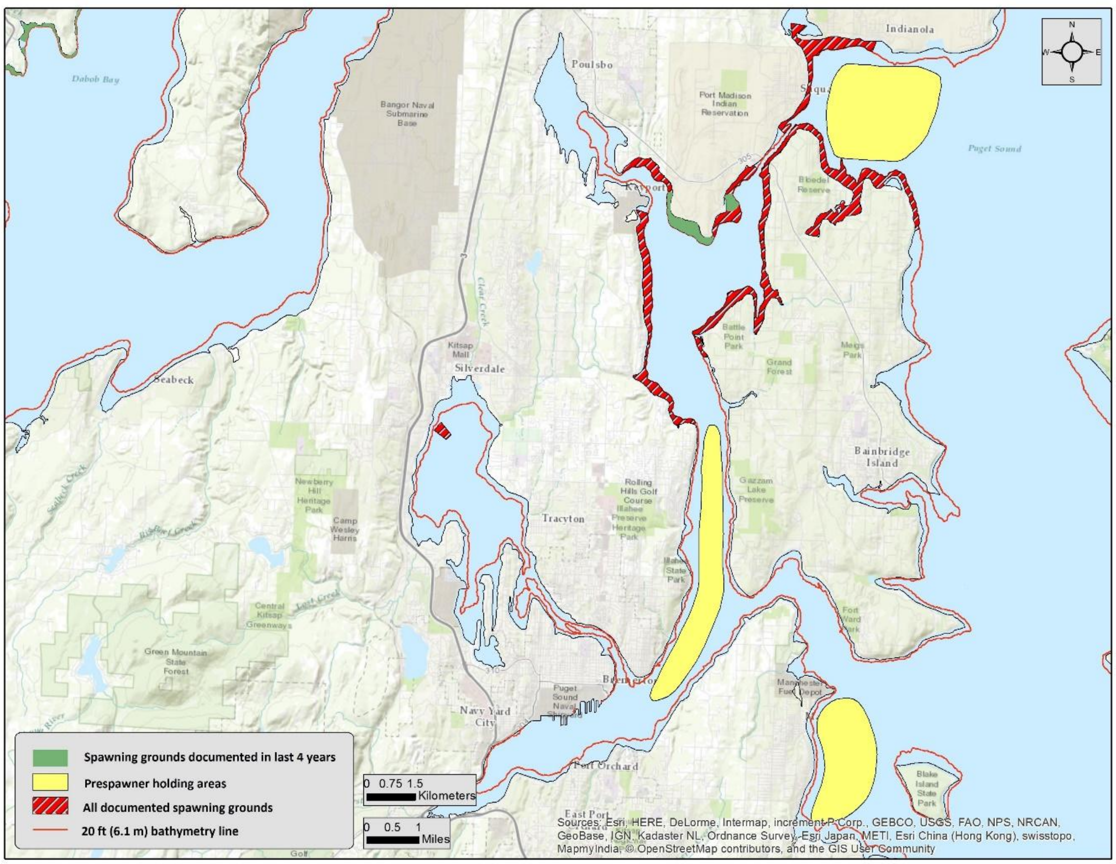
40 year mean (tonnes):	NA
25 year mean (tonnes):	NA
10 year mean (tonnes):	NA
4 year mean (tonnes):	111
Stock Status (4 year):	Unknown

Port Orchard/Madison Herring Stock

OVERVIEW

The Port Orchard/Port Madison herring stock abundance has continued to decrease significantly since 2012 and is now assessed as Critical (92% below the 25-year mean spawning biomass). The order of magnitude declines noted in the 2012 report were attributed to changes in sampling methodology (a return to rake surveys after eleven years of acoustic trawl data), but the trend has continued and no spawn was detected in 2016 for the first time on record. Virtually all observed spawn deposition in recent years was in the vicinity of Point Bolin (southeast of Poulsbo). Herring used to spawn in Hidden Cove, but a toxicology study of larval herring found that the concentration of polycyclic aromatic hydrocarbons (PAHs) was highest in this area, suggesting a link between PAHs and poor embryo health (West et al., 2014). Prior to the cessation of spawning, acoustic/trawl surveys noted an increase in abundance of the Yukon Harbor prespawner holding area east of Blake Island, but the spawning location of those fish, if present, remains unknown.

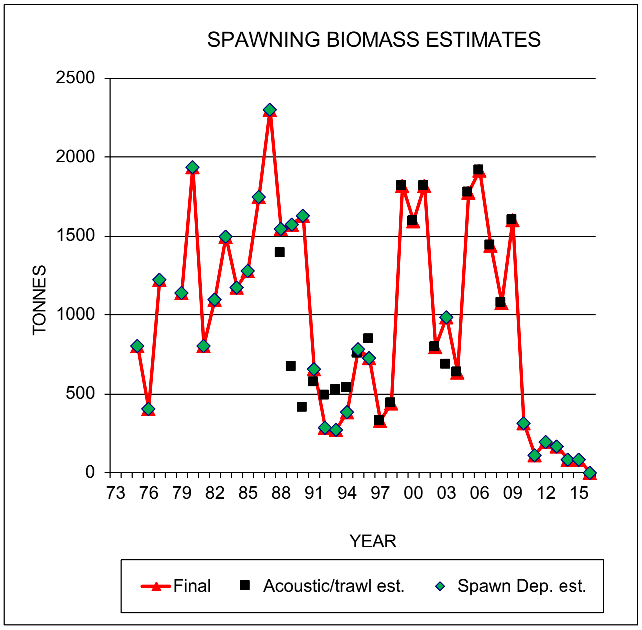
PORT ORCHARD/PORT MADISON SPAWNING GROUNDS 2016 REPORT:



AR013467

STOCK STATUS PROFILE FOR: Port Orchard/Madison Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975	805		805	
1976	406		406	
1977	1223		1223	
1978				
1979	1139		1139	
1980	1935		1935	
1981	808		808	
1982	1101		1101	
1983	1498		1498	
1984	1173		1173	
1985	1284		1284	
1986	1747		1747	
1987	2302		2302	
1988	1547	1394	1547	
1989	1578	674	1578	774
1990	1628	414	1628	1019
1991	655	572	655	308
1992	285	494	285	202
1993	276	528	276	232
1994	385	541	385	94
1995	783	754	783	642
1996	731	845	731	469
1997		327	327	295
1998		444	444	398
1999		1820	1820	1641
2000		1593	1593	1033
2001		1821	1821	1606
2002		797	797	588
2003	984	685	984	611
2004		635	635	361
2005		1776	1776	1067
2006		1916	1916	1494
2007		1442	1442	988
2008		1076	1076	874
2009		1604	1604	699
2010	318		318	NA
2011	112		112	NA
2012	197		197	NA
2013	167		167	NA
2014	82		82	NA
2015	83		83	NA
2016	0		0	NA

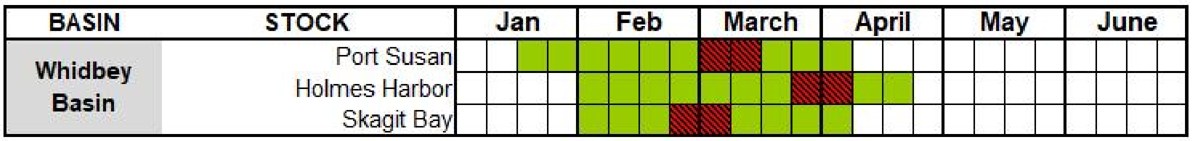


STOCK SUMMARY

40 year mean (tonnes):	1007
25 year mean (tonnes):	786
10 year mean (tonnes):	508
4 year mean (tonnes):	83
Stock Status (4 year):	Critical

Whidbey Basin Herring Stock Profiles

DOCUMENTED AND PEAK HERRING SPAWNING TIMES

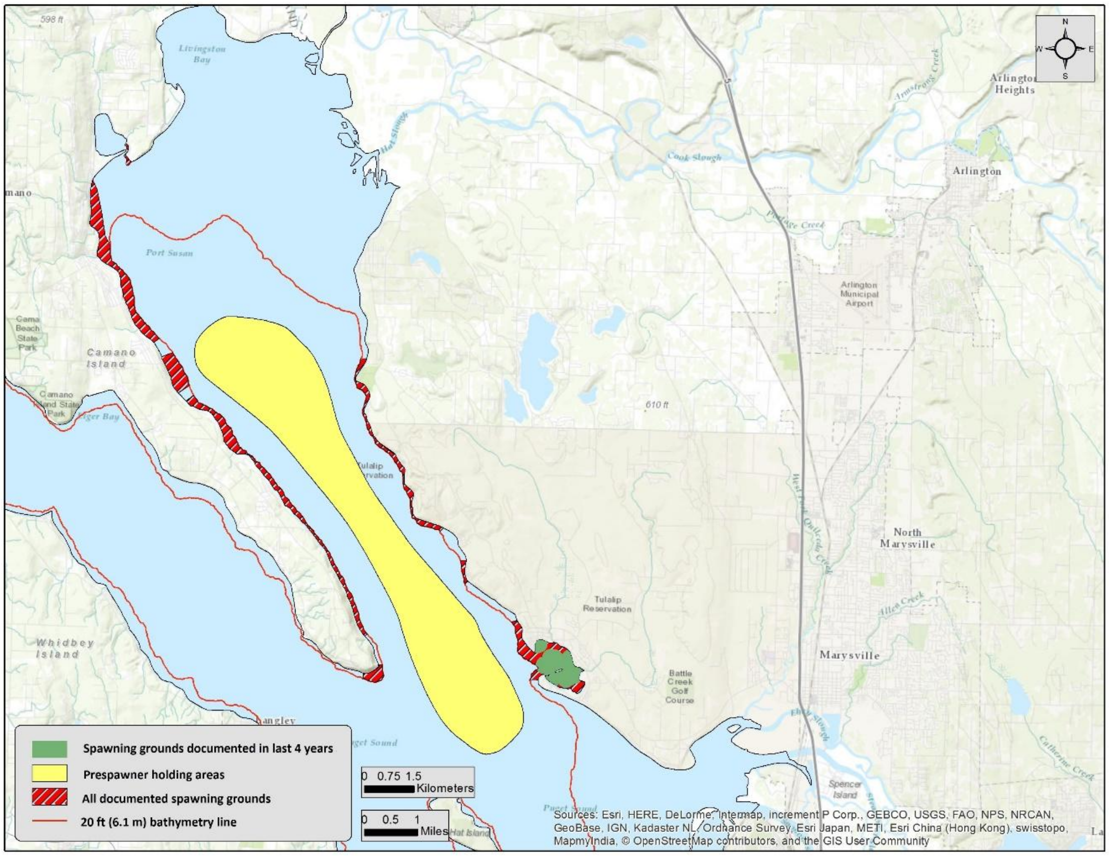


Port Susan Herring Stock

<u>OVERVIEW</u>

Similar to the Squaxin Pass stock, the Port Susan herring stock often deposits significant spawn on rocks and gravel. Outside of Tulalip Bay, where most of the observed spawn deposition had previously been located, marine algae normally used by herring as spawning substrate are sparse (although substantial eelgrass and *Sargassum* beds are found at the southern end of Camano Island). Use of rocky spawning substrate made acoustic/trawl survey assessment the method of choice for this stock, but due to funding cuts and reprioritization of staff duties that activity ended in 2009. Estimated spawning biomass, via spawn deposition surveys, reached a record low in 2013 (26 tonnes) and current stock classification is Critical (89% below the 25-year mean). All observed spawn deposition in recent years has been in/near Tulalip Bay.

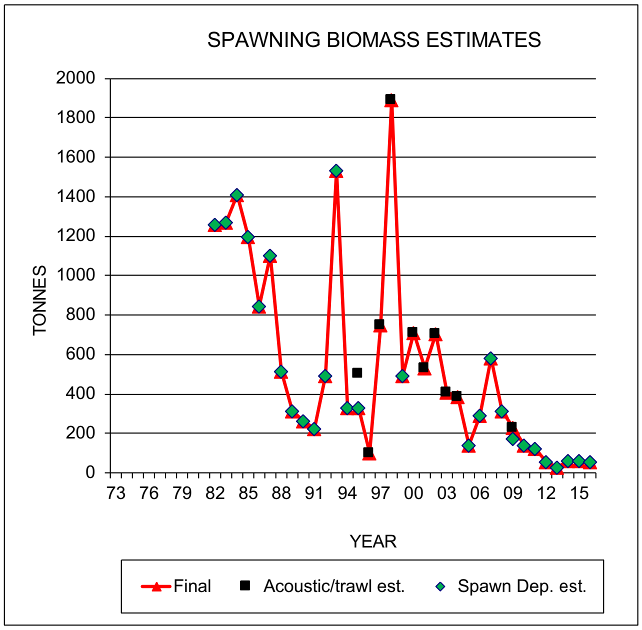
PORT SUSAN SPAWNING GROUNDS 2016 REPORT:



AR013470

STOCK STATUS PROFILE FOR: Port Susan Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976				
1977				
1978				
1979				
1980				
1981				
1982	1262		1262	
1983	1268		1268	
1984	1411		1411	
1985	1198		1198	
1986	847		847	
1987	1103		1103	
1988	517		517	
1989	313		313	
1990	264		264	
1991	222		222	
1992	494		494	
1993	1536		1536	
1994	331		331	
1995	329	505	329	
1996		100	100	68
1997		751	751	608
1998		1891	1891	1158
1999	494		494	
2000		712	712	
2001		533	533	505
2002		703	703	65
2003		408	408	339
2004		389	389	140
2005	142		142	
2006	291		291	
2007	583		583	
2008	313		313	
2009	175	229	229	
2010	138		138	NA
2011	125		125	NA
2012	55		55	NA
2013	26		26	NA
2014	62		62	NA
2015	64		64	NA
2016	55		55	NA



STOCK SUMMARY

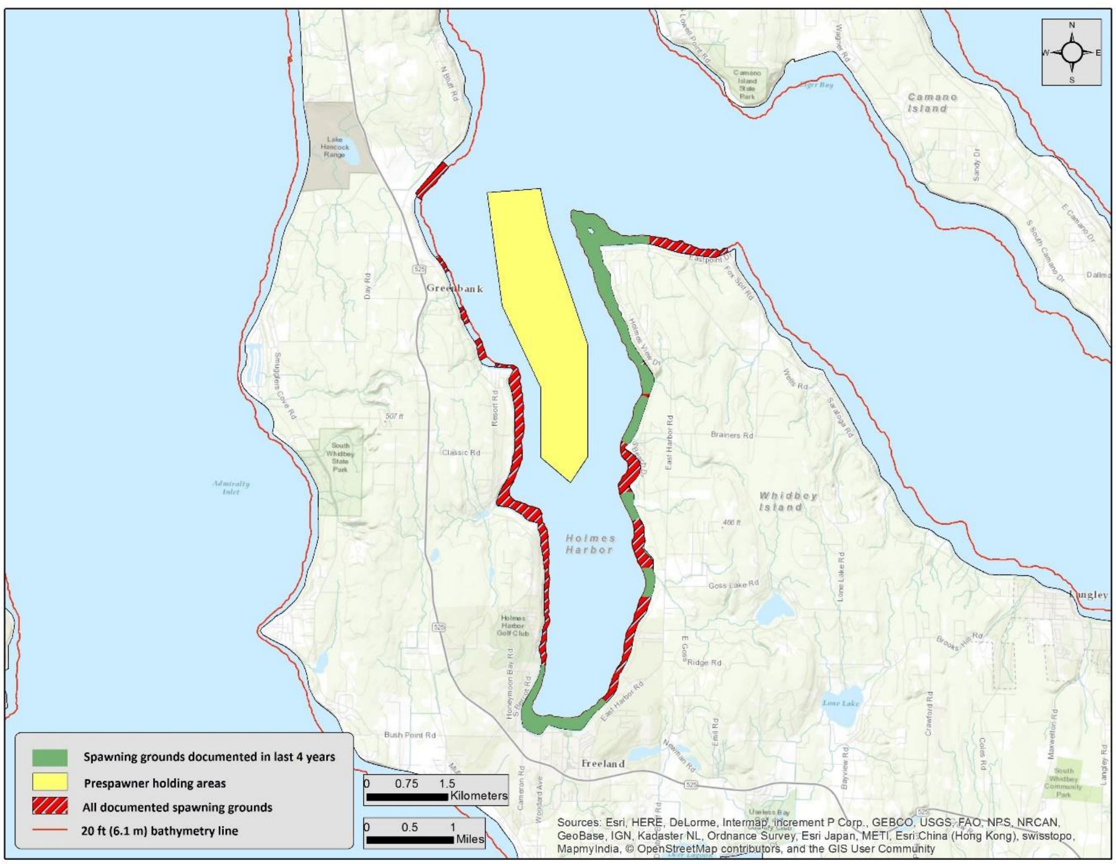
40 year mean (tonnes):	547
25 year mean (tonnes):	430
10 year mean (tonnes):	165
4 year mean (tonnes):	52
Stock Status (4 year):	Critical

Holmes Harbor Herring Stock

<u>OVERVIEW</u>

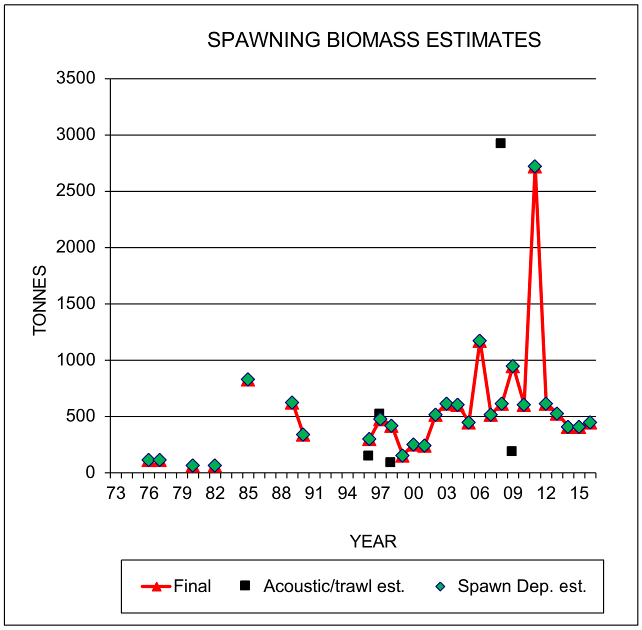
Along with the Quilcene Bay stock, this stock was considered to be one of the largest in Washington waters prior to the start of quantitative surveys in the 1970s, as reported by Chapman et al. (1941), Cleaver and Franett (1946), and Williams (1959). This conclusion was based mainly on fishery observations and landings (brush weir/trap) that reached as high as 325 tonnes in 1937. Estimated spawning biomass for the Holmes Harbor stock has been relatively high since the early 2000s, peaking in 2011 (2,427 tonnes, an almost four-fold increase over the 25-year mean). The recent four years of spawning biomass estimates represent a significant decrease from the peak 2011 biomass, and the stock is Declining (72% of the 25-year mean). Despite an abundance of healthy eelgrass beds throughout, the primary spawning areas have contracted to the southern end of the harbor and along the eastern shore (especially in the area around Baby Island). Limited tag recoveries of adult fish at Swiftsure Bank off the southwest tip of Vancouver Island in the summer, and in early winter reduction fisheries on the southeast coast of Vancouver Island, suggests that at least a portion of the Holmes Harbor stock is migratory.

<u>HOLMES HARBOR SPAWNING GROUNDS 2016 REPORT:</u>



STOCK STATUS PROFILE FOR: Holmes Harbor Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976	114		114	
1977	122		122	
1978				
1979				
1980	71		71	
1981				
1982	71		71	
1983				
1984				
1985	829		829	
1986				
1987				
1988				
1989	629		629	
1990	345		345	
1991				
1992				
1993				
1994				
1995				
1996	305	145	305	
1997	481	518	481	298
1998	421	88	421	128
1999	159		159	
2000	255		255	
2001	249		249	
2002	520		520	
2003	615		615	
2004	611		611	
2005	452		452	
2006	1177		1177	
2007	519		519	
2008	622	2915	622	
2009	948	191	948	
2010	611		611	NA
2011	2724		2724	NA
2012	615		615	NA
2013	531		531	NA
2014	416		416	NA
2015	414		414	NA
2016	448		448	NA



STOCK SUMMARY

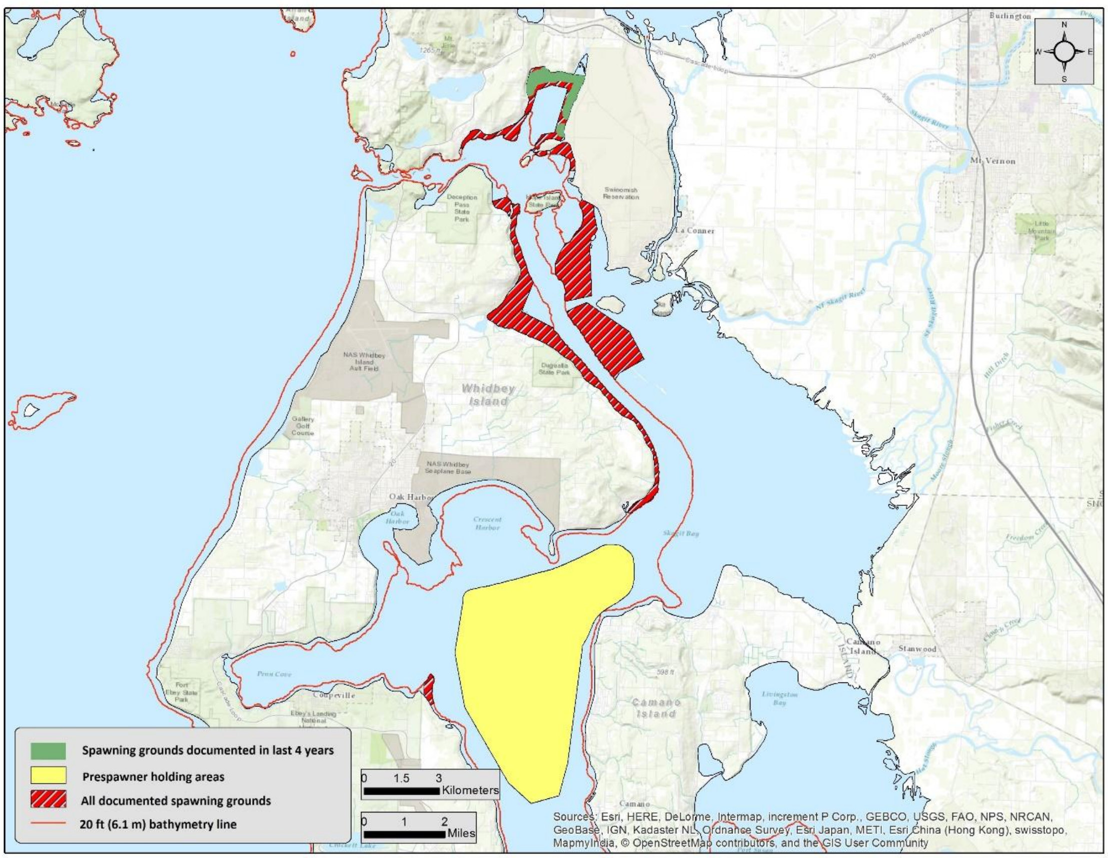
40 year mean (tonnes): NA
25 year mean (tonnes): 623
10 year mean (tonnes): 785
4 year mean (tonnes): 452

Stock Status (4 year): Declining

Skagit Bay Herring Stock

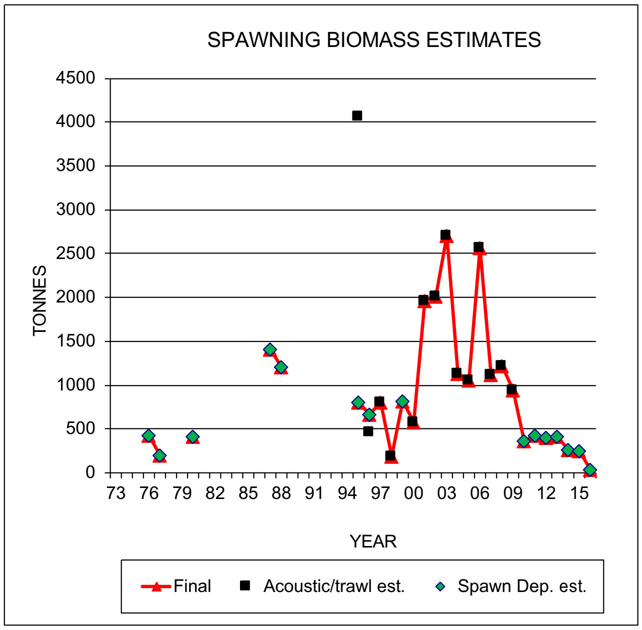
<u>OVERVIEW</u>
Estimated spawning biomass for the Skagit Bay stock since 2009 (i.e., the last season an acoustic/trawl survey was conducted) has dropped by over 75%, to less than 450 tonnes. This apparent decrease is likely the result of a change in assessment methodology, at least in part. However, rake survey data indicate that the stock had a significantly declining trend over the past four years, and hit an all-time low of 44 tonnes in 2016; it is now considered Depressed and will be closely monitored in 2017. Observed spawn deposition since 2009 has been confined to Similk Bay. The close proximity to the prespawner holding area and spawning grounds of the Holmes Harbor stock, and reasonably similar spawn timing, make it likely that intermixing of these two stocks occurs, although peak spawn timing is typically earlier for the Skagit Bay stock.

<u>SKAGIT BAY SPAWNING GROUNDS 2016 REPORT:</u>



STOCK STATUS PROFILE FOR: Skagit Bay Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976	434		434	
1977	206		206	
1978				
1979				
1980	411		411	
1981				
1982				
1983				
1984				
1985				
1986				
1987	1408		1408	
1988	1216		1216	
1989				
1990				
1991				
1992				
1993				
1994				
1995	808	4064	808	
1996	668	473	668	668
1997		810	810	809
1998		190	190	28
1999	821		821	
2000		586	586	
2001		1969	1969	1188
2002		2009	2009	1100
2003		2706	2706	2283
2004		1129	1129	628
2005		1060	1060	419
2006		2564	2564	2064
2007		1121	1121	504
2008		1217	1217	950
2009		940	940	678
2010	365		365	NA
2011	425		425	NA
2012	402		402	NA
2013	412		412	NA
2014	267		267	NA
2015	259		259	NA
2016	44		44	NA



STOCK SUMMARY

40 year mean (tonnes):	NA
25 year mean (tonnes):	944
10 year mean (tonnes):	545
4 year mean (tonnes):	245
Stock Status (4 year):	Depressed

AR013475

Hood Canal Herring Stock Profiles

DOCUMENTED AND PEAK HERRING SPAWNING TIMES

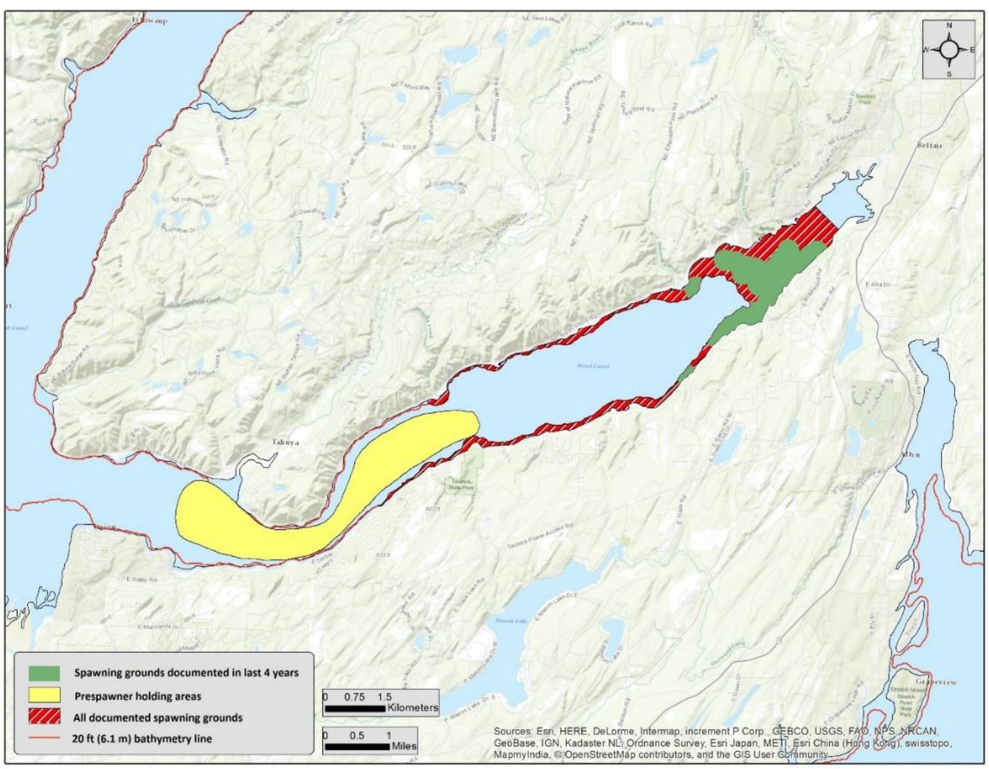
BASIN	STOCK	Jan	Feb	March	April	May	June
Hood Canal	South Hood Canal						
	Quilcene Bay						
	Port Gamble						

South Hood Canal Herring Stock

<u>OVERVIEW</u>

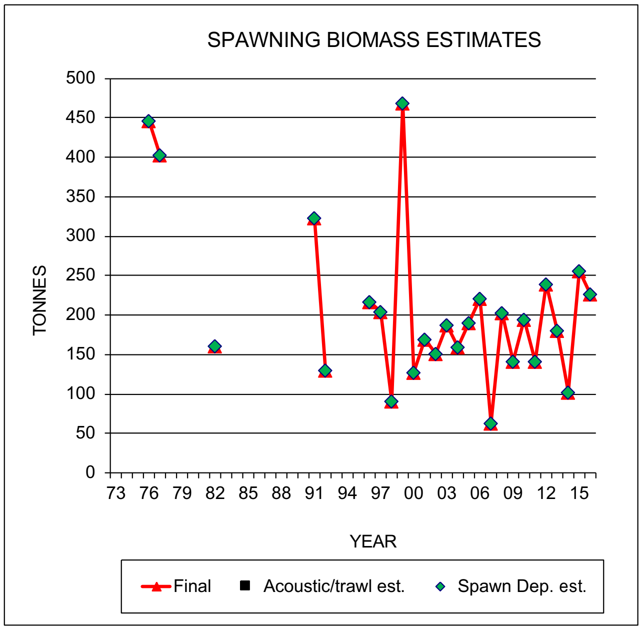
Spawning activity by this small herring stock continues to be confined to Lynch Cove at the head of south Hood Canal. Spawning has begun slightly earlier in recent years (first weeks of January) and is typically finished by early March. Estimated spawning biomass has averaged over 190 tonnes over the past 4 years, with a high of 468 tonnes observed in 1999, and a low of 64 tonnes estimated in 2007. As a result, the stock is considered Healthy (less than 1% above the 25-year mean) and, with the exception of 2007, has been fairly stable since 2000. Effects of repeated anoxic events (low dissolved oxygen levels) in main stem Hood Canal on the abundance of this stock are unknown. The location of this stock's spawning grounds at the end of Hood Canal could eventually contribute to genetic differentiation similar to that observed for Squaxin Pass and remote inlet "resident" herring populations in British Columbia; stock samples have been obtained and are slated for genetic analysis by 2018.

<u>SOUTH HOOD CANAL SPAWNING GROUNDS 2016 REPORT:</u>



STOCK STATUS PROFILE FOR: South Hood Canal Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976	446		446	
1977	403		403	
1978				
1979				
1980				
1981				
1982	161		161	
1983				
1984				
1985				
1986				
1987				
1988				
1989				
1990				
1991	324		324	
1992	131		131	
1993				
1994				
1995				
1996	217		217	
1997	205		205	
1998	92		92	
1999	468		468	
2000	127		127	
2001	170		170	
2002	151		151	
2003	188		188	
2004	160		160	
2005	191		191	
2006	221		221	
2007	64		64	
2008	202		202	
2009	142		142	
2010	194		194	NA
2011	142		142	NA
2012	239		239	NA
2013	181		181	NA
2014	102		102	NA
2015	256		256	NA
2016	226		226	NA



STOCK SUMMARY

40 year mean (tonnes):	NA
25 year mean (tonnes):	185
10 year mean (tonnes):	175
4 year mean (tonnes):	191
Stock Status (4 year):	Healthy

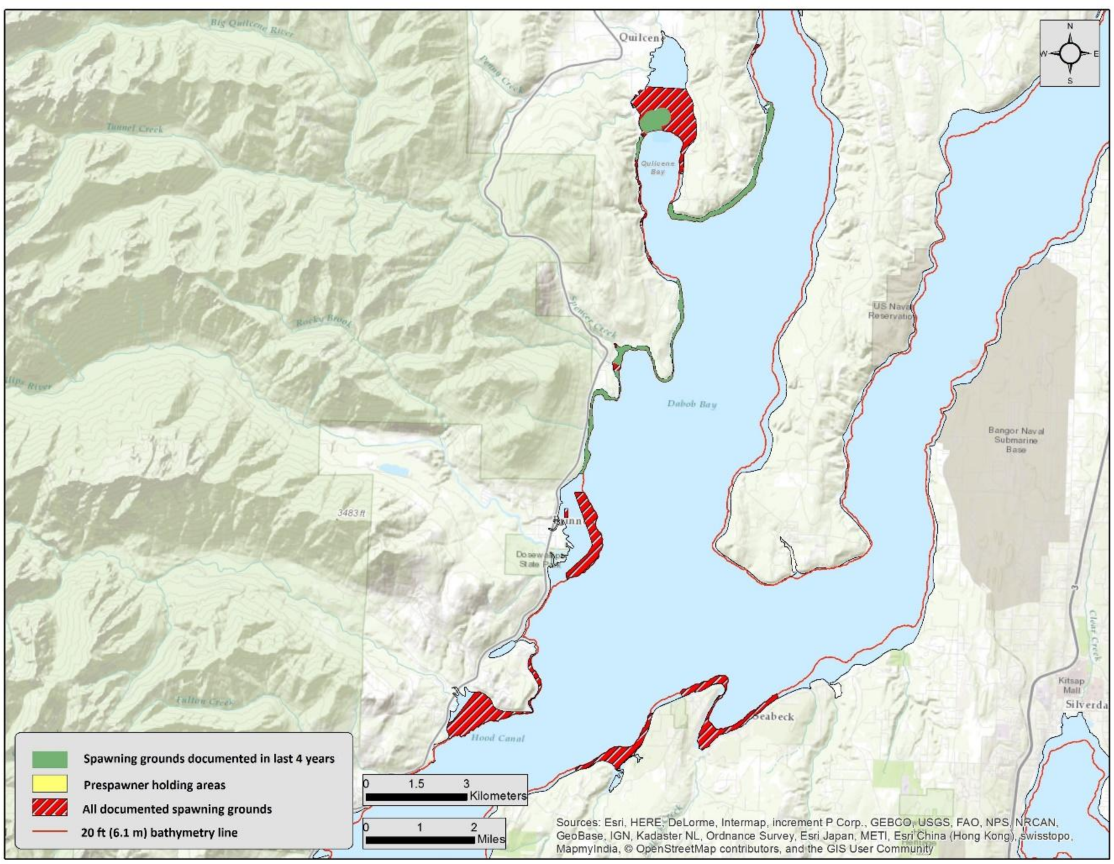
AR013477

Quilcene Bay Herring Stock

<u>OVERVIEW</u>

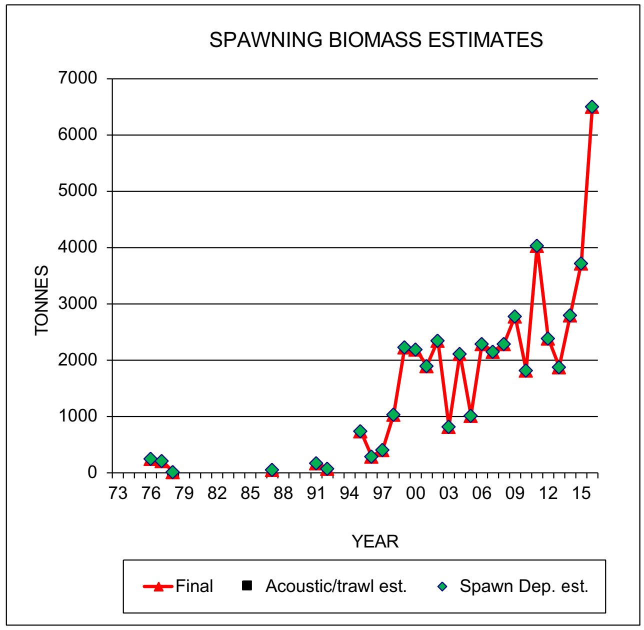
Based primarily on fishery landings, this stock was considered to be one of the largest herring stocks in Washington waters in the 1930s through the 1950s (Chapman et al., 1941; Williams, 1959), followed by a significant decrease in abundance from that time until the mid-1990s. However, despite repeated summer anoxic events, the stock has rebounded, and <u>the Quilcene Bay stock is currently the largest in Puget Sound, making up 52% of the total annual spawning biomass for all of the SSS in 2016</u>. Estimated spawning biomass has increased significantly since 2012 and the 4-year average is 125% above the 25-year mean, increasing dramatically over the past three years. Most spawn deposition has occurred at the southern end and eastern shore (primarily eelgrass habitat) of the Bolton Peninsula, and the shoreline from Jackson Cove to Point Whitney (primarily *Sargassum*). The spawn timing at Quilcene Bay typically runs from late January through early April, peaking in early to mid-March. Limited tag recoveries suggested that this stock is “migratory,” with movement to summer offshore feeding grounds, although recent toxics profile data shows only that the stock inhabits feeding grounds that are separate from other stocks tested. It is possible that most of these herring reside in Hood Canal year round.

<u>QUILCENE BAY SPAWNING GROUNDS 2016 REPORT:</u>



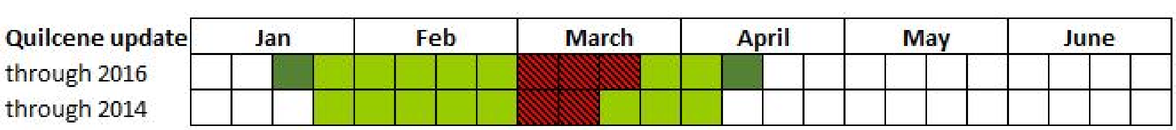
STOCK STATUS PROFILE FOR: Quilcene Bay Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976	253		253	
1977	210		210	
1978	13		13	
1979				
1980				
1981				
1982				
1983				
1984				
1985				
1986				
1987	62		62	
1988				
1989				
1990				
1991	185		185	
1992	88		88	
1993				
1994				
1995	741		741	
1996	298		298	
1997	422		422	
1998	1045		1045	
1999	2235		2235	
2000	2201		2201	
2001	1897		1897	
2002	2345		2345	
2003	831		831	
2004	2125		2125	
2005	1021		1021	
2006	2295		2295	
2007	2152		2152	
2008	2296		2296	
2009	2780		2780	
2010	1825		1825	NA
2011	4031		4031	NA
2012	2382		2382	NA
2013	1880		1880	NA
2014	2810		2810	NA
2015	3717		3717	NA
2016	6496		6496	NA



STOCK SUMMARY

40 year mean (tonnes):	NA
25 year mean (tonnes):	2083
10 year mean (tonnes):	3037
4 year mean (tonnes):	3725
Stock Status (4 year):	Increasing

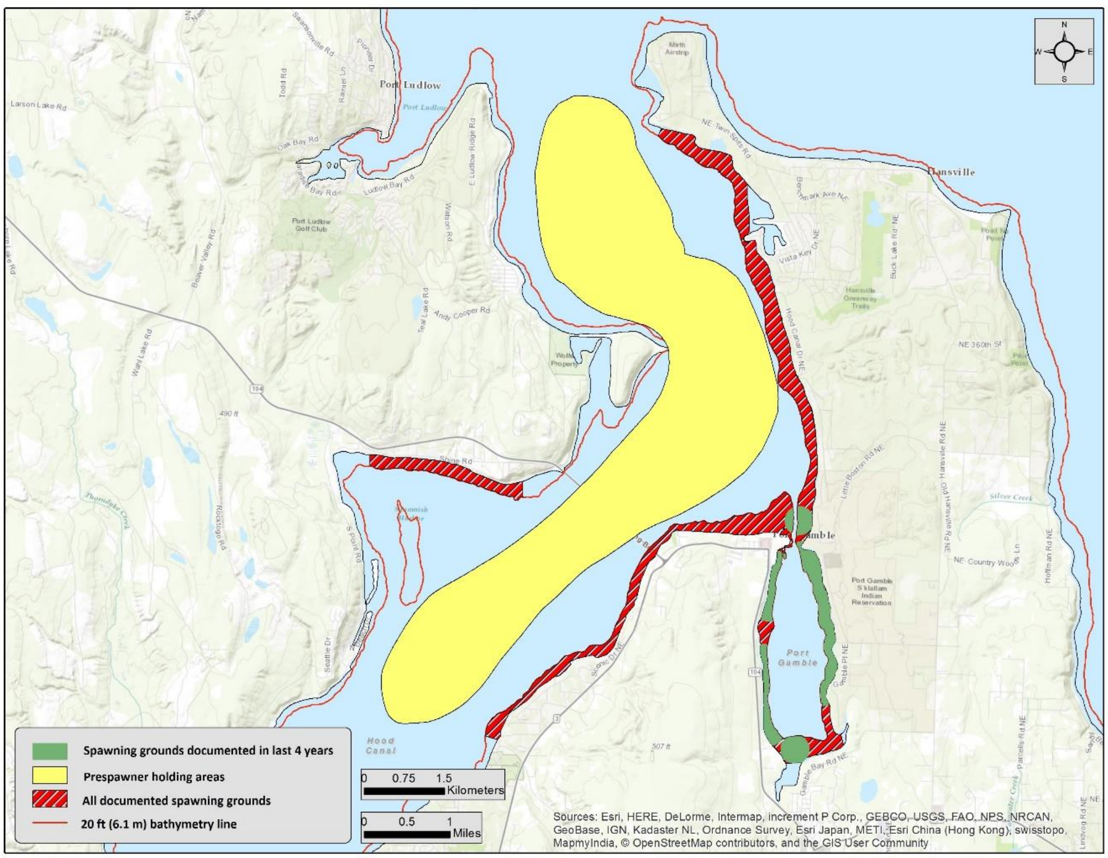


Port Gamble Herring Stock

OVERVIEW

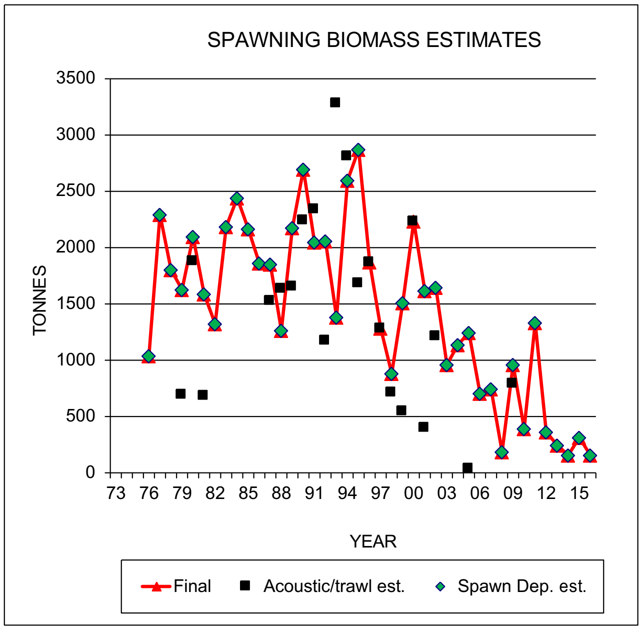
The Port Gamble herring stock has been considered one of the larger stocks in Puget Sound since quantitative survey effort began in the late 1970s. Interestingly, in descriptions of known spawning grounds at the time, there is no mention of this area by Chapman et al. (1941) or Williams (1959). However, this stock has followed a decreasing trend since 2000, when the spawning biomass estimate was over 2,200 tonnes. A decline was noted in 2008 (189 tonnes), followed by a mild increase in abundance of 1,328 tonnes in 2011, but since that time the average has been 249 tonnes and the stock is considered Critical (85% below the 25-year mean). Spawning activity continues to be centered in Port Gamble Bay. Genetic samples from this stock have not been shown to be distinct from other Puget Sound populations (Small et al., 2005; Mitchell, 2006). Higher than average embryo mortalities of deposited herring eggs have been observed from inside Port Gamble Bay, but a recent restoration project to remove creosote pilings and cap contaminated sediment may help boost this stock.

PORT GAMBLE SPAWNING GROUNDS 2016 REPORT:



STOCK STATUS PROFILE FOR: Port Gamble Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976	1036		1036	
1977	2291		2291	
1978	1800		1800	
1979	1624	700	1624	
1980	2095	1884	2095	
1981	1590	690	1590	
1982	1327		1327	
1983	2184		2184	
1984	2436		2436	
1985	2165		2165	
1986	1860		1860	
1987	1856	1531	1856	
1988	1261	1640	1261	889
1989	2173	1655	2173	1422
1990	2693	2241	2693	736
1991	2049	2340	2049	594
1992	2059	1171	2059	1423
1993	1380	3279	1380	1111
1994	2592	2811	2592	297
1995	2865	1689	2865	2179
1996		1867	1867	859
1997		1287	1287	1134
1998	881	718	881	314
1999	1510	552	1510	1296
2000		2231	2231	1738
2001	1614	403	1614	1384
2002	1644	1217	1644	1028
2003	965		965	
2004	1140		1140	
2005	1245	40	1245	
2006	702		702	
2007	749		749	
2008	189		189	
2009	965	792	965	
2010	393		393	NA
2011	1328		1328	NA
2012	367		367	NA
2013	248		248	NA
2014	154		154	NA
2015	313		313	NA
2016	163		163	NA



STOCK SUMMARY

40 year mean (tonnes):	1456
25 year mean (tonnes):	1154
10 year mean (tonnes):	487
4 year mean (tonnes):	219

Stock Status (4 year): Critical

AR013481

Strait of Juan de Fuca Herring Stock Profiles

DOCUMENTED AND PEAK HERRING SPAWNING TIMES

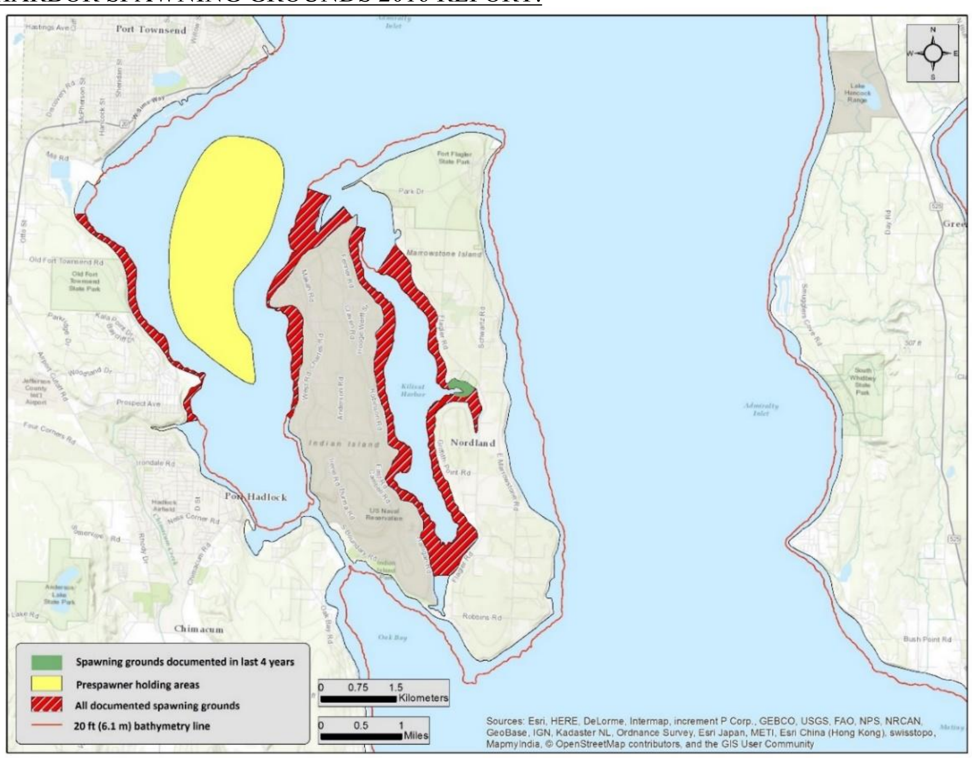
BASIN	STOCK	Jan				Feb				March				April				May				June			
Strait of Juan de Fuca	Kilisut Harbor					D	D	D	P	P	D	D	D	D											
	Discovery Bay					D	D	D	D	D	P	P	D	D											
	Dungeness/Sequim Bay			D	D	D	P	P	D	D	D	D	D												

Kilisut Harbor Herring Stock

<u>OVERVIEW</u>

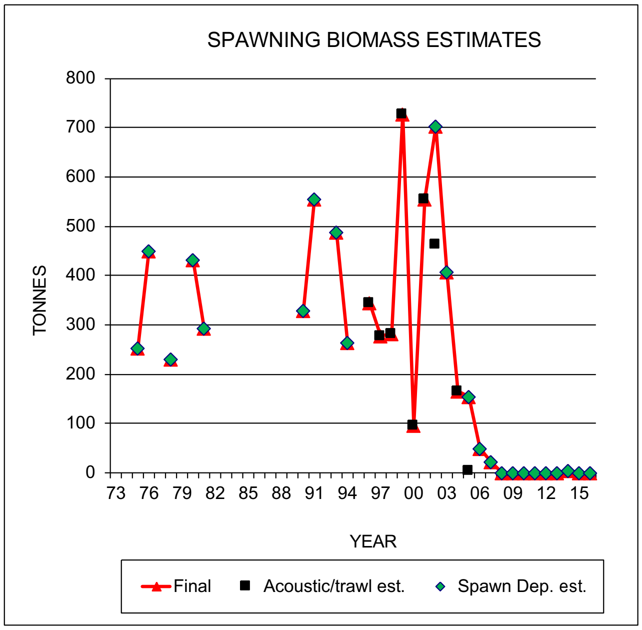
The Kilisut Harbor herring stock is a small Strait of Juan de Fuca/Admiralty Inlet stock that has had spawning activity documented only once since 2007; including a small event in Mystery Bay in 2014 (5 tonnes). Traditionally spawning for this stock ran from early February to early April, with peak spawning in March. Estimated spawning biomass for this stock quickly decreased since peaking in 2002 (702 tonnes). At present, this stock is considered Critical (99.5% below the 25-year mean), only having had detectible spawn once in the past 9 years. A planned restoration at the southern end of Kilisut Harbor, to re-open the tidal channel, will hopefully lead to increased aquatic vegetation and a stock recolonization (Moore, 1975). A sample from this stock was included in one genetic study (Beacham et al., 2008) and significant genetic differentiation was observed between this stock and the Cherry Point stock, with no significant difference compared to the Skagit Bay stock. This finding suggests gene flow between this stock and others in Puget Sound.

<u>KILISUT HARBOR SPAWNING GROUNDS 2016 REPORT:</u>



STOCK STATUS PROFILE FOR: Kilisut Harbor Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975	253		253	
1976	449		449	
1977				
1978	230		230	
1979				
1980	433		433	
1981	294		294	
1982				
1983				
1984				
1985				
1986				
1987				
1988				
1989				
1990	330		330	
1991	556		556	
1992				
1993	488		488	
1994	265		265	
1995				
1996		345	345	
1997		279	279	0
1998		282	282	154
1999		728	728	718
2000		97	97	97
2001		555	555	357
2002	702	463	702	571
2003	406		406	
2004		167	167	
2005	154	5	154	109
2006	49		49	
2007	22		22	
2008	0		0	
2009	0		0	
2010	0		0	NA
2011	0		0	NA
2012	0		0	NA
2013	0		0	NA
2014	5		5	NA
2015	0		0	NA
2016	0		0	NA



STOCK SUMMARY

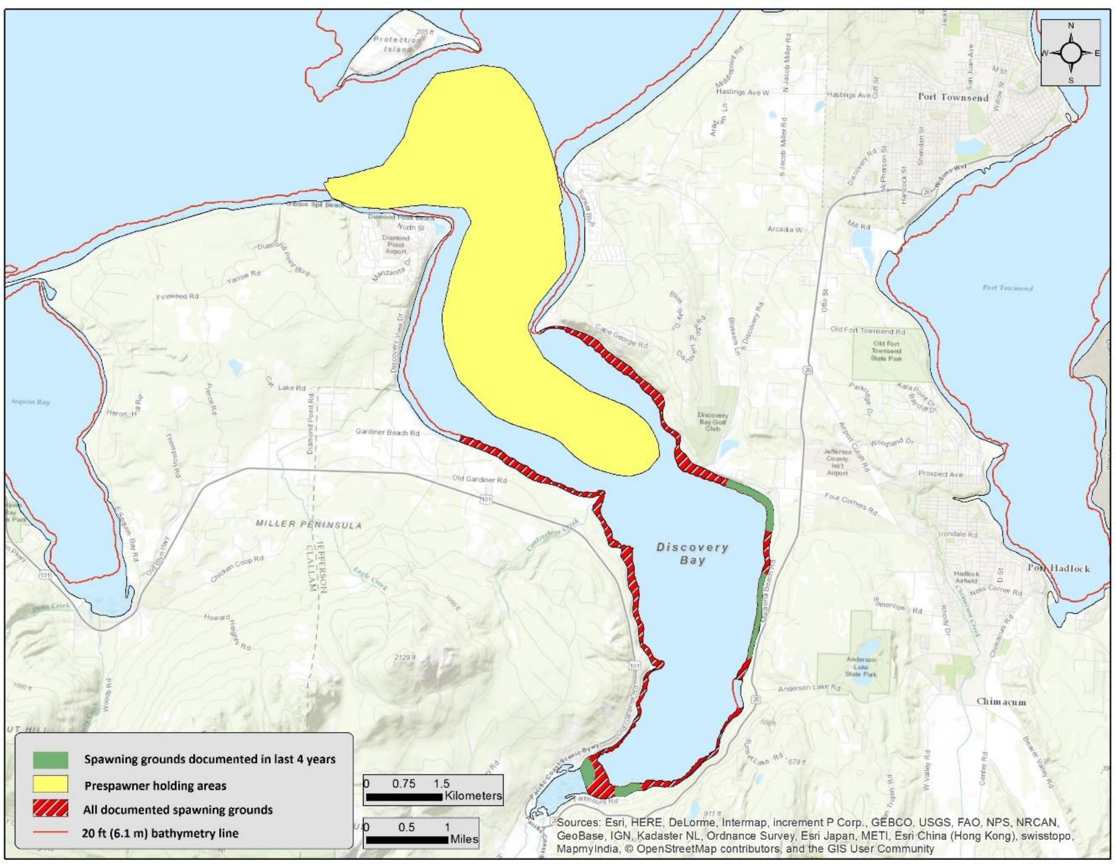
40 year mean (tonnes):	NA
25 year mean (tonnes):	198
10 year mean (tonnes):	3
4 year mean (tonnes):	1
Stock Status (4 year):	Critical

Discovery Bay Herring Stock

OVERVIEW

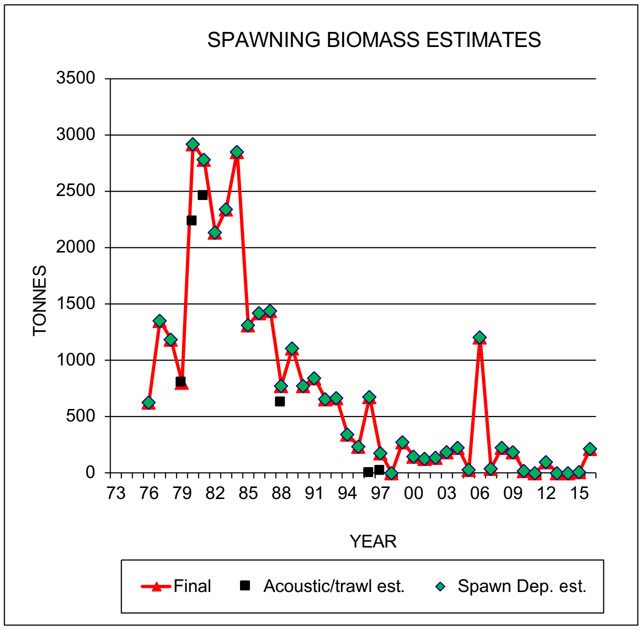
The Discovery Bay herring stock has traditionally been considered the major Strait of Juan de Fuca stock. Its abundance has fluctuated dramatically since the early 1900s, when significant fishery landings suggested sizable spawning biomass. This period was followed by decreased fishery activity and assumed declines in abundance in the 1930s, a return to "relatively high" abundance levels during the 1940s and 1950s (Williams, 1959), documented high abundances (peak of 2,921 tonnes in 1980) in the early 1980s, and generally very low abundance since 1990. The most recent peak was in 2006, but the stock has declined since then, with no spawn detected in 2011 and 2013 and very little in 2014-15. Presently the stock is assessed as Critical (84% below the 25-year average), although the 25-year mean (366 tonnes) no longer encompasses the decline from initial abundance (the mean biomass including all years of data since 1976 is 820 tonnes). The stock has no known fishery interceptions and its spawning grounds are considered to be among the most pristine in Washington. Increased pinniped predation and/or movement to other spawning grounds with similar spawn timing are potential causes for biomass decline.

DISCOVERY BAY SPAWNING GROUNDS 2016 REPORT:



STOCK STATUS PROFILE FOR: Discovery Bay Herring Stock

	SPAWNING BIOMASS ESTIMATES (tonnes)			
YEAR	SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976	632		632	
1977	1350		1350	
1978	1184		1184	
1979		800	800	
1980	2921	2230	2921	
1981	2785	2460	2785	
1982	2137		2137	
1983	2339		2339	
1984	2852		2852	
1985	1313		1313	
1986	1421		1421	
1987	1445		1445	
1988	774	623	774	
1989	1111		1111	
1990	776		776	
1991	839		839	
1992	660		660	
1993	669		669	
1994	340		340	
1995	237		237	
1996	678	5	678	
1997	181	17	181	
1998	0		0	
1999	279		279	
2000	144		144	
2001	124		124	
2002	134		134	
2003	188		188	
2004	229		229	
2005	30		30	
2006	1202		1202	
2007	38		38	
2008	225		225	
2009	186		186	
2010	24		24	NA
2011	0		0	NA
2012	95		95	NA
2013	0		0	NA
2014	5		5	NA
2015	11		11	NA
2016	221		221	NA



STOCK SUMMARY

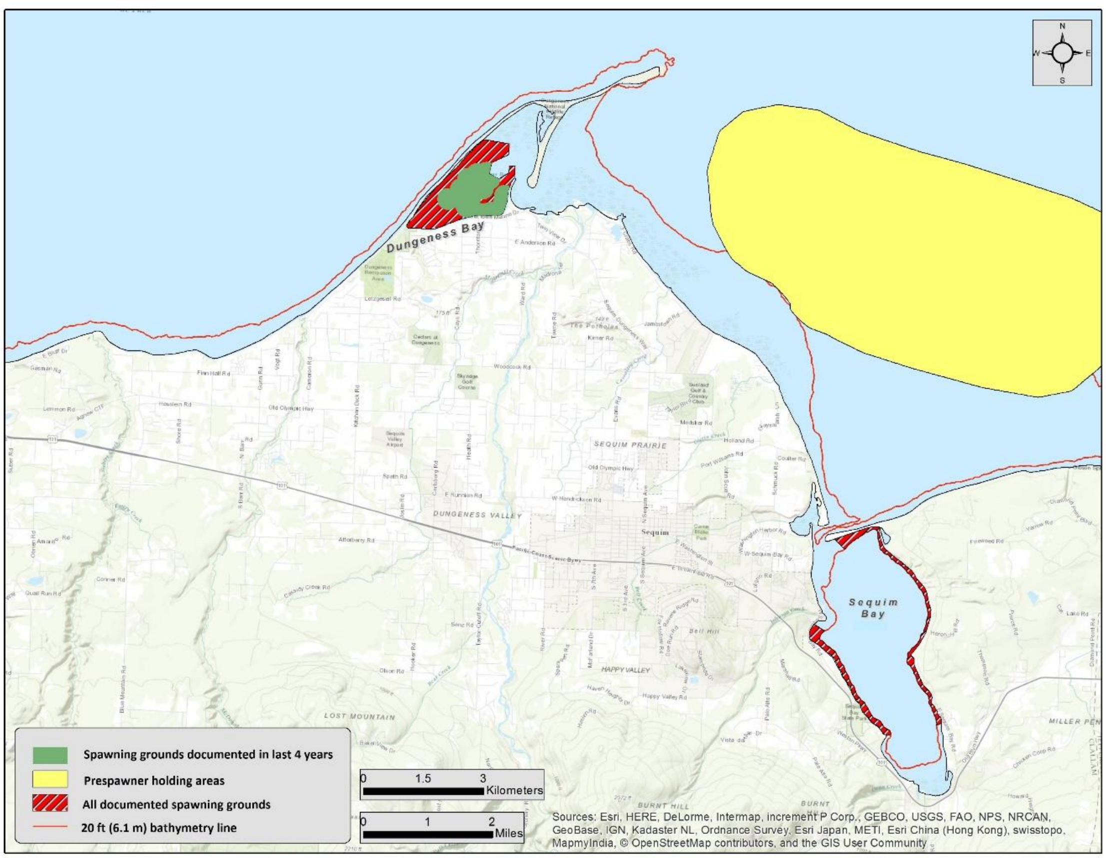
40 year mean (tonnes):	749
25 year mean (tonnes):	236
10 year mean (tonnes):	80
4 year mean (tonnes):	59
Stock Status (4 year):	Critical

Dungeness/Sequim Bay Herring Stock

OVERVIEW

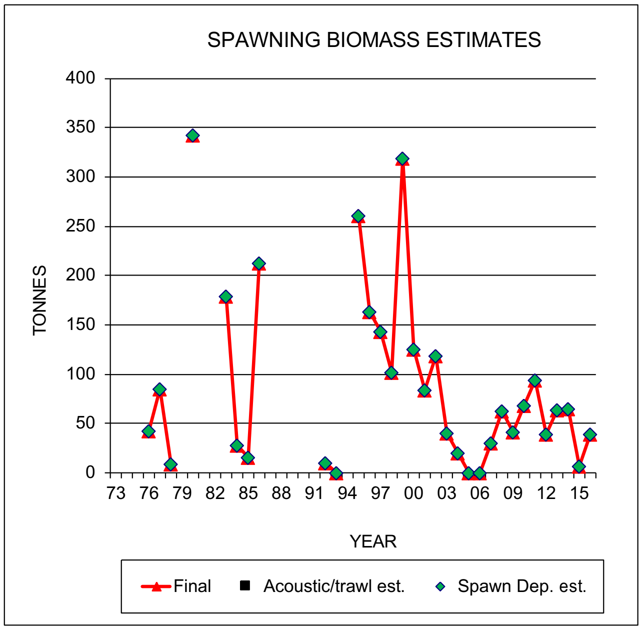
The Dungeness Bay portion of this small stock's spawning grounds has hosted virtually all of its spawning activity in recent years. These spawning grounds are the furthest west of any documented Puget Sound herring stock. Despite the presence of abundant marine vegetation preferred for spawning, only one small spawning event has been documented in Sequim Bay since 1994. Observed spawning activity in Sequim Bay was highest in the early 1980s when peak spawning biomass was documented for the nearby Discovery Bay stock, suggesting a "spillover" effect to Sequim Bay when the Discovery Bay population is at high abundance. Documented spawn timing is slightly earlier for Dungeness Bay compared to Sequim Bay and Discovery Bay, again suggesting a link between those two spawning grounds. A decrease in available spawning substrate has been observed in parts of Dungeness Bay in recent years, but is not considered to be limiting abundance. The stock is presently considered to be Declining (49% below the 25-year mean).

DUNGENESS/SEQUIM BAY SPAWNING GROUNDS 2016 REPORT:



STOCK STATUS PROFILE FOR: Dungeness/Sequim Bay Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976	43		43	
1977	85		85	
1978	9		9	
1979				
1980	343		343	
1981				
1982				
1983	179		179	
1984	28		28	
1985	16		16	
1986	212		212	
1987				
1988				
1989				
1990				
1991				
1992	10		10	
1993	0		0	*(Partial*
1994				*survey)*
1995	260		260	
1996	163		163	
1997	143		143	
1998	102		102	
1999	319		319	
2000	125		125	
2001	84		84	
2002	119		119	
2003	40		40	
2004	20		20	
2005	0		0	
2006	0		0	
2007	31		31	
2008	63		63	
2009	42		42	
2010	68		68	NA
2011	94		94	NA
2012	39		39	NA
2013	64		64	NA
2014	65		65	NA
2015	7		7	NA
2016	40		40	NA



STOCK SUMMARY

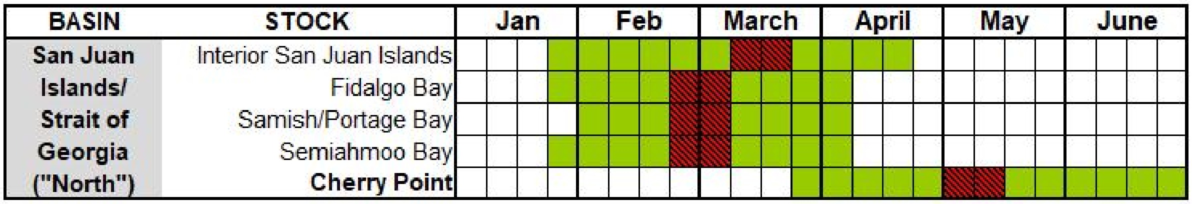
40 year mean (tonnes): NA
25 year mean (tonnes): 79
10 year mean (tonnes): 51
4 year mean (tonnes): 44

Stock Status (4 year): Declining

AR013487

Northern Region Herring Stock Profiles

DOCUMENTED AND PEAK HERRING SPAWNING TIMES

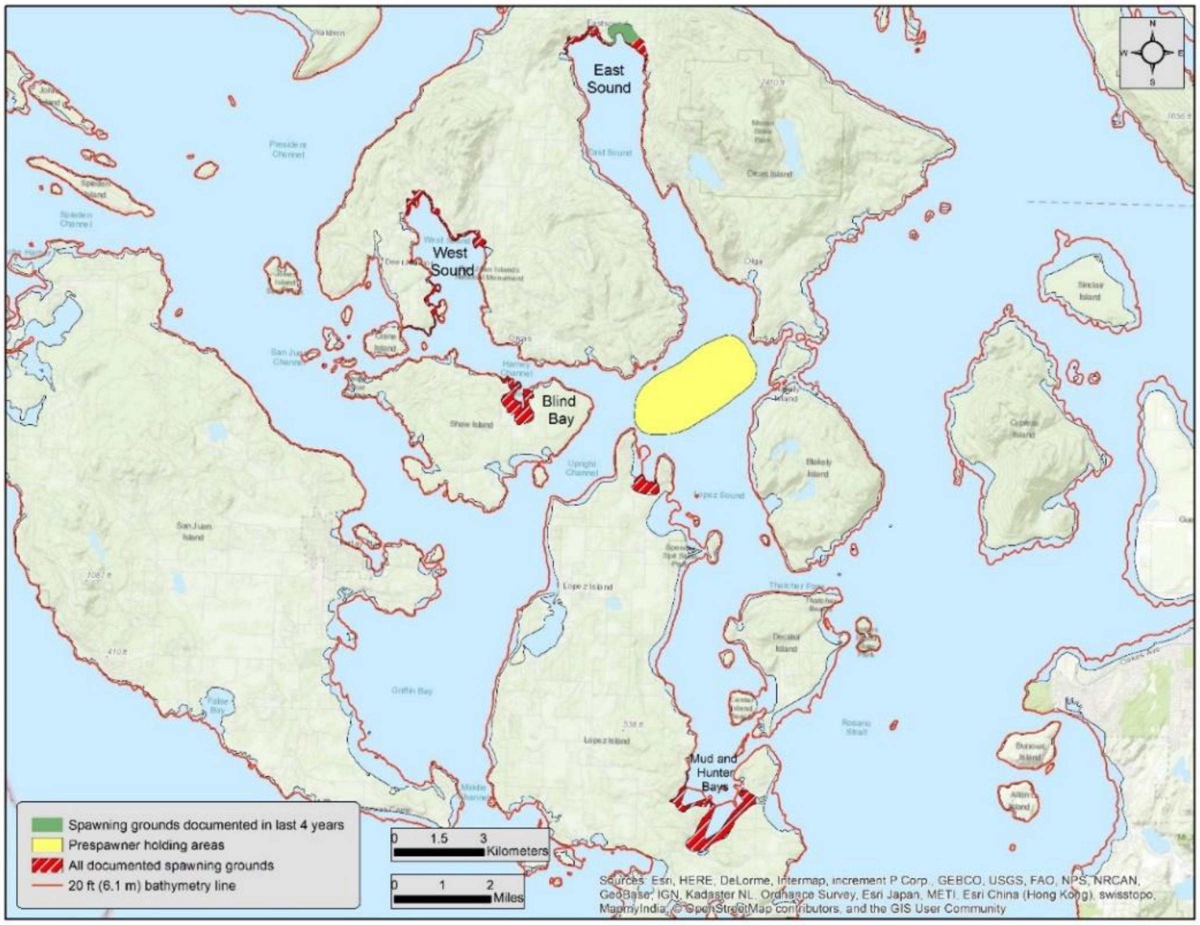


Interior San Juan Islands Herring Stock

<u>OVERVIEW</u>

The Interior San Juan Islands herring stock is small with spawning grounds in several separate areas and one known prespawner holding area near Harney Channel. Documented spawning grounds include West Sound and East Sound (Orcas Island), Mud Bay (Lopez Island), and Blind Bay (Shaw Island), with most spawn deposition observed in the northern end of East Sound. Spawning activity for this stock appears to be somewhat intermittent and does not appear to occur annually. No spawn was detected in 2013 or 2016 and the stock is considered Critical (92% below the 25-year mean), although sampling effort has been sporadic for this stock. Significant portions of eelgrass beds in Blind Bay previously used for spawning have disappeared, but a restoration project planned for 2016-17 should help restore spawning habitat. Spawning activity has been documented from late January into mid-April.

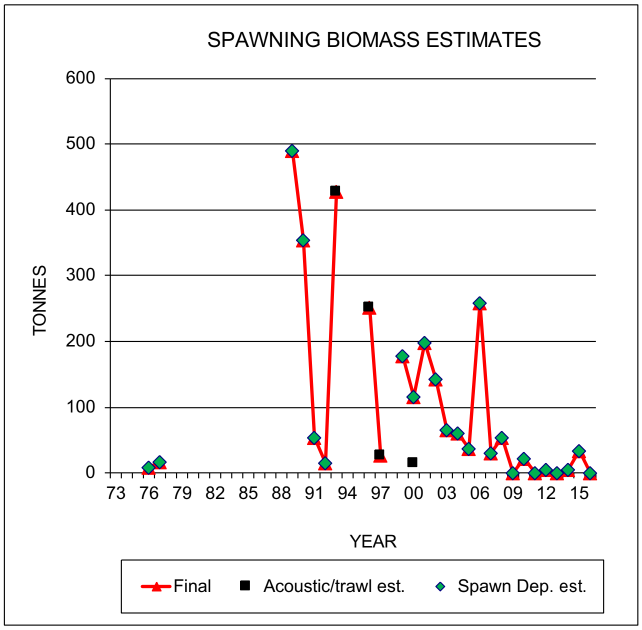
INTERIOR SAN JUAN ISLANDS SPAWNING GROUNDS 2016 REPORT:



AR013489

STOCK STATUS PROFILE FOR: Interior San Juan Islands Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976	9		9	
1977	16		16	
1978				
1979				
1980				
1981				
1982				
1983				
1984				
1985				
1986				
1987				
1988				
1989	491		491	
1990	355		355	
1991	54		54	
1992	15		15	
1993		428	428	
1994				
1995				
1996		251	251	
1997		27	27	27
1998				
1999	179		179	
2000	116	15	116	
2001	198		198	
2002	143		143	
2003	65		65	
2004	61		61	
2005	37		37	
2006	259		259	
2007	30		30	
2008	54		54	
2009	0		0	
2010	22		22	NA
2011	0		0	NA
2012	5		5	NA
2013	0		0	NA
2014	5		5	NA
2015	34		34	NA
2016	0		0	NA



STOCK SUMMARY

40 year mean (tonnes): NA
25 year mean (tonnes): 88
10 year mean (tonnes): 15
4 year mean (tonnes): 10

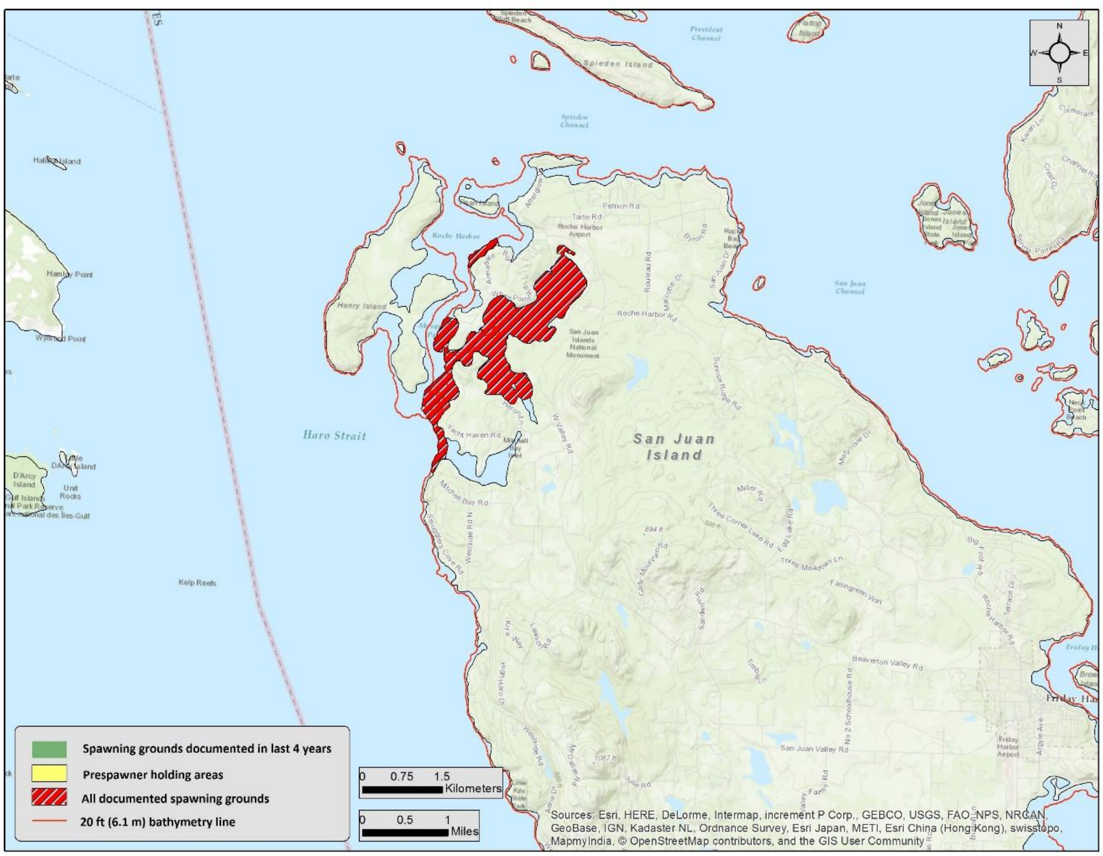
Stock Status (4 year): Critical

Northwest San Juan Island Herring Stock

OVERVIEW

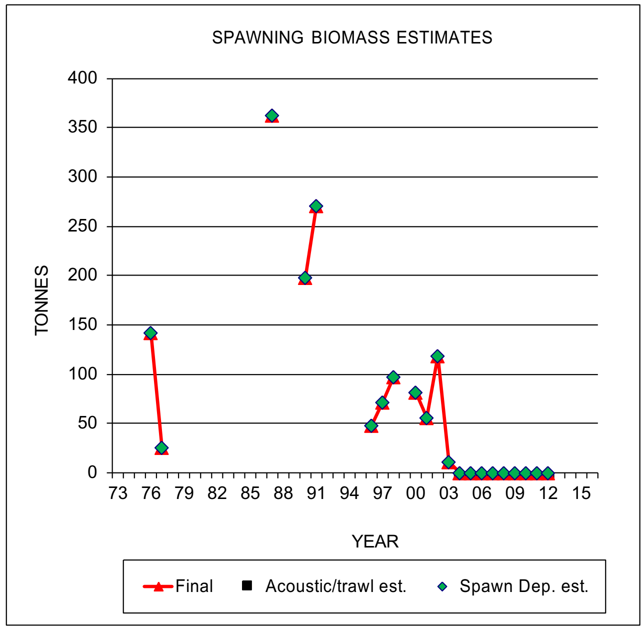
Historically, the Northwest San Juan Island stock was a small stock with spawning grounds primarily in Westcott Bay and Garrison Bay on San Juan Island. Stock distinction from the Interior San Juan Islands stock is based only on geographical separation. The disappearance of extensive eelgrass beds for unknown reasons in Westcott and Garrison Bays, first reported in 2001, has not shown significant improvement. A shift in spawning location to other suitable locations in the vicinity (outside of Westcott and Garrison Bays) has not been documented. Limited spawn deposition survey effort through 2012 did not document any spawning activity, and no surveys have been conducted since 2012. At present this stock's status is categorized as Unknown. It is possible this stock's spawning herring have strayed to other spawning populations with similar spawn timing and better spawning habitat, as suggested for British Columbia herring (Ware and Tovey, 2004). Periodic surveys will be conducted to document aquatic vegetation recovery and/or herring spawn for this stock.

NORTHWEST SAN JUAN ISLANDS SPAWNING GROUNDS 2016 REPORT:



STOCK STATUS PROFILE FOR: NW San Juan Island Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976	142		142	
1977	26		26	
1978				
1979				
1980				
1981				
1982				
1983				
1984				
1985				
1986				
1987	363		363	
1988				
1989				
1990	198		198	
1991	270		270	
1992				
1993				
1994				
1995				
1996	48		48	
1997	72		72	
1998	97		97	
1999				
2000	82		82	
2001	56		56	
2002	119		119	
2003	12		12	
2004	0		0	
2005	0		0	
2006	0		0	
2007	0		0	
2008	0		0	
2009	0		0	
2010	0		0	
2011	0		0	
2012	0		0	
2013				
2014				
2015				
2016				



STOCK SUMMARY

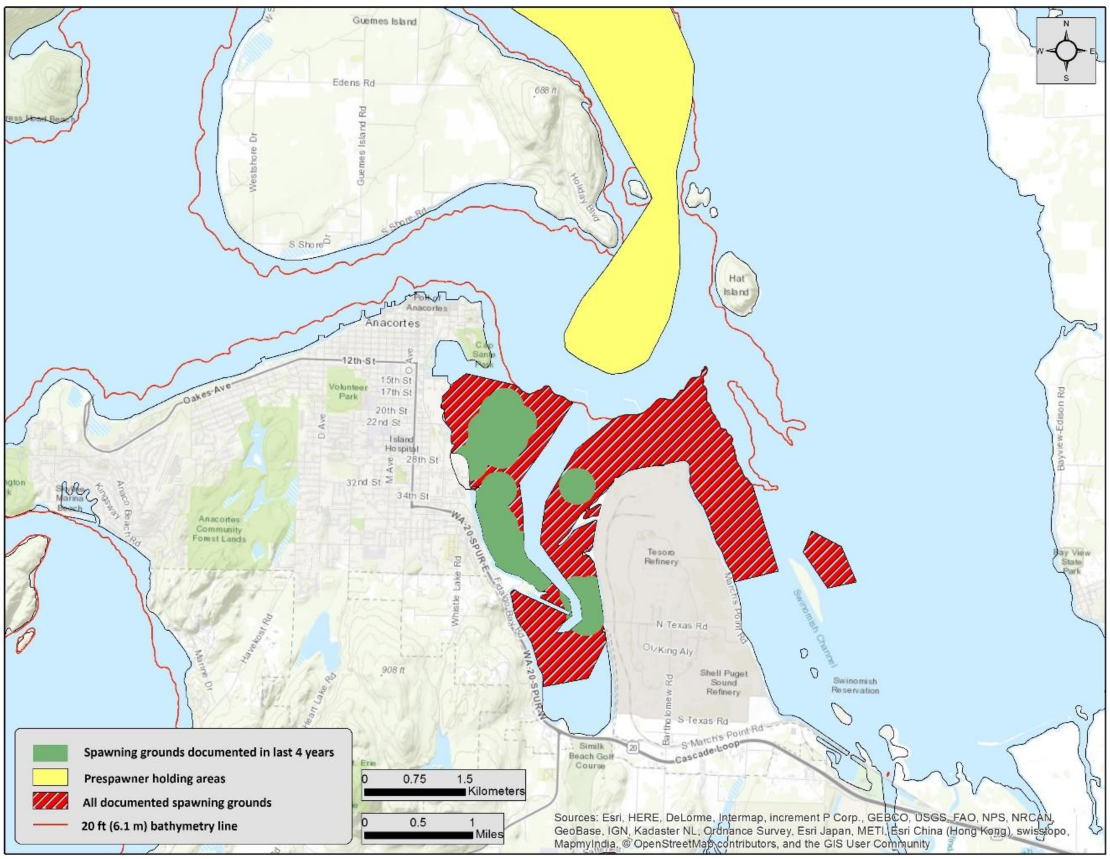
40 year mean (tonnes):	NA
25 year mean (tonnes):	NA
10 year mean (tonnes):	NA
4 year mean (tonnes):	NA
Stock Status (4 year):	Unknown

Fidalgo Bay Herring Stock

OVERVIEW

Formerly considered a medium-sized northern herring stock, the Fidalgo Bay stock has decreased substantially since 2001. Since 2012, annual spawning biomass estimates have been low but highly variable, and the stock is now considered Critical (84% below the 25-year mean), with only 5 tonnes of spawning biomass estimated in 2016. The proximity of its spawning grounds to oil refinery activities at March Point make its status of particular interest. Spawn deposition takes place at very low densities over the large shallow eelgrass flats that encompass much of the bay.

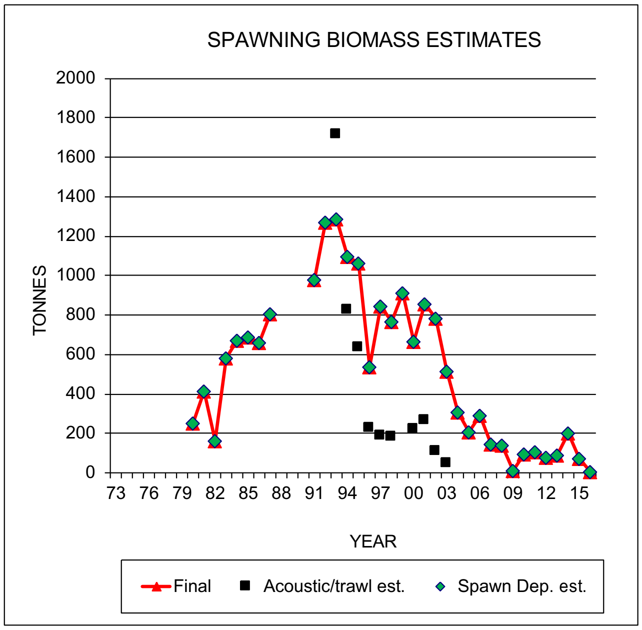
FIDALGO BAY SPAWNING GROUNDS 2016 REPORT:



AR013493

STOCK STATUS PROFILE FOR: Fidalgo Bay Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975				
1976				
1977				
1978				
1979				
1980	250		250	
1981	414		414	
1982	165		165	
1983	581		581	
1984	673		673	
1985	690		690	
1986	663		663	
1987	805		805	
1988				
1989				
1990				
1991	979		979	
1992	1269		1269	
1993	1285	1720	1285	1094
1994	1095	827	1095	535
1995	1064	637	1064	800
1996	535	231	535	248
1997	843	189	843	726
1998	766	187	766	617
1999	912		912	
2000	669	223	669	
2001	856	269	856	454
2002	785	112	785	669
2003	516	50	516	44
2004	308		308	
2005	210		210	
2006	293		293	
2007	144		144	
2008	142		142	
2009	14		14	
2010	93		93	NA
2011	108		108	NA
2012	81		81	NA
2013	91		91	NA
2014	200		200	NA
2015	73		73	NA
2016	5		5	NA



STOCK SUMMARY

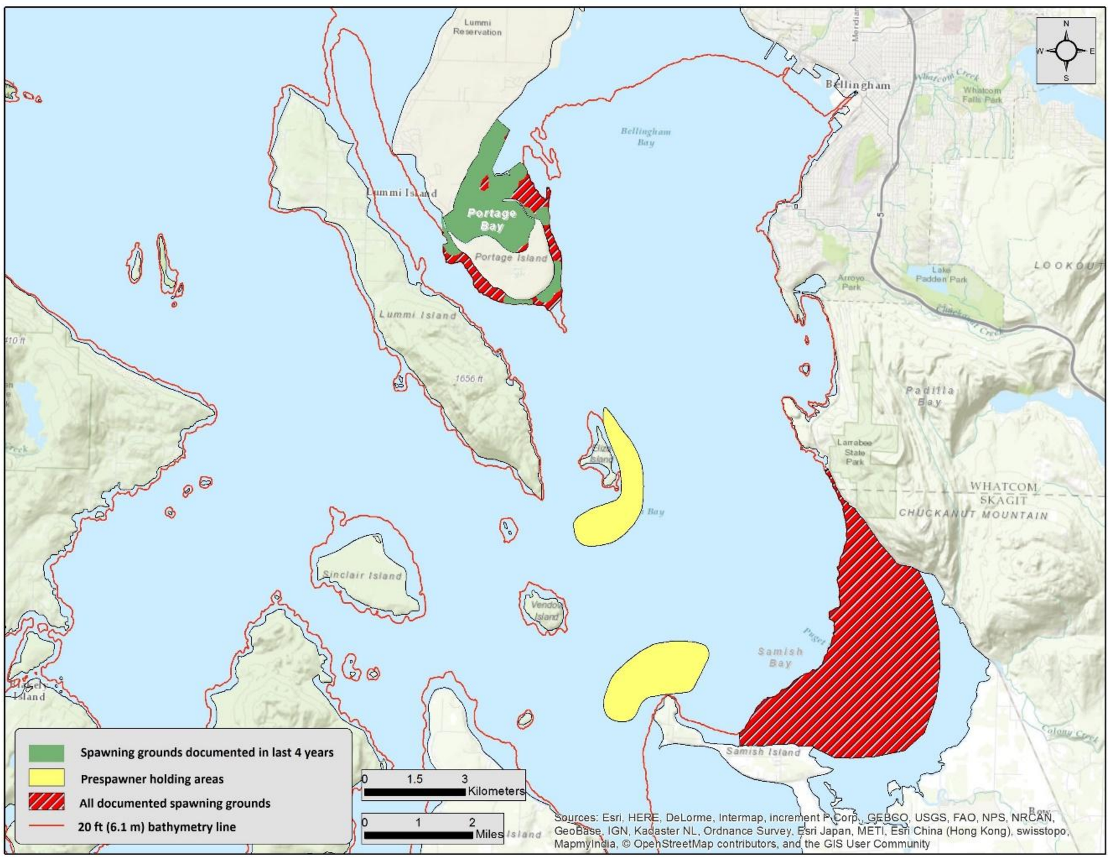
40 year mean (tonnes): 517
25 year mean (tonnes): 494
10 year mean (tonnes): 95
4 year mean (tonnes): 92

Stock Status (4 year): Critical

Samish/Portage Bay Herring Stock

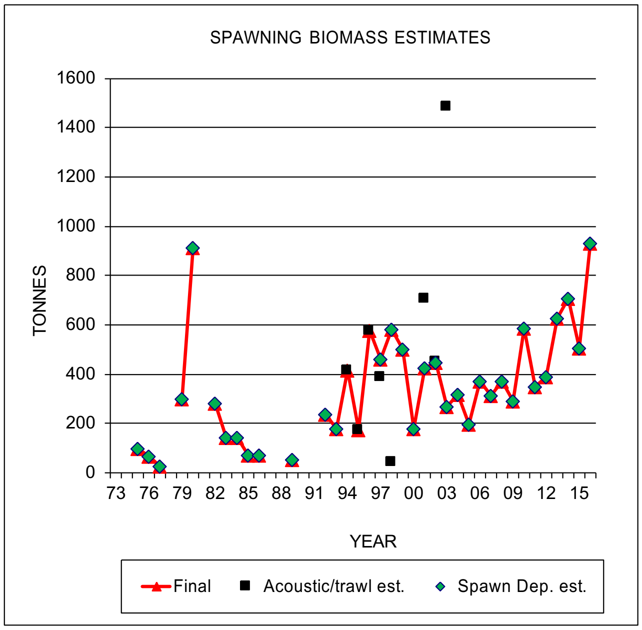
<u>OVERVIEW</u>
Spawning by this northern stock historically occurred in both Samish Bay and Portage Bay, though since 2012 all spawning activity has been observed in the northern (Portage Bay) portion of its documented spawning grounds. Spawning activity typically occurs from early February to late March. This stock has been considered Increasing or Healthy since 1996, and continues to be classified as Increasing today, with a record biomass estimated for 2016 (929 tonnes, or 100% above the 25-year mean).

<u>SAMISH/PORTAGE BAY SPAWNING GROUNDS 2016 REPORT:</u>



STOCK STATUS PROFILE FOR: Samish/Portage Bay Herring Stock

	SPAWNING BIOMASS ESTIMATES (tonnes)			
YEAR	SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975	99		99	
1976	70		70	
1977	29		29	
1978				
1979	302		302	
1980	914		914	
1981				
1982	281		281	
1983	144		144	
1984	145		145	
1985	71		71	
1986	72		72	
1987				
1988				
1989	53		53	
1990				
1991				
1992	238		238	
1993	180		180	
1994		416	416	
1995		176	176	60
1996		577	577	442
1997	462	391	462	410
1998	583	44	583	380
1999	503		503	
2000	178		178	
2001	426	706	426	
2002	450	451	450	257
2003	271	1486	271	18
2004	318		318	
2005	198		198	
2006	374		374	
2007	316		316	
2008	371		371	
2009	290		290	
2010	589		589	NA
2011	351		351	NA
2012	390		390	NA
2013	629		629	NA
2014	706		706	NA
2015	507		507	NA
2016	929		929	NA



STOCK SUMMARY

40 year mean (tonnes): 366
25 year mean (tonnes): 417
10 year mean (tonnes): 508
4 year mean (tonnes): 693

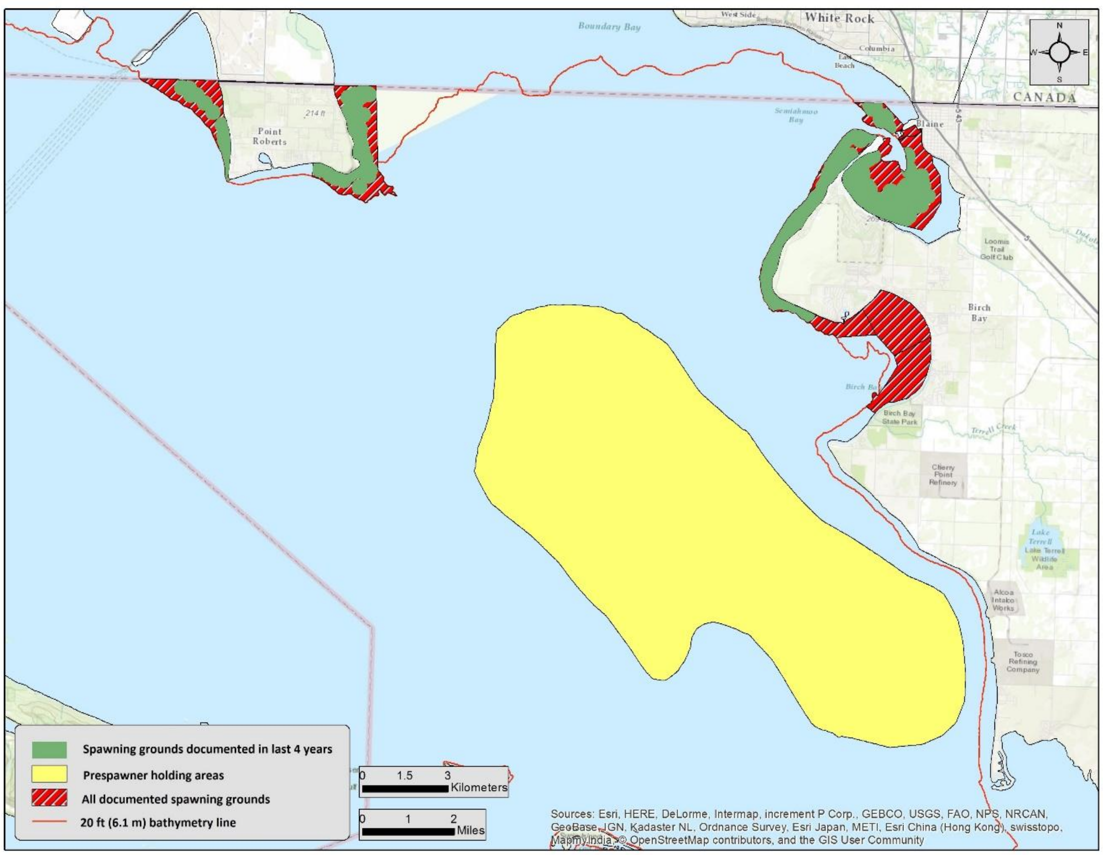
Stock Status (4 year): Increasing

AR013496

Semiahmoo Bay Herring Stock

OVERVIEW
The Semiahmoo Bay herring stock's documented spawning grounds overlap spatially but not temporally with those of the spring spawning Cherry Point stock, with most spawning activity taking place between early February and mid-March. Biological characteristics such as growth rates and spawning behavior differ markedly between the two stocks on a consistent basis. Additionally, two studies (Small et al., 2005; Mitchell, 2006) examining DNA microsatellites concluded that this stock is genetically differentiated from Cherry Point herring without significant observed genetic divergence from other sampled SSS stocks. In contrast to the long term Critical status of the Cherry Point stock, the Semiahmoo Bay stock is considered Increasing (127% above the 25-year mean) and has been robust in recent years, even though the area utilized for spawning has contracted since 2012. The estimate in 2015 marked an all-time high for the Semiahmoo Bay stock with 5,309 tonnes, 381% above the 25-year mean, and was almost certainly an underestimate given that surveys stop at the Canadian border, while spawning likely extends north of that line.

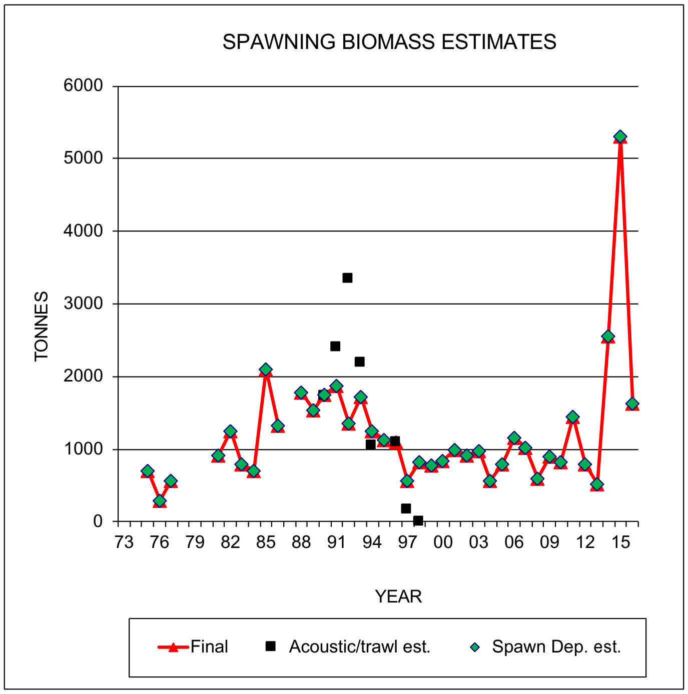
SEMIAHMOO BAY SPAWNING GROUNDS 2016 REPORT:



AR013497

STOCK STATUS PROFILE FOR: Semiahmoo Bay Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973				
1974				
1975	700		700	
1976	291		291	
1977	575		575	
1978				
1979				
1980				
1981	914		914	
1982	1260		1260	
1983	793		793	
1984	700		700	
1985	2109		2109	
1986	1328		1328	
1987				
1988	1783		1783	
1989	1543		1543	887
1990	1751	1732	1751	1427
1991	1870	2409	1870	780
1992	1362	3347	1362	577
1993	1725	2192	1725	1410
1994	1260	1058	1260	613
1995	1129		1129	
1996		1106	1106	
1997	563	178	563	422
1998	834	11	834	663
1999	787		787	
2000	840		840	
2001	996		996	
2002	918		918	
2003	986		986	
2004	571		571	
2005	789		789	
2006	1158		1158	
2007	1020		1020	
2008	601		601	
2009	898		898	
2010	825		825	NA
2011	1456		1456	NA
2012	797		797	NA
2013	516		516	NA
2014	2566		2566	NA
2015	5309		5309	NA
2016	1631		1631	NA



STOCK SUMMARY

40 year mean (tonnes):	1258
25 year mean (tonnes):	1226
10 year mean (tonnes):	1562
4 year mean (tonnes):	2505

Stock Status (4 year): Increasing

Cherry Point Herring Stock

OVERVIEW

The Cherry Point herring stock is unusual in Washington State because of its late "spring" spawning timing (typically running from late April through mid-June). Washington's largest herring stock from the 1970s until the mid-1990s, its abundance has decreased dramatically and it continues to be in dire condition, showing no signs of recovery. As with other stocks with long-term datasets, the 25-year mean (2,310 tonnes) no longer encompasses the decline from initial abundance (the mean biomass including all years of data [since 1973] is 4,106 tonnes, while the initial 1973 biomass estimate was 13,606 tonnes). As discussed previously in this report, several studies (Beacham et al 2001, 2002, 2008; Small et al 2005; Mitchell 2006) examining DNA microsatellites have identified the Cherry Point stock as being genetically distinct from British Columbia and other SSS stocks sampled to date, justifying its management as a discrete stock.

Historically, this stock spawned from inside Bellingham Bay (Portage Bay), along Lummi Island, throughout Birch and Semiahmoo Bays, and north to Point Roberts. Over time the location of spawning activity has contracted northward (

Figure 3), and in recent years the majority of spawn deposition occurred near Birch Point and Point Whitehorn. For the first time ever, no spawn was recorded at or south of Point Whitehorn in 2016. A decrease in available spawning habitat has not been documented for this stock and it does not appear to be habitat limited. Potential causes for the stock's precipitous decline and lack of recovery include climate change, changes in predator/prey abundance, disease, and pollution. However, toxicological studies of Cherry Point herring showed lower levels of polycyclic aromatic hydrocarbons (PAHs) relative to stocks spawning along residential bays in Central Puget Sound; "It is possible that open shorelines such as Cherry Point may dilute or disperse local PAH sources" (West et al., 2014). Also, Cherry Point herring embryos show much higher temperature tolerance compared to other SSS stocks (Marshall, 2011), which may be related to their late spawn time and may provide an important advantage in a time of rapid environmental change. An important data gap for understanding the lack of recovery for Cherry Point herring is larval herring survival and dispersal, as well as stock age structure. In 2016, with funding from the Washington Department of Natural Resources' Aquatic Reserves Program, WDFW initiated a study using variable mesh gill nets to capture adult spawners throughout the spawning season and determine the age structure of this stock; age structure information has been unavailable since acoustic trawl surveys ended in 2010 (2009 for all other stocks). The gill net sampling revealed the presence of spawning herring up to age 8, with a bell curve typical of healthy stocks (Sandell et al., 2019). The study will be repeated in 2017 to confirm these findings and additional details will be provided in an independent report.

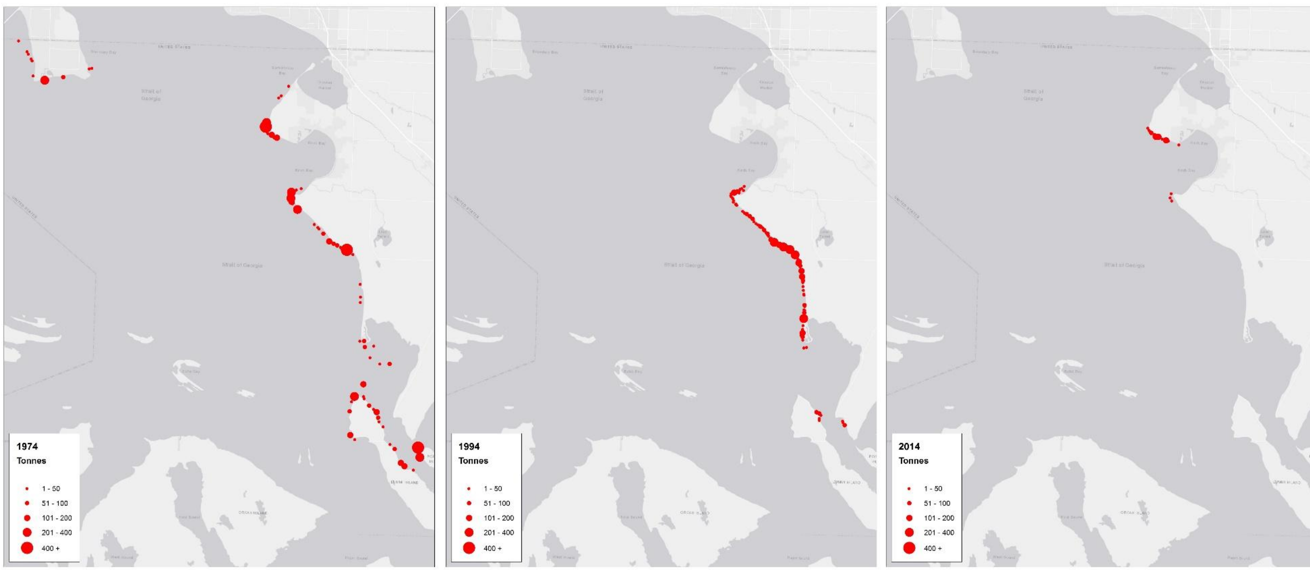
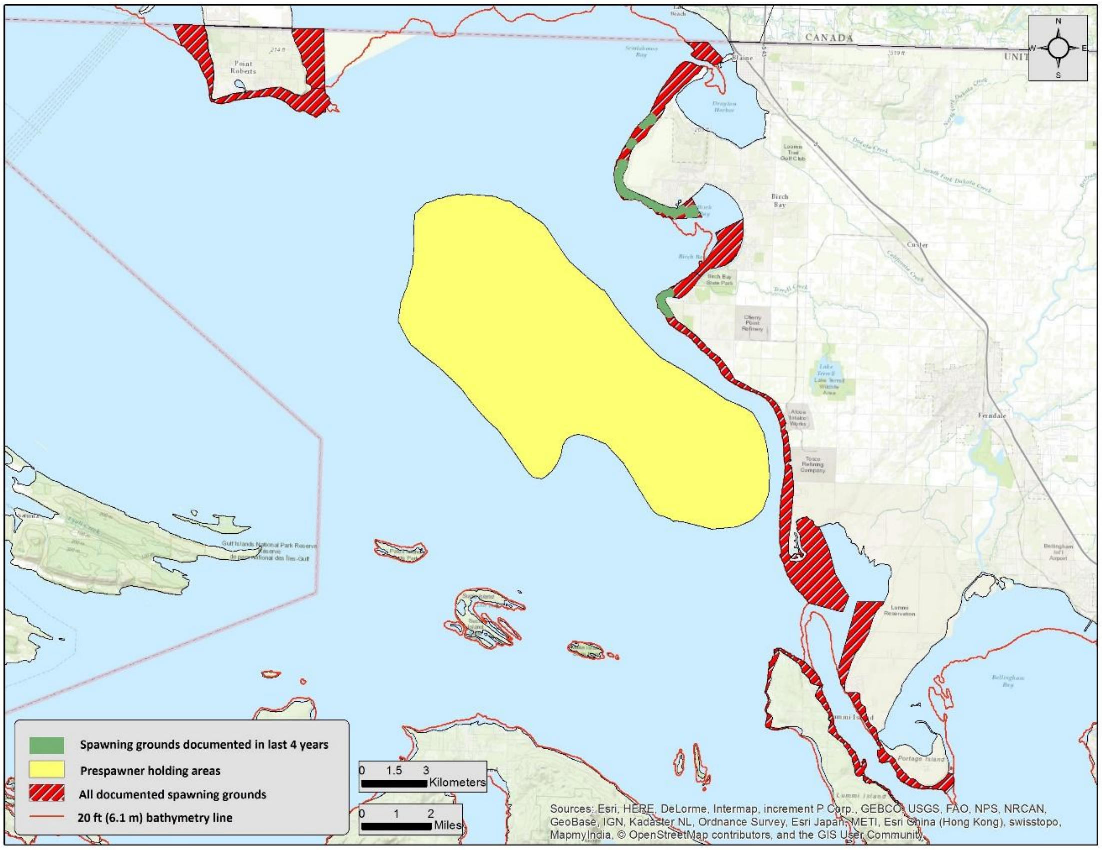


Figure 3: Maps of Cherry Point herring spawn deposition documented in 1974, 1994, and 2014. Red circles indicate locations where eggs where observed. Note the contraction and northerly shift of the spawning area utilized.

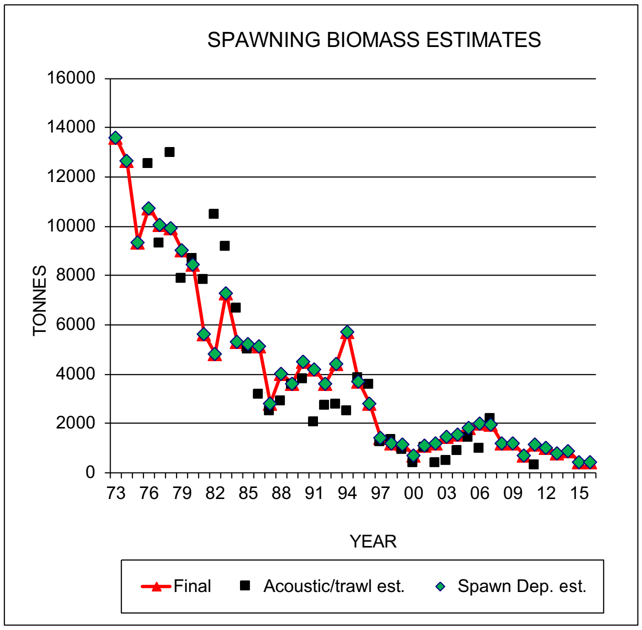
CHERRY POINT SPAWNING GROUNDS 2016 REPORT:



AR013501

STOCK STATUS PROFILE FOR: Cherry Point Herring Stock

YEAR	SPAWNING BIOMASS ESTIMATES (tonnes) SPAWN DEPOSIT SURVEY	ACOUSTIC/ TRAWL SURVEYS	FINAL BIOMASS ESTIMATE	RECRUIT-MENT (tonnes)
1973	13606		13606	
1974	12667		12667	
1975	9378		9378	1733
1976	10745	12548	10745	1051
1977	10067	9317	10067	2730
1978	9955	12985	9955	3212
1979	9033	7878	9033	1024
1980	8463	8699	8463	3334
1981	5642	7835	5642	360
1982	4846	10489	4846	1853
1983	7315	9201	7315	1256
1984	5353	6665	5353	908
1985	5225	5007	5225	2656
1986	5145	3201	5145	2989
1987	2820	2517	2820	1048
1988	4017	2936	4017	1887
1989	3631	3595	3631	2265
1990	4534	3824	4534	1725
1991	4195	2067	4195	1035
1992	3637	2720	3637	1806
1993	4440	2771	4440	3115
1994	5737	2519	5737	3698
1995	3724	3856	3724	1092
1996	2808	3602	2808	700
1997	1428	1270	1428	585
1998	1199	1363	1199	893
1999	1148	954	1148	807
2000	733	396	733	508
2001	1126	1040	1126	617
2002	1207	408	1207	884
2003	1461	503	1461	905
2004	1573	890	1573	20
2005	1823	1420	1823	1618
2006	2010	1000	2010	1841
2007	1968	2208	1968	1374
2008	1227		1227	864
2009	1217		1217	
2010	702		702	NA
2011	1180	304	1180	NA
2012	1016		1016	NA
2013	824		824	NA
2014	910		910	NA
2015	475		475	NA
2016	468		468	NA



STOCK SUMMARY

40 year mean (tonnes):	3357
25 year mean (tonnes):	1762
10 year mean (tonnes):	999
4 year mean (tonnes):	669

Stock Status (4 year): Depressed

Washington Herring Stock Status Summary

Table includes individual, regional (basin), and Puget Sound cumulative stock status summaries since 1988 based on rolling 25-year mean spawning biomass estimates and status classification criteria (described on page 19 of this report). As previously discussed, the value of a stock-by-stock evaluation is affected greatly by stock discreteness; if considerable intermixing/gene flow occurs among most Puget Sound herring stocks, the individual stock statuses presented below may be of reduced importance. It may be more useful to examine abundance levels and trends on a regional or sub-regional basis and also to incorporate genetic findings to date (e.g., separate the Cherry Point and Squaxin Pass stocks from their respective regions) (Figure 4).

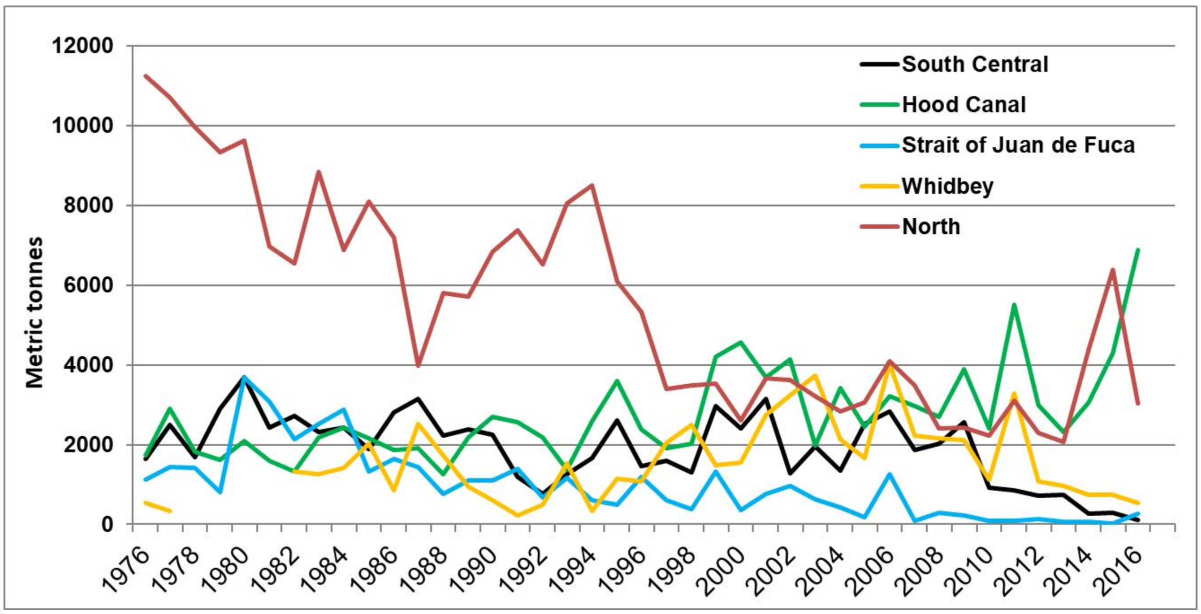


Figure 4: Estimated SSS herring spawning biomass by region/basin (metric tonnes).

For the 2013-16 period, there was a continued drop in SSS herring stocks classified as Increasing or Healthy to 19% (4 of 21; 3 stocks with status considered to be Unknown; see Table). In South Puget Sound (Figure ES3), several herring stocks did not have detectable spawning activity in 2016. Sampling effort will continue in these areas to determine if/when a "recolonization" of spawning herring, similar to that described in areas of British Columbia (Ware & Tovey, 2004), occurs in the future.

The Cherry Point herring stock has shown no signs of improving from its Critical status and the stock's smallest estimated spawning biomass to date was documented in 2016 (this followed a moderate increase in abundance from 2000 through 2006). In this report the status is reported as Depressed rather than Critical only because peak spawning biomass from the 1970s is no longer included in the 25-year data window for determining status. Spawning activity of the Cherry Point stock has contracted northward in recent years, with most observed spawn deposition located near Birch Point. North Puget Sound stocks, even including the Cherry Point stock, are considered Healthy, primarily due to increased abundance for the Semiahmoo Bay and Portage/Samish Bay stocks.

The Strait of Juan de Fuca (Figure ES3) stocks are considered Critical, even with the sharp increase in biomass of the Discovery Bay stock in 2016 (221 tonnes). The condition and spawning biomass of the Discovery Bay stock has been considered an enigma since assessment surveys were started there in 1976. Estimated spawning biomass was over 2,600 tonnes in the early 1980s followed by an unexplained steady decrease to little or no documented spawning activity since 2000, other than a one year jump to 1,202 tonnes in 2006. No recent direct fishery harvest, relatively undisturbed spawning grounds, and good water quality add to the mystery of this stock's recent spawning biomass history.

Regionally, South/Central Puget Sound stocks (Figure ES3) are considered Critical over the past four years but South Puget Sound was considered Healthy in 2000 and Central Puget Sound was Increasing as late as 2008. The overall decline in South/Central Puget Sound stocks is due to declines in most of the stocks in this region, including Purdy, Wollochet Bay, Quartermaster Harbor, and Port Orchard-Port Madison (Figure 5). No spawn was detected at any of these stocks in 2016. Spawn survey efforts will be increased in 2017 to determine if new spawning areas are being utilized to better understand if these decreases are the result of shifts in spawn location.

The Hood Canal stocks (considered part of the Other Stocks Complex), particularly Quilcene Bay, are boosting the estimated total spawning biomass for all of the SSS. The Quilcene Bay stock's 4-year mean is 125% above the 25-year mean and now contributes over half of all SSS herring spawning biomass. While the Quilcene Bay and South Hood Canal stocks are considered Increasing or Healthy, the Port Gamble stock was Declining in 2000 and 2004, Depressed in 2008 and 2012, and has now fallen to Critical for 2016. A recent remediation project to remove creosote pilings in the bay may help improve water quality and larval herring survival.

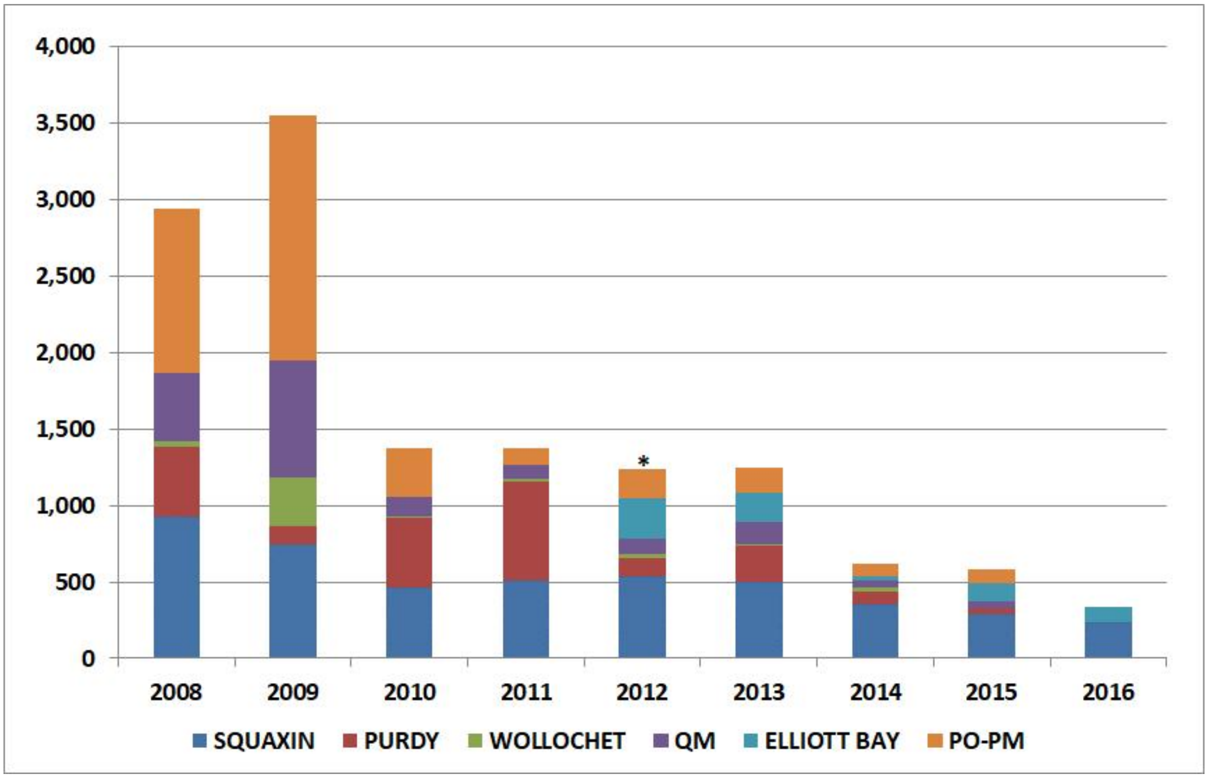


Figure 5: Estimated spawning biomass (tonnes), South/Central Puget Sound, 2008-16. (*Elliott Bay surveys started in 2012; PO/PM= Port Orchard/Port Madison; QM= Quarter Master).

Table 1. Status of herring stocks in the southern Salish Sea based on recent 4-year mean abundance compared to rolling long-term (previous 25-year mean) abundance.

Increasing■- A stock with recent 4-year mean abundance more than 20% above the 25-year mean; **Healthy**■- A stock with recent 4-year mean abundance within 20% of the 25-year mean; **Declining**■- A stock with recent 4-year mean abundance 21-50% below the 25-year mean; **Depressed**■- A stock with recent abundance 51-80% below the 25-year mean; **Critical**■- A stock with recent 4-year mean abundance 81-99% below the 25-year mean; **Undetected**■- A stock that can no longer be found in a formerly consistently utilized spawning ground for four consecutive years; **Unknown**□- Insufficient assessment data to identify stock status with confidence. Individual stocks in **BOLD** font are considered genetically distinct. The number to the right of each stock name indicates the number of years with biomass estimates available for the 25 year average (1988 through 2012).

SOUTHERN SALISH SEA HERRING STOCK STATUS BY BASIN AND STOCK, 1988-2016 (4 year average Vs. 25 year rolling average)									
Basin	**Stock - *# years w/ data 1988-2012***	**1988**	**1992**	**1996**	**2000**	**2004**	**2008**	**2012**	**2016**
South Puget Sound	**Squaxin Pass** - *23*	NO SAMPLE	UNKNOWN	DECLINING	DEPRESSED	INCREASING	HEALTHY	DECLINING	DEPRESSED
	Purdy - *5*	NO SAMPLE	NO SAMPLE	NO SAMPLE	NO SAMPLE	NO SAMPLE	UNKNOWN	UNKNOWN	UNKNOWN
	Wollochet Bay - *13*	NO SAMPLE	NO SAMPLE	NO SAMPLE	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	CRITICAL
	Quartermaster Harbor - *25*	UNKNOWN	DEPRESSED	HEALTHY	HEALTHY	DECLINING	DECLINING	DEPRESSED	CRITICAL
Central Puget Sound	Elliott Bay - *1*	NO SAMPLE	NO SAMPLE	NO SAMPLE	NO SAMPLE	NO SAMPLE	NO SAMPLE	UNKNOWN	UNKNOWN
	Port Orchard-Port Madison - *25*	UNKNOWN	DECLINING	DEPRESSED	HEALTHY	HEALTHY	INCREASING	DEPRESSED	CRITICAL
Hood Canal	South Hood Canal - *19*	NO SAMPLE	UNKNOWN	UNKNOWN	UNKNOWN	DECLINING	HEALTHY	HEALTHY	HEALTHY
	Quilcene Bay - *19*	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	INCREASING	INCREASING	INCREASING	INCREASING
	Port Gamble - *25*	UNKNOWN	INCREASING	HEALTHY	DECLINING	DECLINING	DEPRESSED	DEPRESSED	CRITICAL
Whidbey Basin	Holmes Harbor - *19*	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	INCREASING	INCREASING	INCREASING	DECLINING
	Skagit Bay - *19*	UNKNOWN	NO SAMPLE	UNKNOWN	UNKNOWN	INCREASING	INCREASING	DEPRESSED	DEPRESSED
	Port Susan - *25*	UNKNOWN	UNKNOWN	DECLINING	INCREASING	DECLINING	DEPRESSED	DEPRESSED	CRITICAL
Strait of Juan de Fuca	Kilisut Harbor - *21*	NO SAMPLE	UNKNOWN	UNKNOWN	HEALTHY	INCREASING	CRITICAL	UNDETECTED	CRITICAL
	Discovery Bay - *25*	UNKNOWN	DECLINING	DEPRESSED	CRITICAL	CRITICAL	DEPRESSED	CRITICAL	CRITICAL
	Dungeness/Sequim Bay - *20*	UNKNOWN	UNKNOWN	UNKNOWN	INCREASING	DECLINING	CRITICAL	DECLINING	DECLINING
San Juan Islands/ Strait of Georgia ("North")	Interior San Juan Islands - *21*	NO SAMPLE	UNKNOWN	UNKNOWN	UNKNOWN	DECLINING	DECLINING	CRITICAL	CRITICAL
	NW San Juan Islands - *18*	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNDETECTED	UNDETECTED	NO SAMPLE
	Fidalgo Bay - *22*	UNKNOWN	UNKNOWN	INCREASING	HEALTHY	HEALTHY	DEPRESSED	CRITICAL	CRITICAL
	Samish/Portage Bay - *22*	UNKNOWN	DECLINING	INCREASING	INCREASING	INCREASING	HEALTHY	INCREASING	INCREASING
	Semiahmoo Bay - *25*	UNKNOWN	INCREASING	HEALTHY	DECLINING	DECLINING	DECLINING	HEALTHY	INCREASING
	Cherry Point - *25*	DEPRESSED	DECLINING	DECLINING	CRITICAL	DEPRESSED	DEPRESSED	DEPRESSED	DEPRESSED

Regional Totals	1988	1992	1996	2000	2004	2008	2012	2016
South Puget Sound stocks	INCREASING	HEALTHY	INCREASING	HEALTHY	DECLINING	DECLINING	DECLINING	CRITICAL
Central Puget Sound stocks	INCREASING	INCREASING	DECLINING	HEALTHY	HEALTHY	INCREASING	DECLINING	CRITICAL
Hood Canal Stocks	INCREASING	INCREASING	INCREASING	INCREASING	INCREASING	HEALTHY	INCREASING	INCREASING
Strait of Juan de Fuca stocks	INCREASING	HEALTHY	INCREASING	INCREASING	INCREASING	INCREASING	HEALTHY	DEPRESSED
Whidbey Basin stocks	INCREASING	HEALTHY	DECLINING	DECLINING	DEPRESSED	DEPRESSED	CRITICAL	CRITICAL
Northern stocks	INCREASING	HEALTHY	HEALTHY	DEPRESSED	DEPRESSED	DECLINING	DEPRESSED	HEALTHY
All Stocks combined excluding Quilcene Bay (HC)	INCREASING	INCREASING	HEALTHY	DECLINING	DECLINING	DECLINING	DECLINING	DECLINING
All Stocks combined	INCREASING	INCREASING	HEALTHY	HEALTHY	HEALTHY	HEALTHY	DECLINING	HEALTHY

Summary of Southern Salish Sea Herring Fisheries

Commercial herring fisheries in the SSS have experienced several major shifts since the start of the last century, as described in detail by Trumble (1983) and Williams (1959), and summarized in a previous Washington state stock status report (Stick and Lindquist 2009). This section largely restates these fishery trends with an update since 2012.

Commercial herring fisheries in the early 1900s harvested herring mainly for export, a market that collapsed soon after World War I. From the 1920s through the 1940s, the major portion of herring landings were used as bait for commercial halibut, crab, and shark fisheries. Herring traps accounted for much of the landings beginning in the 1920s. Traps were typically located adjacent to or near spawning grounds to intercept adult fish migrating to and from spawning areas. The most successful trap sites were in Holmes Harbor and at Point Whitney and Jackson Cove near Quilcene Bay in Hood Canal. Total reported herring landings through the 1940s ranged from a low of 33 tonnes in 1942 to a high of 1,189 tonnes in 1926 (Chapman et al. 1941 and Williams 1959).

Commercial herring fishing emphasis in the SSS shifted again in the early 1950s to primarily supply bait to growing recreational salmon fisheries. Changing market conditions and trap location restrictions in 1937 decreased the number of operational herring traps to one (in Holmes Harbor) by 1947 and led to a gradual reduction in trap landings, the last of which occurred in 1971.

The next shift in the SSS herring fishery occurred in 1957 when the reduction of herring to oil and meal was authorized; landings were also used for commercial crab bait. This "general purpose" fishery with most of the fishing effort occurring in Bellingham Bay, resulted in annual landings of 1,360 to 3,175 tonnes. This fishery was phased out by regulation in the early 1980s due to concerns about potential effects on local herring stock abundance, particularly the Cherry Point stock.

In 1972, a sac-roe fishery targeting the Cherry Point herring stock began. Landings in this treaty and non-treaty fishery topped 4,000 tonnes in 1974 (Figure 6). Declines in the Northern herring stocks, particularly the Cherry Point stock, led to the closure of both the general purpose and sac-roe fisheries by the mid-1980s. In 1988, a non-tribal spawn-on-kelp (SOK) and treaty sac-roe fisheries were resumed on the Cherry Point stock. Another decline in Cherry Point stock abundance in the mid-1990s again closed this fishery and has remained closed to date. A minimum spawning biomass of 2,900 tonnes for the Cherry Point stock is currently required before harvest is considered. In addition to ensuring sufficient biomass, concerns regarding the predisposition of herring populations encountered in the SOK fishery to epizootic mortality should also be addressed prior to reopening such a fishery. The epizootic, viral hemorrhagic septicemia (VHS), characterized by high mortality and massive viral shedding among affected cohorts, frequently occurs in herring impoundments used for SOK fisheries (Hershberger et al., 1999). In addition to creating localized epizootics inside the herring impoundments, shed waterborne virus can emanate from the net pens and represent a significant risk factor for initiating VHS epizootics in unconfined herring over a larger geographic area. SOK fishery management options exist that can decrease the probability of localized VHS epizootics within herring net pens (Hershberger et al., 2001), and should be considered if /when conditions warrant reopening of SOK fisheries.

All non-tribal commercial herring fisheries in Washington waters are “limited entry,” which was put into effect in 1974, limiting fishing opportunities to fishers who had made landings in 1971-73. Annual purchase of the gear type license must be made to maintain status. Commercial sport bait fishery landings are generally determined by market conditions, which are heavily influenced by the length of recreational salmon seasons, and holding/processing capacity. Similarly, Williams (1959) and Chapman et al. (1941) reported that herring landings are affected most by variability of fishing effort and that annual catch figures are not a reliable indicator of herring abundance.

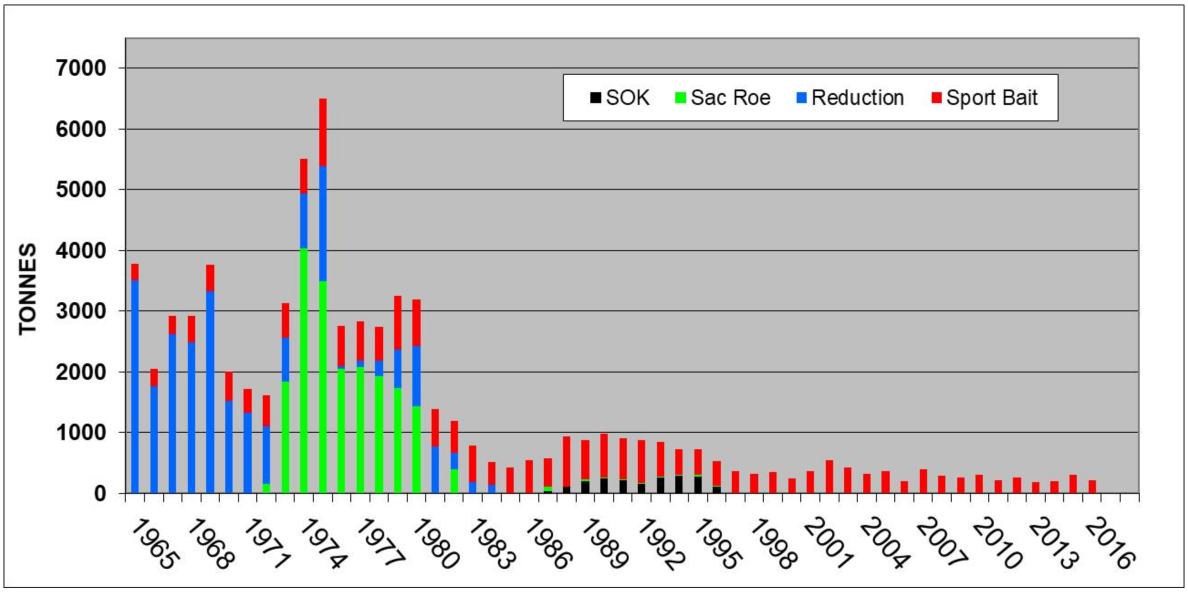


Figure 6: Puget Sound Herring Landings by Fishery Type, 1965-2016.

The “sport bait” herring fishery continues to be the only commercial herring fishery operating in Puget Sound, providing bait for sport salmon and groundfish fisheries. Fishing activity is primarily in South/Central Puget Sound with the majority of landings from two areas; the area around the Tacoma Narrows (Fishery Management Areas 26D and 28A) accounts for roughly 60% of recent landings, and the area around Point No Point (Fishery Management Areas 26A, 25C and 25B) accounts for roughly 40% of recent landings (Figure 7 and Figure 8). Hood Canal has been closed to all commercial herring fishing since 2004 due to concerns about the impacts of low dissolved oxygen and elevated summer temperatures on fish abundance. The sport bait fishery mostly targets 1+ to 2+ year old herring assumed to be an aggregate of stocks within the region. Almost all harvest in recent years has been taken by non-tribal fishers using relatively small (maximum length of 200 feet) lampara seines, with a small portion of landings captured via dip bag net gear.

Although the sport bait fishery targets juveniles to avoid capturing returning spawning fish, it is unknown whether all stocks are caught equally or if some are exploited at higher rates than others. This fishery has a harvest guideline of less than 10% of the cumulative adult herring spawning biomass (SB) estimate os stocks that spawn in South/Central Puget Sound, Hood Canal, and the Whidbey Basin (Bargmann, 1998; Day, 1998), but usually only achieves 2-6% of the SB because of market conditions and processing/holding capacities (Stick et al., 2014).

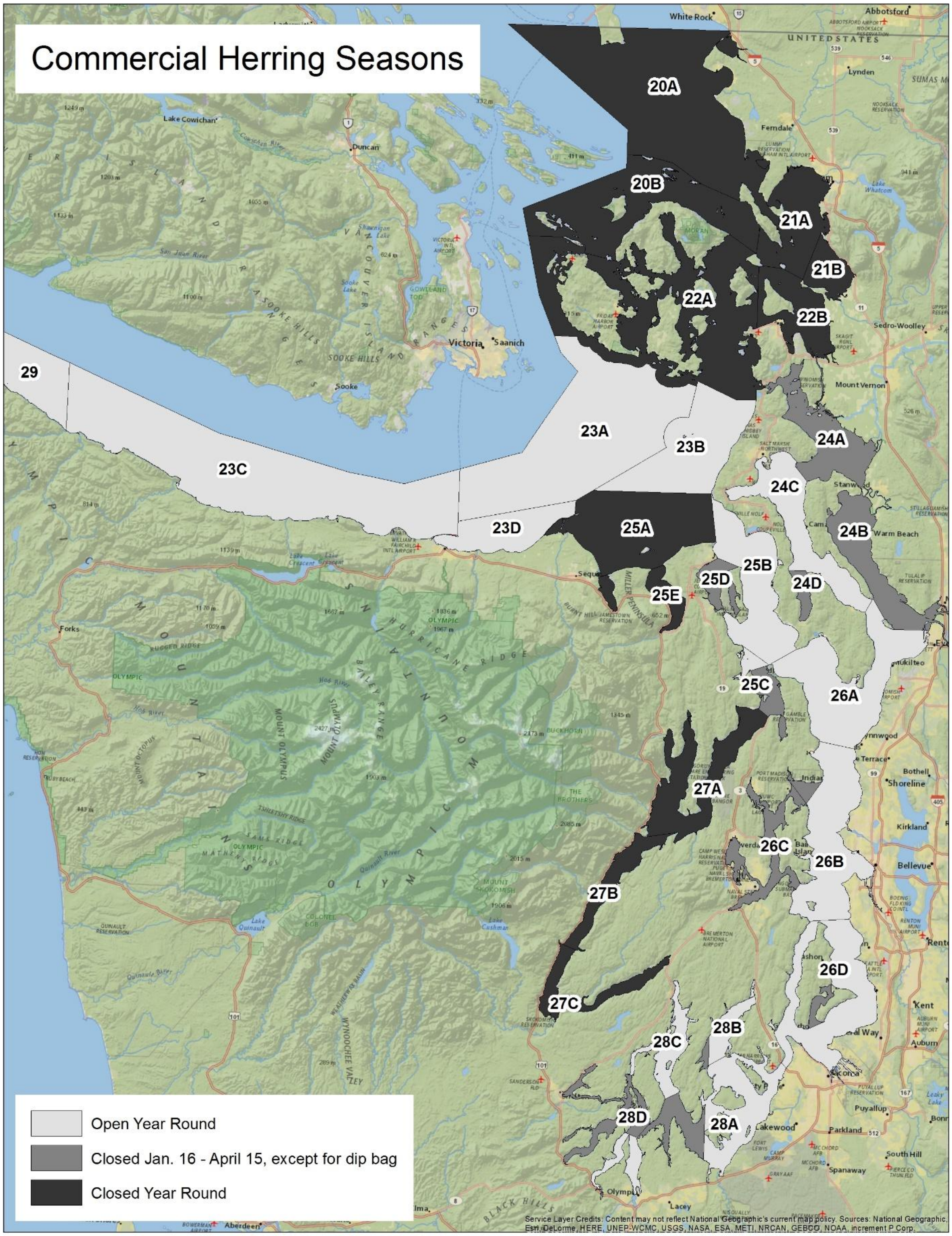


Figure 7: Puget Sound Commercial Herring Areas and Seasons.

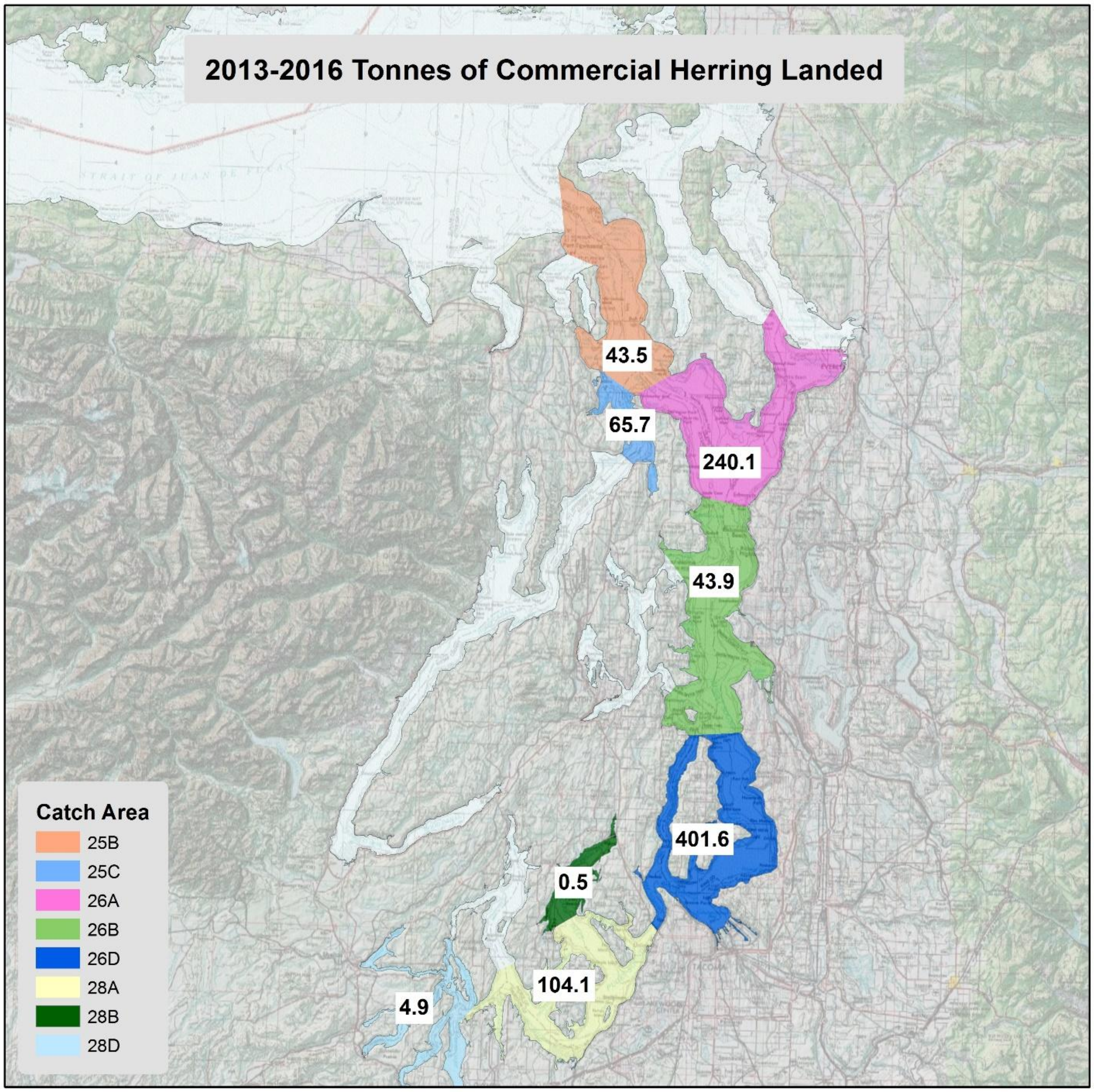


Figure 8: Commercial herring catch in Puget Sound, Washington, 2013-16 by Area.

Natural Mortality

The abundance of herring stocks in the SSS is impacted significantly by variation in mortality rates. Mortality can be attributed to two causes: fishing and natural mortality (all causes other than human harvest).

Adult herring mortality rates of 30-40% are considered typical for herring worldwide (Lemberg et al., 1997). Adult herring mortality and survival was estimated for the Cherry Point stock from 1976-2008. Additional stocks were included in mortality estimates beginning in 1987 when acoustic/trawl survey effort was increased (these surveys ceased in 2009 for most stocks; as a result, mortality rates are no longer estimated). An increase in the annual mortality rate estimate for the Cherry Point herring stock has been repeatedly reported, from a range of 20-40% in the late 1970s to an average of 68% from 1990-2008 (Day 1987; Stick and Lindquist 2009; Landis and Bryant, 2010). The mean estimated annual natural mortality rate for other sampled stocks during that period averaged 72%; again, very high for herring populations. Fishing mortality in the past decade has averaged less than 6% of the total estimated herring spawning biomass.

Significant gene flow among different stocks would affect the accuracy of calculated mortality rates. However, there is no question that there has been a decrease in the mean and median size of sampled adult herring in Puget Sound (Stick et al., 2014). Formal risk assessments of the Cherry Point herring stock cited increased mortality of adults as the primary, but not necessarily entire, cause of this decline (EVS, 1999). A combination of reduced recruitment and non-fishery (natural mortality) related losses of older fish were identified as primary causes of biomass decline (Stout et al., 2001). A study by Shelton et al. (2014) demonstrated high egg mortality (5 to 70%) at five sites across the SSS, with losses attributed to wave height, shoreline armoring and upland development but relatively independent of aquatic vegetation type. The cumulative probability of egg survival at Cherry Point was among the lowest (Ψ=0.001) among the sites tested and was attributed primarily to wave height (Cherry Point is exposed while most other sites are sheltered embayments).

Potential causes of increased natural mortality and a lack of recovery for Cherry Point include pollution, predation, disease, and climatic changes. A brief description of most of these stressors and the potential impact on herring abundance in Puget Sound was included in a previous herring stock status report (Stick and Lindquist, 2009). At present our efforts to understand the factors limiting herring recruitment are hindered by a lack of information on egg-larvae stage survival (anecdotally, egg predation by seabirds appears to be significant), larval-juvenile survival and transport (where do larval herring get swept to by currents, and how does this influence survival?), and overwintering survival of young-of-the-year (Age 0) herring. Each of these stages is likely to encounter considerable mortality.

Contaminant levels in Puget Sound herring may also contribute to mortality. West et al. (2008) examined three persistent organic pollutants (POPs) in herring samples taken from three locations in Puget Sound and three from the Strait of Georgia (U.S. and British Columbia). Herring sampled from South/Central Puget Sound (Squaxin Pass, Quartermaster Harbor, and Port Orchard) were 3 to 9 times more contaminated with polychlorinated biphenyls (PCBs) and 1.5 to 2.5 times more contaminated with dichloro-diphenyl-trichloroethanes (DDTs) than those from the Strait of Georgia (Semiahmoo Bay, Cherry Point, and Denman/Hornby

Island, B.C.). West et al (2008) suggested higher regional sources of POPs, a much smaller drainage area, South Puget Sound's relative isolation from cleaner oceanic waters, and environmental segregation between "Puget Sound" and "Strait of Georgia" herring as causes for the observed differences in contaminant levels.

Although there are no PCB health effects thresholds for Pacific herring, adult herring in central and southern Puget Sound currently exceed a threshold developed for salmon, and PCB levels in herring are not declining (Puget Sound Partnership Toxics in Fish Vital Sign). Additionally, herring embryos have exhibited concentrations of hydrocarbons exceeding health effects thresholds in Puget Sound spawning locations where chronic embryo mortality has been observed (West et al., 2014). Increasing ocean acidification is another factor that could be negatively impacting herring abundance in Washington waters. An increase in the acidity of Puget Sound waters has been documented and is expected to increase in the future (Feeley et al 2010; see also NOAA web page). Its impact on important herring prey, particularly crustaceans such as krill and calanoid copepods, is a matter of ongoing concern.

Though location-specific variation in the intensity of diverse stressors cannot always be rigorously assessed with regard to quantitative effects on the status of specific stocks, operating models of factors affecting herring populations in the entirety of the Salish Sea are currently in development. Together with collaborators from academic (University of Washington, Oregon State University), federal government (NOAA Fisheries, USGS, Canadian Department of Fisheries and Oceans), and tribal entities (Lummi Indian Tribe, Cowichan Tribes, Port Gamble S'Klallam Tribe, Q'ul-lhanumutsun Aquatic Resource Society), and with funding from The Sea Doc Society, the WDFW has undertaken a wide-reaching literature review, data compilation, and data synthesis effort complemented by solicitation of expert opinion from natural resource managers in both Washington and B.C (SSPHAMST, 2018). This information is now being used by collaborators at the University of Washington to formalize a qualitative network model that will allow managers to simulate policy changes that affect stressor intensity in a biologically plausible framework. Ultimately, it is hoped that such simulations may be used to strategically plan management actions that enhance herring survival and reproduction for decades to come. Policy changes of this sort will be noted in future installments of reports in this series, as appropriate.

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Appendix A. Annual southern Salish Sea herring spawning biomass estimates by stock, 1973-2016.

Table of Spawning Biomass Estimates (tonnes)

	South Sound				Central Sound		Hood Canal			Whidbey Basin			Strait of Juan de Fuca			North Sound					
Year	*Squaxin Pass*	Purdy Lagoon	Wollochet Bay	Quarter-master Harbor	Elliott Bay	Port Orchard-Port Madison	South Hood Canal	Quilcene Bay	Port Gamble	Holmes Harbor	Skagit Bay	Port Susan	Kilisut Harbor	Discovery Bay	Dungeness /Sequim Bay	Interior San Juan Islands	NW San Juan Islands	Fidalgo Bay	Samish/ Portage Bay	Semi-ahmoo Bay	*Cherry Point*
1973																					13606
1974																					12667
1975	270					805							253						99	700	9378
1976	1940			1231		406	446	253	1036	114	434		449	632	43	9	142		70	291	10745
1977	18			1282		1223	403	210	2291	122	206			1350	85	16	26		29	575	10067
1978	53			1687				13	1800				230	1184	9						9955
1979	124			1761		1139			1624					800					302		9033
1980	620			1751		1935			2095	71	411		433	2921	343			250	914		8463
1981	700			1612		808			1590				294	2785				414		914	5642
1982				1613		1101	161		1327	71		1262		2137				165	281	1260	4846
1983				825		1498			2184			1268		2339	179			581	144	793	7315
1984				1257		1173			2436			1411		2852	28			673	145	700	5353
1985				605		1284			2165	829		1198		1313	16			690	71	2109	5225
1986				1071		1747			1860			847		1421	212			663	72	1328	5145
1987				838		2302		62	1856		1408	1103		1445			363	805			2820
1988				680		1547			1261		1216	517		774						1783	4017
1989				815		1578			2173	629		313		1111		491			53	1543	3631
1990	513			618		1628			2693	345		264	330	776		355	198			1751	4534
1991	855			526		655	324	185	2049			222	556	839		54	270	979		1870	4195
1992	699			470		285	131		2059			494		660	10	15		1269	238	1362	3637
1993	541			975		276			1380			1536	488	669	0	428		1285	180	1725	4440
1994	204			1281		385			2592			331	265	340				1095	416	1260	5737
1995	142			1815		783		741	2865		808	329		237	260			1064	176	1129	3724
1996	339			730		731	217	298	1867	305	668	100	345	678	163	251	48	535	577	1106	2808
1997	135			1272		327	205	422	1287	481	810	751	279	181	143	27	72	843	462	563	1428
1998	62			859		444	92	1045	881	421	190	1891	282	0	102		97	766	583	834	1199
1999	430			1140		1820	468	2235	1510	159	821	494	728	279	319	179		912	503	787	1148
2000	337		129	674		1593	127	2201	2231	255	586	712	97	144	125	116	82	669	178	840	733
2001	1449		121	1197		1821	170	1897	1614	249	1969	533	555	124	84	198	56	856	426	996	1126
2002	2858		96	377		797	151	2345	1644	520	2009	703	702	134	119	143	119	785	450	918	1207
2003	1997		138	844		984	188	831	965	615	2706	408	406	188	40	65	12	516	271	986	1461
2004	751		47	660		635	160	2125	1140	611	1129	389	167	229	20	61	0	308	318	571	1573
2005	396		61	686		1776	191	1021	1245	452	1060	142	154	30	0	37	0	210	198	789	1823
2006	685		24	895		1916	221	2295	702	1177	2564	291	49	1202	0	259	0	293	374	1158	2010
2007	505		32	400		1442	64	2152	749	519	1121	583	22	38	31	30	0	144	316	1020	1968
2008	930	450	41	445		1076	202	2296	189	622	1217	313	0	225	63	54	0	142	371	601	1227
2009	748	113	86	765		1604	142	2780	965	948	940	229	0	186	42	0	0	14	290	898	1217
2010	463	454	10	130		318	194	1825	393	611	365	138	0	24	68	22	0	93	589	825	702
2011	513	645	19	87		112	142	4031	1328	2724	425	125	0	0	94	0	0	108	351	1456	1180
2012	534	122	28	98	263	197	239	2382	367	615	402	55	0	95	39	5	0	81	390	797	1016
2013	503	236	9	142	194	167	181	1880	248	531	412	26	0	0	64	0		91	629	516	824
2014	357	76	35	40	26	82	102	2810	154	416	267	62	5	5	65	5		200	706	2566	910
2015	294	29	0	50	122	83	256	3717	313	414	259	64	0	11	7	34		73	507	5309	475
2016	236	0	0	0	99	0	226	6496	163	448	44	55	0	221	40	0		5	929	1631	468

[If you would like a digital copy of these data, please email <todd.sandell@dfw.wa.gov>]

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