NOAA Technical Memorandum NMFS-NWFSC-76

Status Review of Cherry Point Pacific Herring *(Clupea pallasii)*

and Updated Status Review of the Georgia Basin Pacific Herring Distinct Population Segment under the Endangered Species Act

June 2006

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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and Updated Status Review of the Georgia Basin Pacific Herring Distinct Population Segment under the Endangered Species Act

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Executive Summary

In 2001 the National Marine Fisheries Service (NMFS) completed a status review of Pacific herring (*Clupea pallasii* Valenciennes, 1847) in Puget Sound under the U.S. Endangered Species Act (ESA). At that time, a Biological Review Team (BRT) concluded that spawning populations of Pacific herring from Puget Sound and the Strait of Georgia constituted the Georgia Basin Pacific herring distinct population segment (DPS), and that this DPS was neither in danger of extinction nor likely to become so in the foreseeable future throughout all or a significant portion of its range.

On 22 January 2004 and 14 May 2004, NMFS received petitions seeking to list Pacific herring that spawn at Cherry Point, Washington (a subset of the Georgia Basin Pacific herring DPS), as a threatened or endangered "species" under the ESA. NMFS evaluated each petition to determine whether the petitioner provided "substantial information" as required by the ESA to list a species. Additionally, NMFS evaluated whether information contained in the petitions might support the identification of a DPS that might warrant listing as a species under the ESA. NMFS determined that the 22 January 2004 petition failed to present substantial scientific and commercial information indicating that the petitioned action may be warranted. However, the agency found that the supplemental information contained in the 14 May 2004 petition did present substantial scientific and commercial information, or cited such information in other sources, that the petitioned action may be warranted and, subsequently, NMFS initiated an updated status review of the Georgia Basin Pacific herring DPS with particular reference to Cherry Point Pacific herring.

The Pacific herring BRT—consisting of scientists from the Northwest Fisheries Science Center, Alaska Fisheries Science Center, and the National Ocean Service—was reformed by NMFS, and the team reviewed and evaluated scientific information compiled by NMFS staff from published literature and unpublished data. Information presented at a public meeting in November 2004 in Seattle, Washington, was also considered. The BRT also reviewed additional information submitted to the ESA Administrative Record.

The BRT was charged with consideration of the following questions:

1. In light of all information, including new information not available at the time of the last status review, does the Cherry Point Pacific herring stock meet the criteria necessary to be considered a DPS as defined by the joint National Oceanic and Atmospheric Administration (NOAA)-U.S. Fish and Wildlife Service (USFWS) DPS policy?
2. If not, what is the DPS that includes the Cherry Point stock?
3. Is the DPS to which the Cherry Point stock belongs in danger of extinction or likely to become so in the foreseeable future throughout all or a significant portion of its range?

In addition, the BRT was asked to consider whether any portion of the identified DPS(s) contribute significantly to the abundance, productivity, distribution, or diversity of the DPS, such that its loss would significantly impair the long-term viability of the DPS. Finally, the BRT was tasked with providing a description of threats to the viability of the identified DPS(s), including (if known) their source(s), severity, geographic scope, and relative contribution to survival risk. However, as was the case in the previous status review, the BRT did not attempt a rigorous analysis of threats and their relative contribution to survival risk. There are several reasons for this.

1. The BRT chose to focus primarily on the question of whether a DPS is at risk rather than how it came to be at risk. Although the latter question is important, a population or DPS that has been reduced to low abundance will continue to be at risk for demographic and genetic reasons until it reaches a larger size, regardless of the reasons for its initial decline. Furthermore, in some cases, a factor that was important in causing the original declines may no longer be an impediment to recovery.
2. Unlike many ESA-listed species that face a single primary threat, Pacific herring face numerous potential threats throughout every stage of their life cycle. It is therefore relatively easy to simply list current and past potential threats to Pacific herring populations, but it is much more difficult to evaluate the relative importance of a wide range of interacting factors.
3. Evaluating the degree to which historic factors for decline will continue to pose a threat in the future generally requires consideration of issues that are more in the realm of social science than biological science—such as whether proposed changes will be funded, and, if funded, will be implemented effectively.

Although this report does not consider threats or factors for decline in a comprehensive way, the BRT did consider major risk factors that were identified in the previous status review and in the petition. Evaluation of conservation measures and making of a final listing recommendation for the DPS to which Cherry Point Pacific herring belongs is the responsibility of the NMFS Northwest Regional Office.

Guidance on what constitutes a distinct population segment is provided by the joint NMFS-USFWS interagency policy on vertebrate populations. To be considered "distinct," a population, or group of populations, must be "discrete" from the remainder of the species to which it belongs, and "significant" to the species to which it belongs as a whole. Discreteness and significance are further defined by the services in the following policy language (USFWS-NMFS 1996, p. 4725).

> Discreteness: A population segment of a vertebrate species may be considered discrete if it satisfies either one of the following conditions:
>
> 1. It is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors. Quantitative measures of genetic or morphological discontinuity may provide evidence of this separation.
> 2. It is delimited by international governmental boundaries within which differences in control of exploitation, management of habitat, conservation status, or regulatory mechanisms exist that are significant in light of section 4(a)(1)(D) of the Act.

Significance: If a population segment is considered discrete under one or more of the above conditions, its biological and ecological significance will then be considered in light of Congressional guidance (see Senate Report 151, 96th Congress, 1st Session) that the authority to list DPSs be used "sparingly" while encouraging the conservation of genetic diversity. In carrying out this examination, the Services will consider available scientific evidence of the discrete population segment's importance to the taxon to which it belongs. This consideration may include, but is not limited to, the following:

1. Persistence of the discrete population segment in an ecological setting unusual or unique for the taxon,
2. Evidence that loss of the discrete population segment would result in a significant gap in the range of a taxon,
3. Evidence that the discrete population segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historic range, or
4. Evidence that the discrete population segment differs markedly from other populations of the species in its genetic characteristics.

After consideration of the all available scientific data, the Pacific herring BRT concluded, nearly unanimously, that Cherry Point Pacific herring were "discrete" under the provisions of the joint NMFS-USFWS DPS policy. However, there was no support on the BRT for a finding that Cherry Point Pacific herring were "significant" to the taxon of Pacific herring as a whole, as defined in the joint NMFS-USFWS DPS policy. The BRT identified a variety of evidence to support its conclusion that Cherry Point Pacific herring are a discrete population, including locally unique spawn timing, occupation of a locally unusual exposed coastline for spawning, and physiological factors such as unusual growth rate characteristics for the locality and differential accumulation of toxic contaminants in relation to other local Puget Sound Pacific herring populations indicative of disparate rearing conditions compared to Pacific herring in Puget Sound proper. In regards to the significance question, the BRT noted that Pacific herring are widely distributed across the North Pacific Rim and have a large number of stocks distributed throughout their extensive range. The BRT also recognized that the occurrence of other Pacific herring stocks with unusual spawn timing for their area was not exceptional, and that other Pacific herring stocks also spawn on fairly exposed coastlines of inshore waters in the Pacific Northwest that can be subject to high-energy wave action. The previous Pacific herring BRT discussed the significance of the Cherry Point Pacific herring stock with respect to the taxon to which it belongs (i.e., the whole biological species, *Clupea pallasii*) and came to a similar finding as reported in the previous status review.

The BRT considered up to seven possible DPS configurations that might conceivably incorporate the petitioned population (Cherry Point Pacific herring). A majority of the BRT supported retention of the current Georgia Basin Pacific herring DPS, as described in the previous status review. Although there was significant support on the BRT for a larger DPS than Georgia Basin, the BRT as a whole did not feel compelled by the evidence to enlarge the boundaries of the present DPS. The BRT determined that the Cherry Point Pacific herring population is part of the previously defined Georgia Basin Pacific herring DPS, which includes the marine waters of Puget Sound, the Strait of Georgia, and eastern Juan de Fuca Strait in both the U.S. and Canada.

Available information (genetics, life history, tagging studies) suggests that population structure of Pacific herring roughly conforms to the classical concept of a metapopulation, in which local subpopulations are linked demographically by at least episodic migration, and extinction and recolonization of local subpopulations are common over ecological time frames. Available information also suggests that the Georgia Basin DPS of Pacific herring does not differ substantially in general features of biology from Pacific herring in other areas. Therefore, the BRT concluded that, as a reasonable approximation, the classical metapopulation model provides a framework for assessing extinction risk of the DPS. In order to explicitly address the "significant portion of its range question," the BRT addressed the question, "Are subpopulation declines more pervasive and more pronounced than we would expect to find in a healthy metapopulation?" To evaluate this question, the BRT considered trends in eight different areas of the DPS, roughly defined on the basis of geography, life history, and genetics (Cherry Point, Squaxin Pass, South/Central Puget Sound, Strait of Juan de Fuca, Bute Inlet, Eastern Strait of Georgia [SOG] Inlets, Northern SOG, and North Puget Sound plus Southern SOG). Overall abundance is declining within some of these areas and increasing in others. These patterns of abundance and distribution within the Georgia Basin DPS appeared to be fairly typical of what is seen in other Pacific herring populations throughout northwestern North America, including many relatively pristine areas in southeastern Alaska and British Columbia.

However, the BRT also identified reasons for concern about some local subpopulations within the DPS and some potential future developments that would increase risks to the DPS. First, metapopulation theory indicates that in source-sink systems the existence of sinks can buffer extinction risk of the entire metapopulation, compared to a scenario in which the sink areas cease to function at all. Second, the BRT recognized that the classical metapopulation concept does not perfectly fit the Georgia Basin Pacific herring DPS. The pattern of subpopulation structure in the DPS is more similar to the mixed structure metapopulation model than to a classical metapopulation. Although the DPS is characterized by high levels of homogeneity, the Cherry Point population and some subpopulations such as Squaxin Pass are relatively more distinctive, based on spawn timing, growth rate, contaminant profiles, and genetic differences. And as noted above, the BRT concluded that Cherry Point Pacific herring meets the DPS criteria to be considered a "discrete" population. These differences were not considered of a magnitude suggestive of long-term evolutionary divergence, but it was considered possible that demographic linkages between these and other subpopulations in the DPS are weak enough that they are largely demographically independent on ecological time scales. If these subpopulations were lost, recolonization might take longer than it would for areas that are part of a classical metapopulation. Still, the BRT did not feel that current risks to these areas represent risks to a significant portion of the range of the DPS as a whole. Furthermore, overall abundance of the DPS is at historically high levels, and the number of kilometers of coastline used by Pacific herring for spawning has also been increasing. The BRT concluded that available evidence does not suggest unusual levels of risk to the DPS as a whole, nor to a significant part of the DPS. Therefore, the BRT concluded that the DPS is not at risk of extinction in all or a significant portion of its range, nor likely to become so in the foreseeable future. The approaches and conclusions taken by the BRT are consistent with previous NMFS status reviews, including the extensive reviews of Pacific salmon along the west coast of North America.

Finally, the BRT noted that Pacific herring play important roles in the Georgia Basin ecosystem. If the fundamental biological processes necessary for Pacific herring were to be disrupted in the future, such that the metapopulation ceased to function effectively, the consequences for other species could be substantial. Although these consequences are difficult to predict, it is worth noting that Pacific herring are important forage fish for both Pacific salmon (*Oncorhynchus* spp.) and killer whales (*Orcinus orca*), so collapse of the Pacific herring DPS could have serious negative effects on these other protected species.

Acknowledgments

The status review for Cherry Point Pacific herring was conducted by a team of scientists from the Northwest Fisheries Science Center (NWFSC), Alaska Fisheries Science Center (AFSC), and the National Ocean Service (NOS). This biological review team (BRT) relied on comments and informational reports submitted by the public and by state, tribal, and federal agencies. The authors acknowledge the efforts of all who contributed to this record, especially the Washington Department of Fish and Wildlife (WDFW) and Department of Fisheries and Oceans Canada (DFO).

Numerous individual fishery scientists and managers provided information that aided in preparation of this document and deserve special thanks. We particularly wish to thank Drs. Jake Schweigert and Doug Hay of DFO, Pacific Biological Station, and Kurt Stick, Dr. Maureen Small, and Greg Bargmann of WDFW for updated information, data, opinions, and advice. We also wish to thank three anonymous scientists whose peer review of this document provided added clarity.

Introduction

In 2001 the National Marine Fisheries Service (NMFS) completed a status review (Stout et al. 2001a) of Pacific herring (*Clupea pallasii* Valenciennes, 1847)[1] in response to a petition (Wright 1999) seeking to list 18 species of marine fishes, including Pacific herring, in Puget Sound under the U.S. Endangered Species Act (ESA). Following acceptance of the 1999 petition (NMFS 1999), NMFS formed a Pacific herring Biological Review Team (BRT), consisting of scientists from the Northwest Fisheries Science Center, Alaska Fisheries Science Center (AFSC), National Ocean Service (NOS), and the U.S. Fish and Wildlife Service (USFWS) to determine whether Pacific herring in Puget Sound is a "species" under the ESA and, if so, whether the "species" is in danger of extinction (endangered) or likely to become so (threatened). Importantly, for vertebrates the ESA allows listing not only of species and subspecies, but also of distinct population segments (DPSs—see detailed discussion in The "Species" Question subsection on page 3). In 2001, the Pacific herring BRT concluded that spawning populations of Pacific herring from Puget Sound (including Cherry Point), the Strait of Georgia (SOG), and the Strait of Juan de Fuca in the U.S. and Canada constitute a Georgia Basin Pacific herring DPS (Stout et al. 2001a). In 2001, the Pacific herring BRT also concluded that the Georgia Basin DPS, containing the petitioned Puget Sound Pacific herring populations, was neither in danger of extinction nor likely to become so in the foreseeable future throughout all or a significant portion of its range (Stout et al. 2001a, NMFS 2001).

On 22 January 2004 and 14 May 2004, NMFS received petitions seeking to list Pacific herring that spawn at Cherry Point, Washington, as a threatened or endangered species under the ESA. NMFS evaluated each petition to determine whether the petitioner provided substantial information as required by the ESA to list a species. The agency also reviewed other readily available information and consulted with state and tribal biologists to determine whether general agreement existed on the uniqueness, distribution, abundance, and threats to the petitioned stock. Additionally, NMFS evaluated whether available information might support the identification of a distinct population segment that might warrant listing as a species under the ESA. NMFS determined that the 22 January 2004 petition failed to present substantial scientific and commercial information indicating that the petitioned action may be warranted. However, the agency found that the supplemental information contained in the 14 May 2004 petition did present substantial scientific and commercial information, or cited such information in other sources, that the petitioned action may be warranted (NMFS 2004) and subsequently, NMFS initiated an updated status review of the Georgia Basin Pacific herring DPS with particular reference to Cherry Point Pacific herring.

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[1] Following Nelson et al. (2004), the specific name for Pacific herring is herein spelled *–ii*, the original spelling.

Scope and Intent of Present Document

In order to meet the provision in the ESA that listing determinations be made with the best available scientific and commercial information, NMFS formed a team of scientists with diverse backgrounds in marine fish biology and marine habitats to conduct this review. This reconstituted Pacific herring Biological Review Team (BRT)[2] reviewed and evaluated scientific information compiled by NMFS's staff from published literature and unpublished data. Information presented at a public meeting in November 2004 in Seattle, Washington, was also considered. The BRT also reviewed additional information submitted to the ESA Administrative Record.

The BRT was charged with consideration of the following questions in helping NMFS address whether Cherry Point Pacific herring is a DPS and whether the DPS containing Cherry Point Pacific herring is at risk of extinction throughout all or a significant portion of its range.

1. In light of all information, including new information not available at the time of the last status review, does the Cherry Point Pacific herring stock meet the criteria necessary to be considered a DPS as defined by the joint NOAA-USFWS DPS policy (explained in The "Species" Question subsection on page 3)?
2. If not, what is the DPS that includes the Cherry Point stock?
3. Is the DPS to which the Cherry Point stock belongs in danger of extinction or likely to become so in the foreseeable future throughout all or a significant portion of its range?

In order to explicitly address the question of whether the DPS containing the Cherry Point population was threatened or endangered in a significant portion of its range, the BRT was also asked to consider whether any portion of the identified DPS that contains Cherry Point Pacific herring contribute significantly to the abundance, productivity, distribution, or diversity of the DPS, such that its loss would significantly impair the long-term viability of the DPS. In addition the BRT was tasked with providing a description of threats to the viability of the identified DPS that contains Cherry Point Pacific herring, including (if known) their source(s), severity, geographic scope, and relative contribution to survival risk.

Key Questions in ESA Evaluations

Two key questions must be addressed in determining whether a listing under the ESA is warranted: First, is the entity in question a species as defined by the ESA? Second, if so, is the species in danger of extinction (endangered) or likely to become so (threatened)? This document provides the conclusions of the BRT regarding both the identification of a Pacific herring DPS that incorporates Cherry Point Pacific herring and the risk of extinction to that DPS.

[2] The BRT for Cherry Point Pacific herring consisted of the following members: Dr. Tracy Collier, Jonathan Drake, Dr. Michael Ford, Kurt Fresh, Dr. Richard Gustafson, Dr. Richard Methot, Dr. James Myers, Heather Stout, Donald Van Doornik, and Dr. Robin Waples from NWFSC; Mark Carls from AFSC; and Dr. Alan Mearns from NOS.

The "Species" Question

As amended in 1978, the ESA allows listing of distinct population segments of vertebrates as well as named species and subspecies. Guidance on what constitutes a distinct population segment is provided by the joint USFWS-NMFS interagency policy on vertebrate populations (USFWS-NMFS 1996). This policy states that to be considered "distinct," a population, or group of populations, must be "discrete" from the remainder of the species to which it belongs, and "significant" to the species to which it belongs as a whole. Discreteness and significance are further defined by the services in the following policy language (USFWS-NMFS 1996, p. 4725).

> Discreteness: A population segment of a vertebrate species may be considered discrete if it satisfies either one of the following conditions:
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> 1. It is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors. Quantitative measures of genetic or morphological discontinuity may provide evidence of this separation.
> 2. It is delimited by international governmental boundaries within which differences in control of exploitation, management of habitat, conservation status, or regulatory mechanisms exist that are significant in light of section 4(a)(1)(D) of the Act.
>
> Significance: If a population segment is considered discrete under one or more of the above conditions, its biological and ecological significance will then be considered in light of Congressional guidance (see Senate Report 151, 96th Congress, 1st Session) that the authority to list DPS's be used "sparingly" while encouraging the conservation of genetic diversity. In carrying out this examination, the Services will consider available scientific evidence of the discrete population segment's importance to the taxon to which it belongs. This consideration may include, but is not limited to, the following:
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> 1. Persistence of the discrete population segment in an ecological setting unusual or unique for the taxon,
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> 3. Evidence that the discrete population segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historic range, or
> 4. Evidence that the discrete population segment differs markedly from other populations of the species in its genetic characteristics

This joint USFWS-NMFS policy applies to all vertebrate species, and does not elaborate on the specific manner in which the information related to DPS status should be analyzed. NMFS has developed a policy on the kinds of evidence that can be considered to evaluate distinctiveness of populations in Pacific salmon species (*Oncorhynchus* spp.) (Waples 1991a, 1991b, 1995), and similar kinds of evidence can be used to assess distinctiveness of populations or groups of populations of marine fishes. This Pacific salmon policy (Waples 1991a, 1991b, 1995) advocates a holistic approach in which all available information is considered, as well as a consideration of the strengths and limitations of such information in delineating distinct population segments. Important information includes natural rates of migration and recolonization, evaluations of the efficacy of natural barriers to migration, and measurements of genetic differences between populations. Data from protein electrophoresis and DNA analyses can be particularly useful for determining distinctiveness, because gene frequency differences among populations may reflect limited gene flow between areas.

The joint USFWS-NMFS policy states that international boundaries within the geographical range of the species may be used to delimit a distinct population segment in the United States. This criterion is applicable if differences in the control of exploitation of the species, the management of the species' habitat, the conservation status of the species, or regulatory mechanisms differ between countries that would influence the conservation status of the population segment in the United States. However, in past assessments of evolutionarily significant units (ESUs) in Pacific salmon and DPSs in marine fish, NMFS has placed the emphasis on biological information in defining DPSs and has considered political boundaries only at the implementation of ESA listings. Therefore, the BRT focused on biological information in identifying DPSs of Pacific herring, regardless of political boundaries.

Extinction Risk

The ESA (Section 3) defines the term endangered species as "any species which is in danger of extinction throughout all or a significant portion of its range." The term threatened species is defined in the same section of the ESA as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." The ESA states that a variety of information should be used in evaluating the level of risk faced by a species or a DPS, including:

1) The present or threatened destruction, modification, or curtailment of its habitat or range,
2) Overutilization for commercial, recreational, scientific, or educational purposes,
3) Disease or predation,
4) The inadequacy of existing regulatory mechanisms, and
5) Other natural or man-made factors affecting its continued existence.

According to the ESA, the determination of whether a species is threatened or endangered should be made on the basis of the best scientific information available on its current status, after taking into consideration conservation measures that are proposed or are in place.

Summary of Information Presented by the Petitioners

On 22 January 2004, NMFS received a petition from the Center for Biological Diversity and copetitioners (Center for Biological Diversity et al. 2004) to designate the Cherry Point Pacific herring stock as a DPS and list it as a threatened or endangered species and to designate critical habitat under the ESA. On 14 May 2004, the same petitioners submitted additional scientific information (Werntz 2004) regarding the stock structure of the Cherry Point and other Pacific Northwest Pacific herring stocks. NMFS treated the two submissions as separate petitions and evaluated each one to determine whether they presented substantial scientific or commercial information indicating that the petitioned actions may be warranted. Section 424.14(b)(1) of NMFS ESA implementation regulations defines "substantial information" as the amount of information that would lead a reasonable person to believe that the measure proposed in the petition may be warranted. Section 424.14(b)(2) of these regulations lists factors to be considered in evaluating the petition, including whether the petition contains detailed narrative justification for the recommended measure, a description of past and present numbers of geographical distributions of the species, and a description of threats facing the species.

NMFS found that the 22 January 2004 petition failed to present substantial scientific and commercial information indicating that the petitioned action was warranted. However, NMFS found that the 14 May 2004 petition did present substantial scientific and commercial information indicating that the petitioned action may be warranted. Information presented in either petition that is deemed pertinent to the DPS questions of discreteness and significance and to the extinction risk question will be summarized herein.

The majority of the physical, physiological, ecological, and behavioral evidence for separation of Cherry Point Pacific herring from other populations, as cited by the petitioners, was considered by the BRT at the time of the previous status review of Puget Sound Pacific herring (Stout et al. 2001a). Pertinent data and studies cited by the petitioners that was not available at the time of the previous status review included: 1) microsatellite DNA information in Beacham et al. (2001), 2) microsatellite DNA information in Small et al. (2004), 3) a stable isotope study of Pacific herring otoliths (Gao et al. 2001), 4) spawner biomass estimates for Cherry Point Pacific herring from 2001 to 2004, and 5) citation of various oral presentations that occurred at the 2002 Herring Summit and Pacific Coast Herring Workshop held in Bellingham, Washington.

The DPS Question: Summary of Evidence for "Discreteness"

The petitioners argued that the Cherry Point Pacific herring stock should be considered discrete due to "unique genetic characteristics, physiology, diet and spawning behavior, and other factors" (Center for Biological Diversity et al. 2004, p. 29) that indicate it is markedly separated from other Pacific herring stocks. In particular, the petitioners claimed that recent microsatellite DNA studies cited as Beacham et al. (2001), Beacham (2002), and Small et al. (2004) show Cherry Point Pacific herring to be genetically distinct from other Pacific herring stocks in the Puget Sound and Strait of Georgia. In addition, the petitioners cited Gao et al. (2001) as evidence of marked physiological separation of the Cherry Point stock. Gao et al. (2001) analyzed oxygen and carbon isotope ratios in otoliths (ear bones) from spawning Pacific herring collected at Cherry Point, and at Port Orchard and Squaxin Pass in south Puget Sound. The petitioners agued that the Gao et al. (2001) study indicates that early rearing of Cherry Point Pacific herring occurs in a different environment than other Puget Sound Pacific herring populations and that young Cherry Point Pacific herring remain in estuarine environments and do not migrate offshore. The petitioners also argued that the Cherry Point stock is markedly separated from other Pacific herring by a higher average infection rate with certain parasites compared to other stocks of Pacific herring; by a juvenile diet that may differ from other Puget Sound stocks; by the physical separation of its "spawning grounds" (Center for Biological

Diversity et al. 2004, p. 29) from other Pacific herring; by its ability to spawn in a relatively open, high-energy shoreline habitat; and by its late spawning period (early April to early June), relative to other Pacific herring in Puget Sound that spawn in protected waters from mid-January to mid-April.

The DPS Question: Summary of Evidence for "Significance"

The petitioners argued that the Washington Department of Fish and Wildlife (WDFW) Cherry Point Pacific herring stock is significant to the species as a whole based on its persistence in an ecological setting that is unusual and unique to Pacific herring, on its genetic differentiation from other populations as reported in Beacham et al. (2001) and Small et al. (2004), and by its reported significance to the health and function of the Puget Sound ecosystem. The petitioners further argued that the distinctly different spawn timing of Cherry Point Pacific herring, which leads to different relationships with prey and predators, indicates the presence of characteristics that may be "essential for continued evolution and survival of the Pacific herring species" (Center for Biological Diversity et al. 2004, p. 34).

Summary of Abundance and Population Trends

The petitioners cited historical abundance data for the Cherry Point Pacific herring stock from 1973 to 2000 that indicated a decline of 94% in the stock biomass, from a high of almost 15,000 to a low of 800 short tons. The petitioners also presented three years of population abundance data (2001–2003) for Cherry Point Pacific herring that has appeared since the previous status review. The population has shown an increasing trend over these three years, with the 2003 spawner biomass estimate of 1,611 short tons reaching its highest level since 1996. The petitioners also pointed out that WDFW sets the number of spawners that they feel necessary for the population to replace itself and sustain a harvest at 3,200 short tons, approximately twice the current abundance level. The petitioners acknowledged that the recent increase in abundance may be "in response to the increased ocean productivity associated with the Pacific Decadal Oscillation (PDO)" (Center for Biological Diversity et al. 2004, p. 9).

The petitioners cited Bargmann (2001) for evidence that recent recruitment of Cherry Point Pacific herring into the spawning population has been below average (1,000 tons versus an average of 2,000 tons), although recruitment from the 2000 broodyear "was quite effective" (Center for Biological Diversity et al. 2004, p. 10). The petitioners argued that a "recruitment class failure" (Center for Biological Diversity et al. 2004, p. 10) could result in a precipitous decline in Cherry Point Pacific herring abundance.

Summary of Risk Factors

Major concerns of the petitioners included 1) reduction and degradation of Cherry Point Pacific herring habitat by industrial development and pollution, 2) compression of the age structure, and 3) increased depensatory mortality due to increased predation and fishing pressure on smaller schools. The petitioners in particular highlighted threats to Cherry Point Pacific herring from industrial activity near the spawning beaches. The petitioners' list of industrial activities included dock construction and operation, outfall discharge, increased vessel traffic, accidental oil spills, noise pollution, introduction of nonindigenous aquatic species resulting from ballast water discharge, and release of biocides that are often used to treat ballast water prior to discharge.

Summary of New Information Sources—Not Included in the Petition

Numerous studies that were not cited by the petitioners and that were not available at the time of the previous status review were consulted. These included 1) published scientific literature (Hay et al. 2001a, Hay and McKinnell 2002) and fisheries agency reports (Schweigert and Flostrand 2000, Flostrand and Schweigert 2002, 2003, 2004) summarizing results of Pacific herring tagging operations in British Columbia; 2) a series of four fisheries agency reports summarizing the metapopulation structure of British Columbia Pacific herring (Ware et al. 2000, Ware and Schweigert 2001, 2002, Ware and Tovey 2004); 3) an updated version of Beacham's microsatellite DNA study of population structure of British Columbia Pacific herring (Beacham et al. 2002); 4) a series of two peer-reviewed (Hart Hayes and Landis 2004, Landis et al. 2004) and two nonpeer-reviewed (Landis et al. 2000, Markiewicz et al. 2001) risk assessments of the Cherry Point Pacific herring stock; 5) an independent assessment of the Strait of Georgia Pacific herring roe fishery (Wallace and Glavin 2003); 6) a series of annual qualitative surveys of the Cherry Point shoreline (Kyte 1999, 2000, 2001, 2002, 2003, 2004); 7) a study documenting an increased incidence of a protistan parasite in older Puget Sound Pacific herring (Hershberger et al. 2002); and 8) a series of fisheries agency annual stock assessments of British Columbia Pacific herring (Schweigert 2001, 2002, 2004).

Approaches to the Species Question

The BRT considered several kinds of information to attempt to delineate DPSs of Pacific herring. The first kind of information considered was geographical variability in life history characteristics and morphology. Such traits usually have an underlying genetic basis, but are often strongly influenced by environmental factors from one locality to another. Information related to this category included patterns of marine species' distribution (zoogeography) that may indicate changes in the physical environment that are shared with the species under review. The second kind of information consisted of tag and recapture studies, which give insight into the physical movement of individuals between areas. The third kind of information consisted of traits that are inherited in a predictable way and remain unchanged throughout the life of an individual. Differences among populations in the frequencies of markers at these traits may reflect isolation between the populations. In all studies of population structure, investigators should strive to compare data gathered from spawning aggregations of fish to avoid the potential for sampling from stock or population mixtures. The analyses of the above types of information are discussed briefly in the following sections.

Life History and Morphology

Isolation between populations may be reflected in several variables, including differences in life history variables (e.g., spawning timing, seasonal migrations), spawning location, parasite incidence, growth rates, morphological variability (e.g., morphometric and meristic traits), and demography (e.g., fecundity, age structure, length and age at maturity, mortality), among others. Although some of these traits may have a genetic basis, they are usually also strongly influenced by environmental factors over the lifetime of an individual or over a few generations. Differences can arise among populations in response to environmental variability among areas and can sometimes be used to infer the degree of independence among populations or subpopulations. Begg et al. (1999) have emphasized the necessity to examine the temporal stability of life history characteristics in order to determine whether differences between populations persist across generations. Many life history differences are often not correlated with variation at neutral molecular genetic markers, either indicating that they are environmentally influenced, or that patterns of genetic adaptation differ from patterns of gene flow and drift that are the primary factors influencing neutral molecular markers.

The analysis of applied or acquired tags can indicate the degree of migration between localities. These tags include physical tags that are attached to a fish and later recovered, parasites that are characteristic of specific regions because of differential resistance or occurrence, and elemental profiles that reflect local environmental conditions or diets. These tags provide evidence of movement of individuals from one place to another, but not necessarily of population connectivity through gene flow. Because these kinds of population markers are not inherited, they must be applied each generation or must arise naturally anew each generation.

Marine Zoogeographic Provinces

Ekman (1953), Hedgpeth (1957), Briggs (1974), and Allen and Smith (1988) summarized the distribution patterns of coastal marine fishes and invertebrates and defined major worldwide zoogeographic zones or provinces. The coastal region from Puget Sound to Sitka, Alaska, was considered a transition zone and could be classified as part of either of two provinces recognized by Briggs (1974): Aleutian or Oregonian. The southern boundary of the Oregonian Province is generally recognized as Point Conception, California, and the northern boundary of the Aleutian Province is similarly recognized as either Nunivak or the Aleutian Islands (Allen and Smith 1988). Briggs (1974) placed the boundary between the Oregonian and Aleutian Provinces at Dixon Entrance in southern Southeast Alaska, based on the well-studied distribution of mollusks, but indicated that distributions of fishes, echinoderms, and algae gave evidence for placement of this boundary in the vicinity of Sitka, Alaska. Peden and Wilson (1976) investigated the distributions of inshore fishes in British Columbia and found Dixon Entrance to be of minor importance as a barrier to fish distribution. A more likely boundary between these faunas was suggested to occur near either Sitka, Alaska, or Cape Flattery, Washington (Peden and Wilson 1976, Allen and Smith 1988).

Genetic Methods

Differences in life history traits among populations may provide little information on reproductive isolation between populations, because the genetic basis of many phenotypic and life history traits is unknown. The BRT also considered molecular genetic evidence that might be used to define reproductively isolated populations or groups of populations of fish in Puget Sound. Most molecular genetic markers appear to be largely unaffected by natural selection, so that geographical differences in gene frequencies can be interpreted in terms of gene flow and genetic drift. The analysis of the geographical distributions of these markers may reveal historical dispersals, equilibrium levels of migration (gene flow), and past isolation. Commonly, evidence for genetic population structure is based on the analysis of protein variants (allozymes), microsatellite loci (variable numbers of short tandem DNA repeats), and mitochondrial DNA (mtDNA).

Herring and the Metapopulation Concept

A metapopulation was defined by Levins (1970, p. 105) as:

> a population of populations which go extinct locally and recolonize. A region is suitable for a metapopulation if the mean extinction rate is less than the migration rate.

As envisioned by Levins (1969, 1970), two of the central characteristics of a metapopulation were that local subpopulations are linked by migration and are subject to periodic extinction (extirpation) and recolonization. Consequently, not all suitable habitats would be simultaneously occupied. Levins' ideal metapopulation included the assumptions that subpopulations have independent dynamics, that the exchange rate between subpopulations is so low that it has no affect on local subpopulation dynamics, and that all habitat patches have equal isolation and equal area (Levins 1970). In practice, most of Levins' assumptions have been relaxed and no real metapopulation has been identified that satisfies all these criteria (Hanski and Simberloff 1997).

Hanski and Simberloff (1997) have emphasized that local subpopulations within a metapopulation are spatially structured and migration among the subpopulations has some effect on local subpopulation dynamics. Harrison and Taylor (1997) noted that the underlying concept in the many refinements to Levins' metapopulation model is that "persistence of species depends on their existence as sets of local populations, largely independent yet interconnected by migration" (Harrison and Taylor 1997, p. 27). Kritzer and Sale (2004) advocated that linkage of local- and regional-scale population processes beyond extinction-recolonization analysis can be considered under the metapopulation concept for marine fishes. Kritzer and Sale (2004) argued that "the critical feature of metapopulations is the coupling of spatial scales, whereby local populations experience partially independent dynamics but receive some identifiable demographic influence from other populations" (Kritzer and Sale 2004, p. 138).

Under the metapopulation concept of Atlantic herring (*Clupea harengus*) population structure proposed by McQuinn (1997), local Atlantic herring populations may be perpetuated through a process he termed the "adopted-migrant hypothesis" (McQuinn 1997, p. 298), where juvenile Atlantic herring that associate with and synchronize their maturation with schools of adult Atlantic herring will adopt the migration and homing patterns of the adults. Thus local spawning populations are maintained by "repeat rather than natal homing to spawning areas, while local population persistence is ensured through the social transmission of migration patterns and spawning areas from adults to recruiting individuals" (McQuinn 1997, p. 298). In McQuinn's (1997) adopted-migrant hypothesis, hydrographic forces on larvae and the effects of schooling of juveniles leads to the majority of individuals spawning in their native population. Thus differences in the mean values of meristic and morphometric measurements that reflect environmental differences during development are maintained, although strays from other populations are adopted by local populations and gene flow is significant (McQuinn 1997). McQuinn (1997) stated that the adopted-migrant hypothesis is consistent with genetic studies on Atlantic herring that have not observed temporally persistent differences, since no genetic differences would be expected between Atlantic herring populations with the hypothesized level of gene flow. Although McQuinn's (1997) metapopulation concept and adopted-migrant hypothesis were first formulated for Atlantic herring, they have equal application in the case of Pacific herring. Along these lines, Ware and co-authors (Ware et al. 2000, Ware and Schweigert 2001, 2002, Ware and Tovey 2004) have provided evidence indicating that the major migratory stocks of Pacific herring in British Columbia "are spatially structured and interact as a metapopulation" (Ware and Tovey 2004, p. 1). Dispersal rate and straying in both Atlantic (Huse et al. 2002) and Pacific herring (Ware and Schweigert 2002) appear to be density dependent and increase with abundant recruitment, resulting in periodic waves of dispersal that radiate throughout the metapopulation.

Evidence supporting the hypothesis that the five major migratory stocks of British Columbia Pacific herring form a spatially structured metapopulation include: 1) the spatially fragmented distribution of spawning habitat (Hay et al. 1989, Ware et al. 2000, Hay and McCarter 2004a), 2) evidence of disappearance and recolonization events (Ware and Tovey 2004), 3) evidence of significant migration (straying) between the five main stock assessment regions as indicated by tagging data (Hay et al. 1999, 2001a, Ware et al. 2000), and 4) high levels of gene flow as shown by DNA microsatellite analyses (Beacham et al. 2001, 2002). Smedbol et al. (2002) proposed that to be considered a metapopulation a system must meet the following two criteria: 1) local populations must be shown to exchange low levels of individuals, and 2) extinction and recolonization must be documented. Both of these metapopulation criteria have been met for Georgia Basin Pacific herring. Many authors (McQuinn 1997, Ware et al. 2000, Smedbol et al. 2002, Smedbol and Wroblewski 2002) have emphasized that local subpopulations should be considered the basic fisheries management units and that conservation of subpopulation structure is essential for the preservation of spawning potential and genetic and life history diversity.

DPS Determination for Cherry Point Pacific Herring

BRT DPS Deliberations Process

Extensive documentation of Pacific herring life history information and environmental features of Puget Sound and the Strait of Georgia considered relevant to the DPS discreteness and significance questions were presented in the previous Pacific herring status review (Stout et al. 2001a). This information included detailed reviews of Pacific herring spawn location, spawn timing, results of tagging experiments, seasonal migration patterns, larval retention areas, parasite incidence, growth rate, size-at-age, age structure, age-at-maturity, and morphological differentiation throughout the species range across the North Pacific Rim from San Diego, California to the Yellow Sea in Asia. Rather than duplicate this information, the following discussions will emphasize detailed information specifically relevant to the discreteness and significance decisions for Cherry Point Pacific herring.

BRT Determinations of ESA Discreteness and Significance

The BRT was nearly unanimous in its conclusion that Cherry Point Pacific herring represent a discrete population under the language of the joint USFWS-NMFS DPS policy. A small minority of the BRT concluded that Cherry Point Pacific herring are not discrete from the remainder of the species. The BRT identified a variety of evidence to support its conclusion that Cherry Point Pacific herring are a discrete population, including locally unique spawn timing, occupation of a locally unusual exposed coastline for spawning, and physiological factors such as unusual growth rate characteristics for the locality and differential accumulation of toxic contaminants in relation to other local Puget Sound Pacific herring populations indicative of disparate rearing conditions compared to Pacific herring in Puget Sound proper.[3]

Although the BRT determined that Cherry Point Pacific herring represent a discrete population, there was no support on the BRT for Cherry Point Pacific herring to be considered significant to the taxon as a whole, as defined in the joint USFWS-NMFS DPS policy. The previous Pacific herring BRT discussed the significance of the Cherry Point Pacific herring stock with respect to the taxon to which it belongs (i.e., the whole biological species, *Clupea pallasii*) and came to a similar finding as reported in the previous status review (Stout et al. 2001a).

In accordance with the joint USFWS-NMFS DPS policy (USFWS-NMFS 1996), considerations that can be used to determine a discrete population's significance to the taxon as a whole include 1) persistence of the population segment in an ecological setting unusual or unique

[3] J. West, Washington Dept. Fish and Wildlife, Marine Resources Division, Olympia, WA. Pers. commun., 30 Nov. 2004.

for the taxon, 2) evidence that loss of the population segment would result in a significant gap in the range of the taxon, 3) evidence that the population segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historic range, and 4) evidence that the population segment differs markedly from other populations of the species in its genetic characteristics. In reference to the first consideration above, the BRT noted that Pacific herring are widely distributed across the North Pacific Rim and have a very large number of stocks distributed evenly throughout their extensive range. The BRT also recognized the occurrence of other Pacific herring stocks with exceptional spawn timing for their local region, and that other Pacific herring stocks also spawn on fairly exposed coastlines as evidenced by a history of being periodically exposed to high wave energy and storms (see following subsection). Neither the second nor the third significance considerations apply to the Cherry Point Pacific herring population, as loss of this population would not result in a significant gap in the range of Pacific herring and it does not represent the only surviving natural occurrence of Pacific herring. Finally, the BRT concluded that the low level of genetic differentiation between the Cherry Point population and other herring populations indicated some degree of demographic isolation, but was not sufficiently great to indicate that the Cherry Point population differed “markedly” from other herring populations in its genetic characteristics. In particular, the BRT noted that the overall pattern of genetic variation within Pacific herring indicated a high level of gene flow among populations. Detailed evidence supporting the BRT’s conclusions on discreteness and significance are presented in the following subsection.

Evidence Supporting Discreteness and Significance Decisions

Distribution of Pacific Herring

Pacific herring in the Eastern Pacific Ocean range from northern Baja California north to at least the Mackenzie Delta in the Beaufort Sea. Pacific herring are also found in the Russian Arctic from the Chukchi Sea in the east to the White Sea in the west, although the boundary between Atlantic and Pacific herring is unclear in this region (Hay et al. 2001b). In the Northwestern Pacific they are found throughout the western Bering Sea, the east coast of Kamchatka, and the Sea of Okhotsk; on the east and west coasts of Hokkaido, Japan; and south and west to the Yellow Sea off the Korean Peninsula (Haegele and Schweigert 1985, Hay et al. 2001b). Haegele and Schweigert (1985) and the previous status review (Stout et al. 2001a) reviewed the extensive distribution of Pacific herring spawning grounds in California, Oregon, Washington, British Columbia, and Alaska. Over this range there are a large number of Pacific herring stocks or metapopulations and numerous occurrences of other more diverse localized populations.

Number of Identified Stocks of Pacific herring

Most recent investigators recognize Atlantic and Pacific herring as separate species, *Clupea harengus* and *C. pallasii*, respectively (Whitehead 1985). However, much of the earlier literature indicated that differences between Atlantic and Pacific herring were representative of only a subspecific separation, as *C. h. harengus* (Atlantic herring) and *C. h. pallasii* (Pacific herring).

Hay et al. (2001b) inventoried worldwide Atlantic and Pacific herring stocks and identified major Pacific herring stocks in the Eastern Pacific, western North Pacific, and southwestern North Pacific. In the Eastern Pacific, more than 20 populations or stocks of Pacific herring are recognized, normally with biomass estimates of less than 100,000 metric tons each, particularly in California, British Columbia, southeast Alaska, central Alaska, and western Alaska (eastern Bering Sea) (Hay et al. 2001b). Each of these populations or stocks is comprised of Pacific herring that spawn at numerous locations. Many smaller local populations are also recognized from California to central Alaska. Pacific herring in the eastern Bering Sea differ from other Pacific herring in the Eastern Pacific; they migrate longer distances, live to older ages, and obtain almost twice the body size of Pacific herring that occur in the Gulf of Alaska and further south (Hay et al. 2001b).

In the northwestern Pacific, three different life history forms of Pacific herring are recognized: 1) a long-lived, migratory sea Pacific herring; 2) a coastal form that undergoes little or no migration; and 3) a lagoon Pacific herring that is associated throughout its life with low-salinity estuarine areas (Hay et al. 2001b). In Russian waters of the western North Pacific, major Pacific herring stocks include Korf-Karagin Pacific herring, Gizhiga-Kamchatka Pacific herring, Okhotsk Pacific herring, Dekastri Pacific herring, and Peter the Great Bay Pacific herring (Hay et al. 2001b). Historically, Hokkaido-Sakhalin Pacific herring spawned along southeastern Sakhalin and northwestern Hokkaido. Small local populations have also been recognized in this region. Another major stock of Pacific herring is recognized in the Yellow Sea (Hay et al. 2001b). Numerous herring populations occur in the coastal seas of the Arctic Ocean, including the Beaufort Sea off northern Alaska and Yukon and the Northwest Territories, although their taxonomic affinity to Pacific herring is uncertain (Hay et al. 2001b).

Persistence and Spawn Timing

Hay and McCarter (1997) emphasized the fact that "the continued occupation of an area is a fundamental consideration of any definition of stock" (Hay and McCarter 1997, p. 172). The same can certainly be said for a distinct population segment. Although Pacific herring have supported Native American fisheries in Washington State for millennia prior to Euro-American contact and statewide Pacific herring landing records begin in 1889 (Chapman et al. 1941), the first site-specific fishery landings report for Cherry Point (reported as Birch Bay) begins in 1935 when approximately 41 short tons were landed (Williams 1959, WDF 1969) (see Figures 1–3 for locations mentioned in the text).

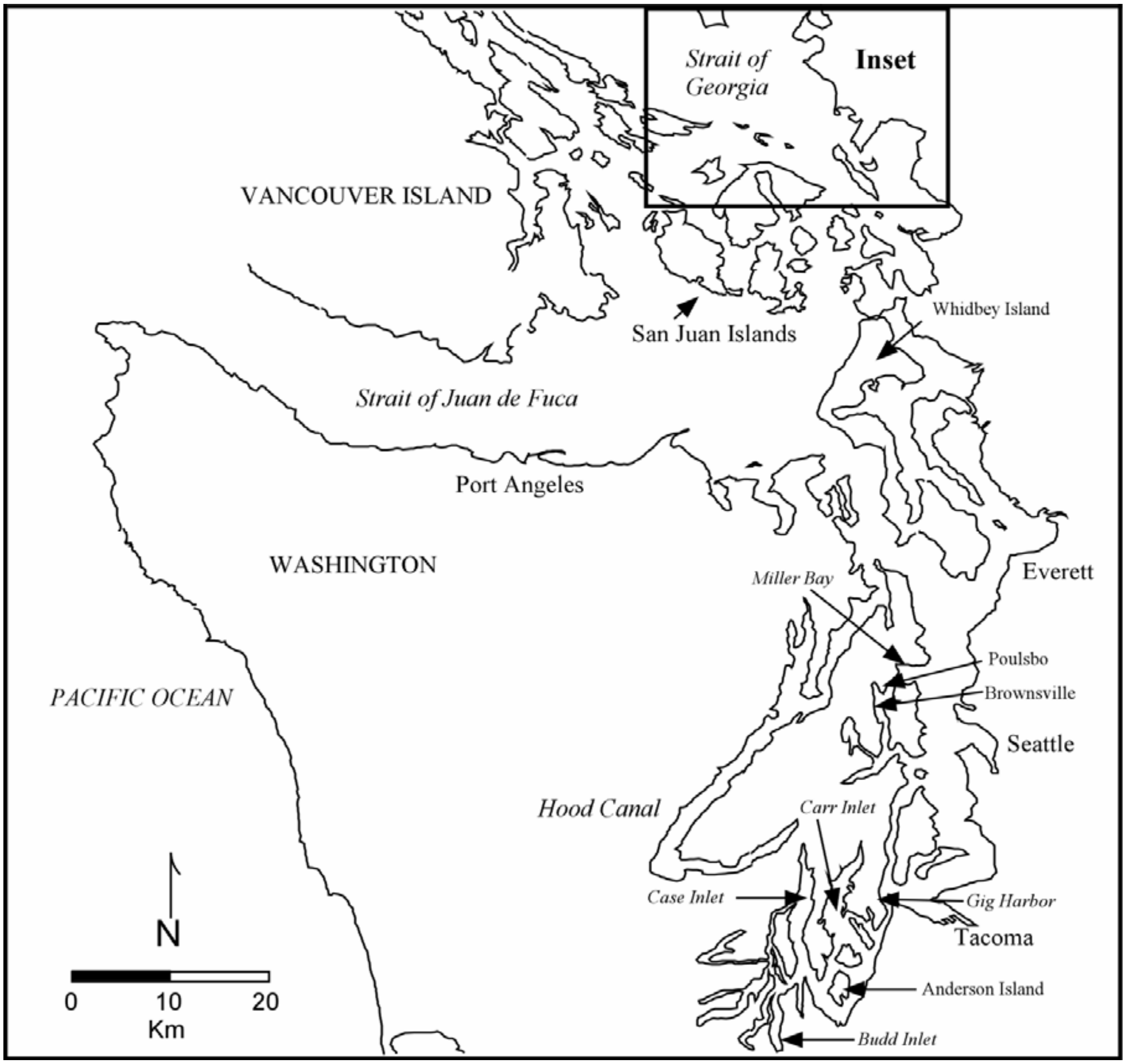

Figure 1. Regional water masses of Puget Sound and geographical locations mentioned in the text. See Figure 2 for detail of the inset area.

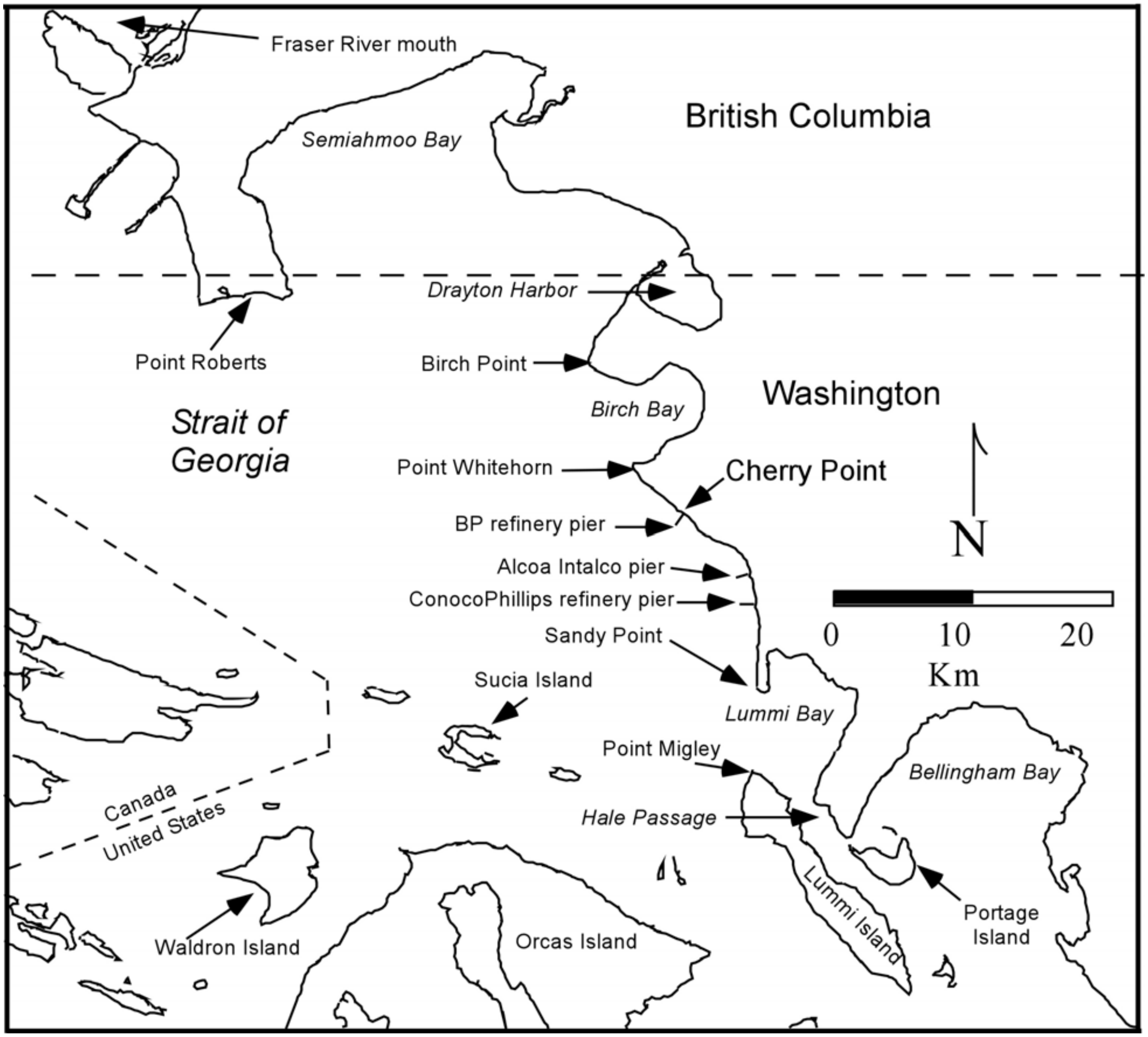

Figure 2. Geographical location of Cherry Point and other localities mentioned in the text.

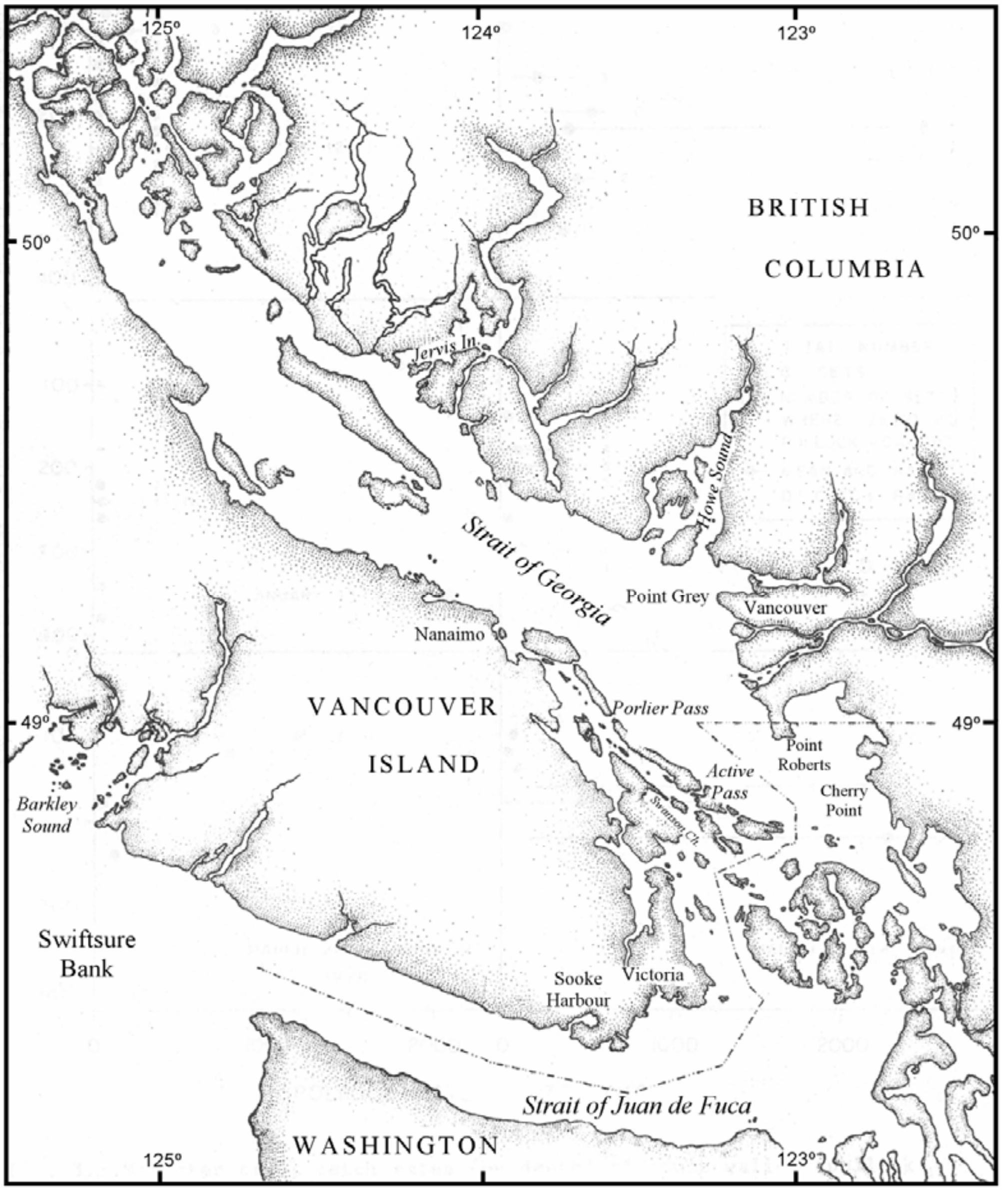

Figure 3. Geographical locations in the Strait of Georgia and on the southern coast of British Columbia mentioned in the text.

The first historical reference to Pacific herring spawning during April to June in the vicinity of Cherry Point (then defined as Birch Point and Hales Pass)[4] was found in a short article in the February 1916 issue of the popular publication Pacific Fisherman. This article describes the establishment of Washington State herring reserves where harvest was prohibited during the time of spawning (Pacific Fisherman 1916, p. 21) and stated that:

> Several herring reserves on Puget Sound were set aside on Jan. 19 by Fish Commissioner Darwin and the closed season of each announced as follows:
>
> Port Hadlock, Jan. 1 to Feb. 15; Hales pass, April 1 to June 15; Jackson cove, Feb. 15 to March 31; Birch point, April 1 to June 15; Holmes harbor, Feb. 15 to March 31.

The establishment of Pacific herring reserves at Birch Point and Hales Pass (Hale Passage, Whatcom County) from 1 April to 15 June, while other areas of Puget Sound were set aside from January to March, indicates that late-spring spawning Pacific herring have been recognized in the vicinity of Cherry Point for at least 90 years. Although not definitive as to spawn timing, the June 1905 issue of Pacific Fisherman refers to Pacific herring being caught in large numbers in Hale's Pass (Hale Passage, Whatcom County) at Lummi Island during the "past month" (Pacific Fisherman 1905a, p. 17) and to Pacific herring entering salmon traps at Birch Bay (Pacific Fisherman 1905b). These records, if accurate as to timing, would extend the historical record for Cherry Point late-spring spawning Pacific herring to almost 100 years. Spawning at all other Pacific herring locations in Puget Sound, Hood Canal, and the Strait of Juan de Fuca currently occurs from late January through early April (Trumble 1983, Lemberg et al. 1997, O'Toole et al. 2000) with peak spawning starting the last week of February or the first week of March (Table 1) (O'Toole et al. 2000). Spawning at Cherry Point begins in early April and ends in early June with peak spawning activity around 10 May (Table 1) (O'Toole et al. 2000).

Currently, five Pacific herring management regions are recognized by Department of Fisheries and Oceans Canada (DFO) in British Columbia: 1) Queen Charlotte Islands, 2) North Coast (Prince Rupert District), 3) Central Coast, 4) Strait of Georgia, and 5) West Coast Vancouver Island. Johnstone Strait is not considered a management region at this time, although it was in the past. Each of these regions is further divided into Statistical Areas, which are further divided into sections, which are named and numbered (Hay and McCarter 2004a). The boundaries of each of the 108 Pacific herring sections are illustrated by region in Figure 4. In general, Pacific herring spawn from January to May in southern British Columbia and from mid-January to June in northern British Columbia (Taylor 1964, Hourston 1980). Spawn timing by herring section in each region is illustrated in Figures 5–9.

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[4] There are two locations in Washington inshore waters currently named Hale Passage; one in south Puget Sound separating Fox Island and the Kitsap Peninsula (Pierce County), and the other in the southern Strait of Georgia separating Lummi Island and the mainland (Whatcom County). Many early references referred to Hale Passage in Whatcom County as Hale Pass, Hales Pass, or Hales Passage. When confusion could occur as to which Hale Passage is being referred to, we identify the location by parenthetical reference to the location's county.

Table 1. Range (gray shading) and peak (black shading) of documented spawn timing for WDFW Puget Sound Pacific herring stocks. Modified from Lemberg et al. (1997), O'Toole et al. (2000), and WDFW.*

Puget Sound herring stock (abbr.)	**January**				**February**				**March**				**April**				**May**				**June**			
Squaxin Pass (SP)			gray	gray	gray	gray	gray	black	black	gray														
Wollochet Bay (WB)	gray	gray	gray	gray	black	black	gray	gray	gray	gray														
Quartermaster Harbor (QM)	gray	gray	gray	black	black	gray	gray	gray	gray	gray	gray	gray	gray											
Port Orchard / Port Madison (PO)	gray	gray	gray	gray	gray	gray	gray	gray	black	black	gray	gray	gray	gray										
South Hood Canal (SH)		gray	gray	gray	black	black	gray	gray	gray	gray	gray													
Quilcene Bay (QB)				gray	gray	gray	gray	gray	black	black	gray	gray	gray											
Port Gamble (PG)			gray	gray	gray	gray	gray	black	black	gray	gray	gray	gray											
Kilisut Harbor (KH)					gray	gray	gray	black	black	gray	gray	gray	gray											
Port Susan (PS)			gray	gray	gray	gray	gray	gray	black	black	gray	gray	gray											
Holmes Harbor (HH)					gray	gray	gray	gray	gray	gray	gray	black	black	gray	gray									
Skagit Bay (SB)					gray	gray	gray	black	black	gray	gray	gray	gray											
Fidalgo Bay (FB)				gray	gray	gray	gray	black	black	gray	gray	gray	gray											
Samish Bay / Portage Bay (SPB)					gray	gray	gray	black	black	gray	gray	gray	gray											
Interior San Juan Islands (ISJ)				gray	gray	gray	gray	gray	gray	black	black	gray	gray	gray	gray									
Northwest San Juan Islands (NSJ)			gray	gray	gray	gray	gray	gray	gray	gray	gray	gray	gray	gray										
Semiahmoo Bay (SAB)				gray	gray	gray	gray	black	black	gray	gray	gray	gray											
Cherry Point (CHPT)												gray	gray	gray	gray	gray	black	black	gray	gray	gray	gray	gray	
Discovery Bay (DIB)					gray	gray	gray	gray	gray	black	black	gray	gray											
Dungeness Bay (DB)			gray	gray	gray	black	black	gray	gray	gray	gray	gray												

* K. Stick, Washington Dept. Fish and Wildlife, La Conner, WA. Pers. commun., 30 Nov. 2004.

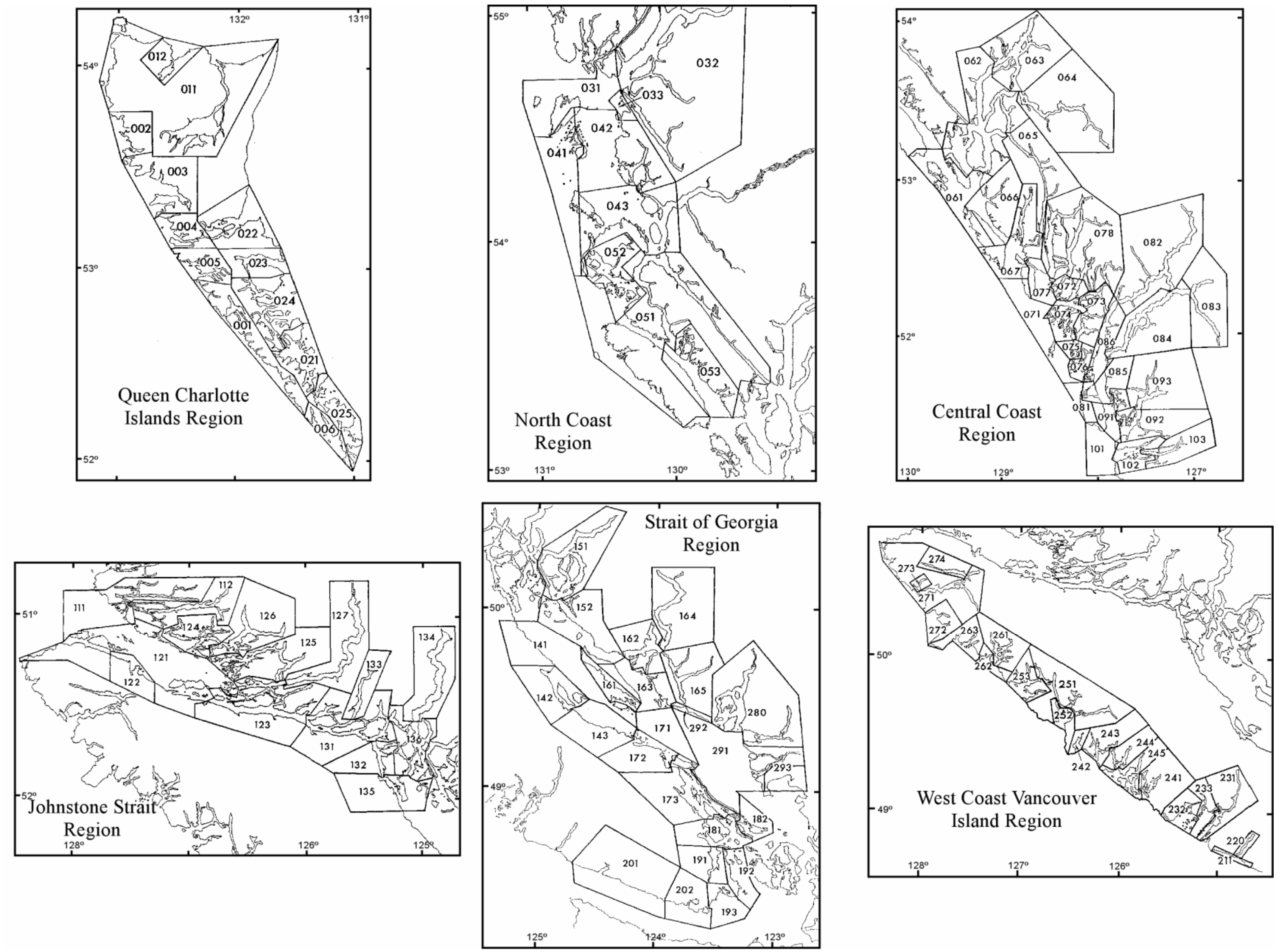

Figure 4. DFO Pacific herring sections in the six regions of British Columbia. Maps modified from those available at http://www.pac.dfo-mpo.gc.ca/sci/herring/bulletin_e.htm (DFO 2004).

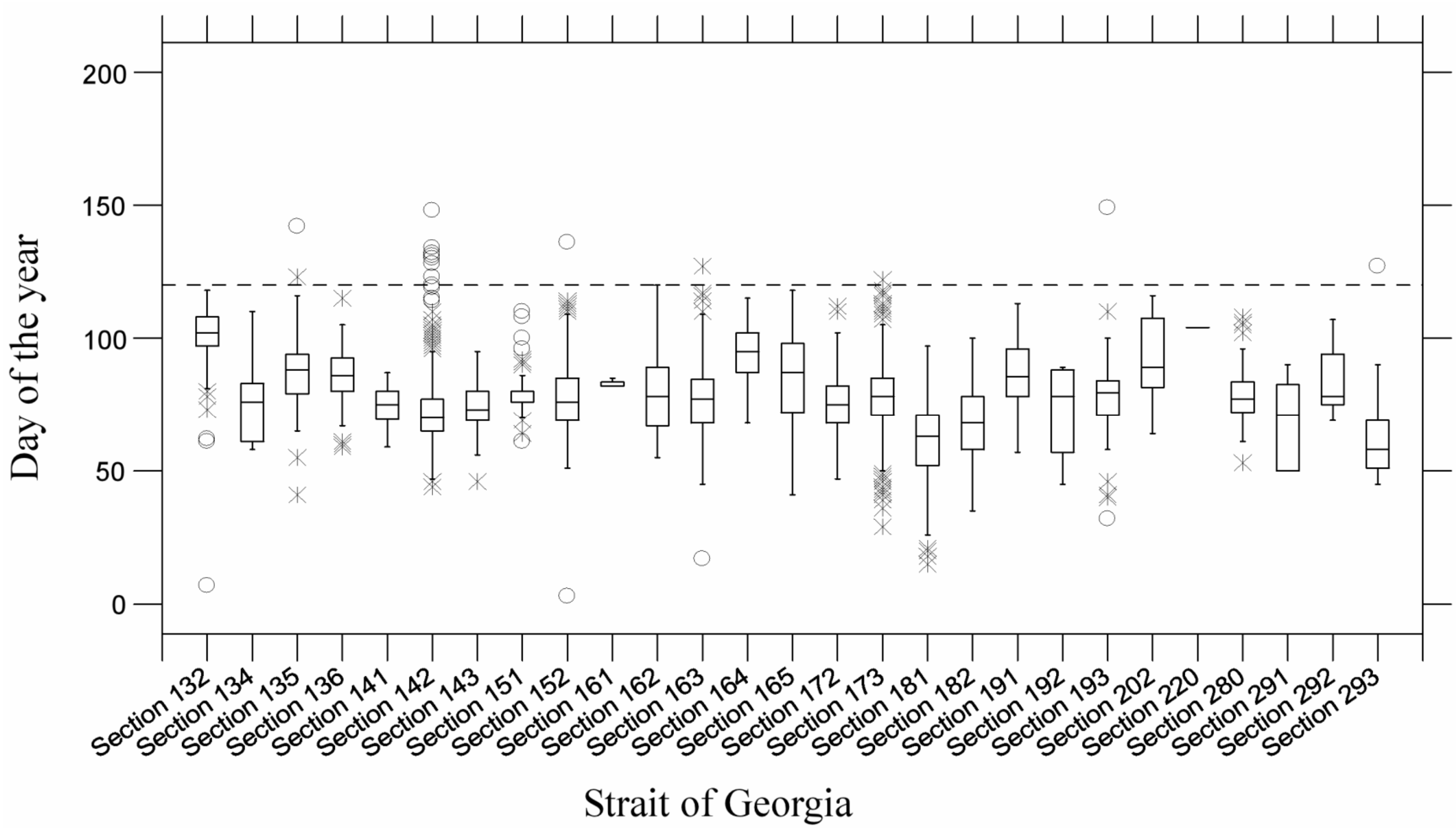

Figure 5. Pacific herring spawn timing observations (Julian Calendar day of the year corrected for leap years) by DFO herring sections in the British Columbia Strait of Georgia herring management region from 1928 to 2004. Length of each box shows the range within which the central 50% of the values fall, and the center line in each box marks the median of the sample. Circles represent far outside values and Xs represent outside values. Horizontal line indicates the 120th day of the year (approximately 1 May). See Figure 4 for geographical location of sections. Data from http://www-sci.pac.dfo-mpo.gc.ca/herspawn/default.htm (DFO 2004).

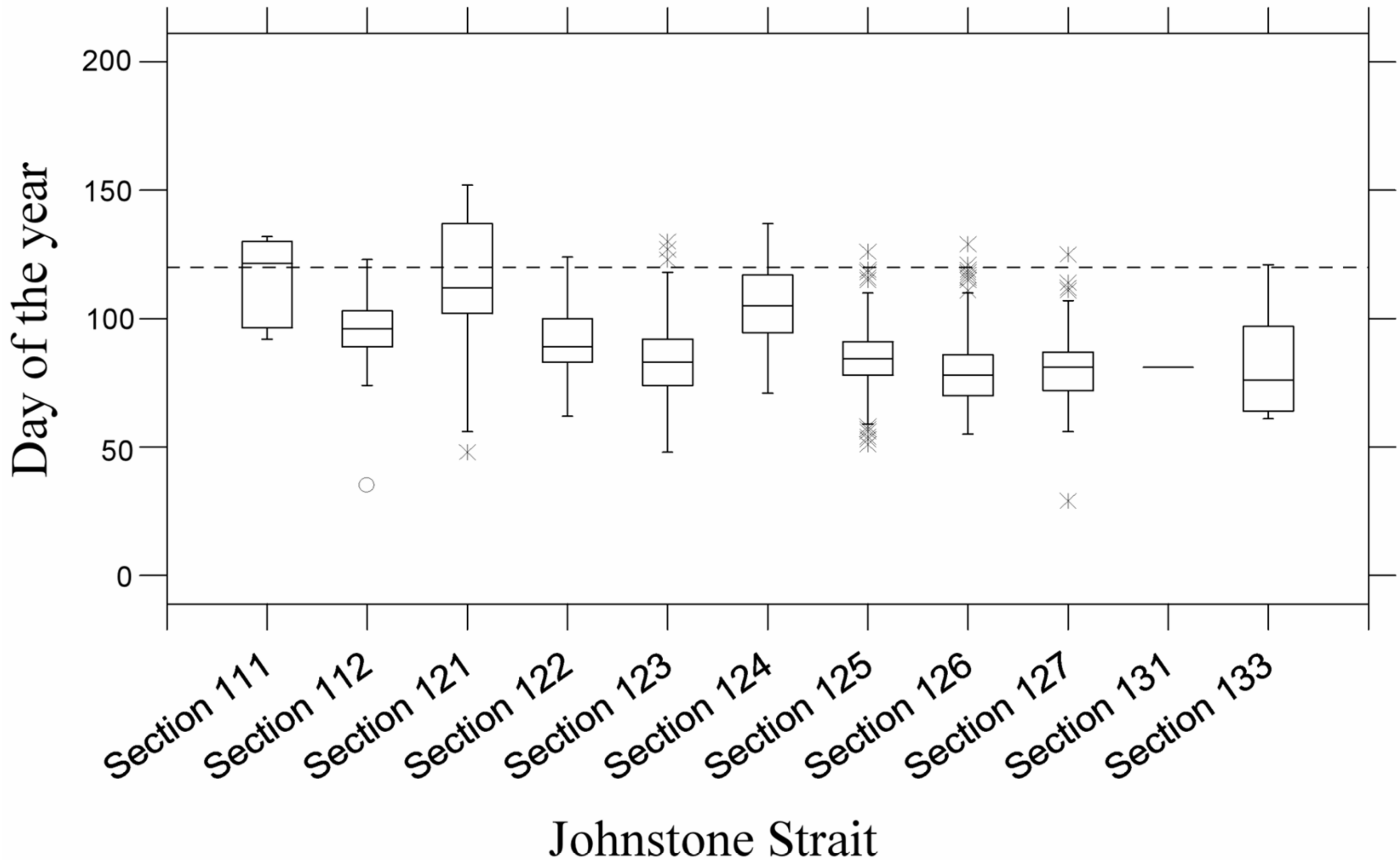

Figure 6. Pacific herring spawn timing observations (Julian Calendar day of the year corrected for leap years) by DFO herring sections in the British Columbia Johnstone Strait herring management region from 1928 to 2004. Length of each box shows the range within which the central 50% of the values fall, and the center line in each box marks the median of the sample. Circles represent far outside values and Xs represent outside values. Horizontal line indicates the 120th day of the year (approximately 1 May). See Figure 4 for geographical location of sections. Data from http://www-sci.pac.dfo-mpo.gc.ca/herspawn/default.htm (DFO 2004).

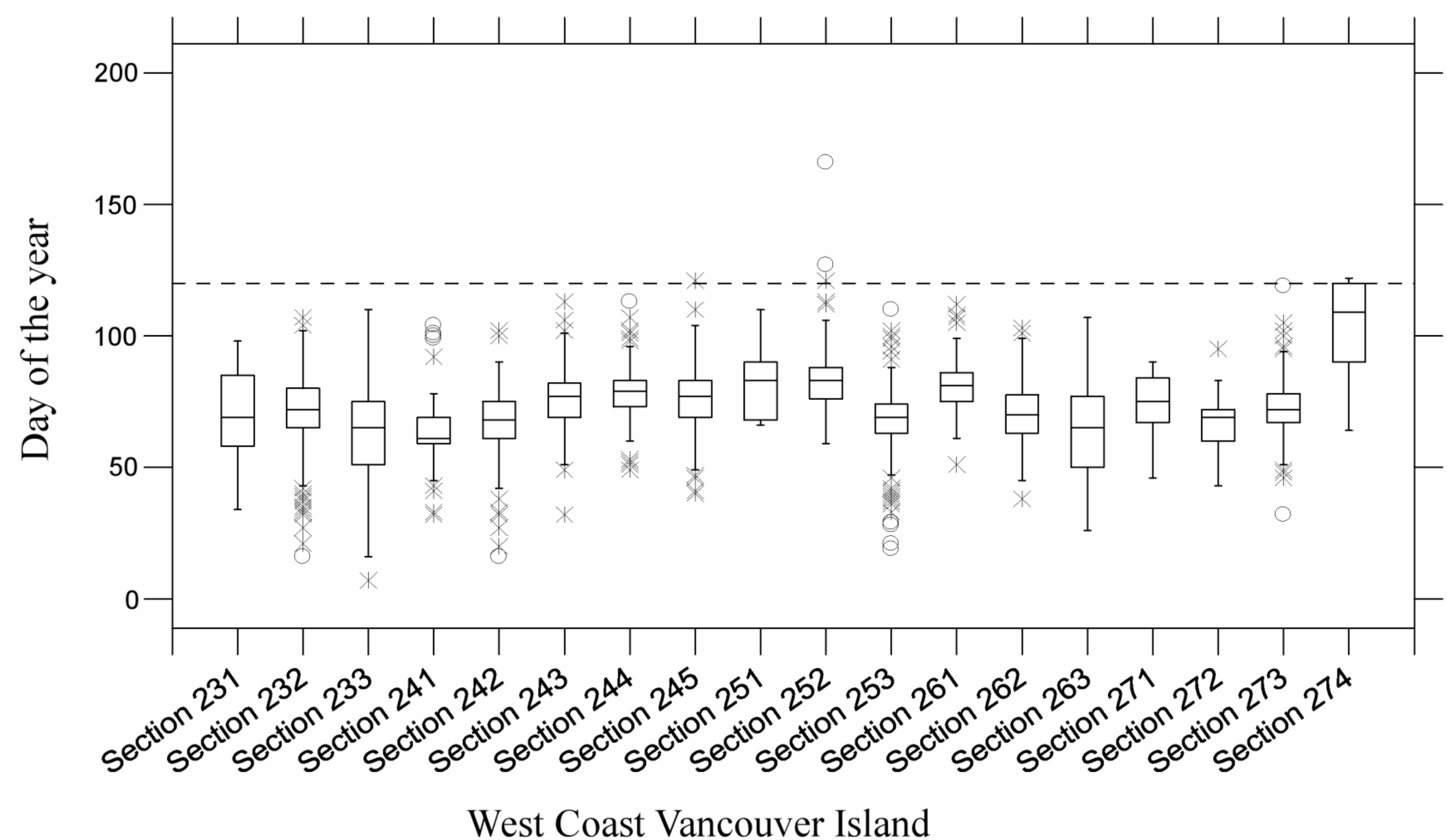

Figure 7. Pacific herring spawn timing observations (Julian Calendar day of the year corrected for leap years) by DFO herring sections in the British Columbia West Coast Vancouver Island herring management region from 1928 to 2004. Length of each box shows the range within which the central 50% of the values fall, and the center line in each box marks the median of the sample. Circles represent far outside values and Xs represent outside values. Horizontal line indicates the 120th day of the year (approximately 1 May). See Figure 4 for geographical location of sections. Data from http://www-sci.pac.dfo-mpo.gc.ca/herspawn/default.htm (DFO 2004).

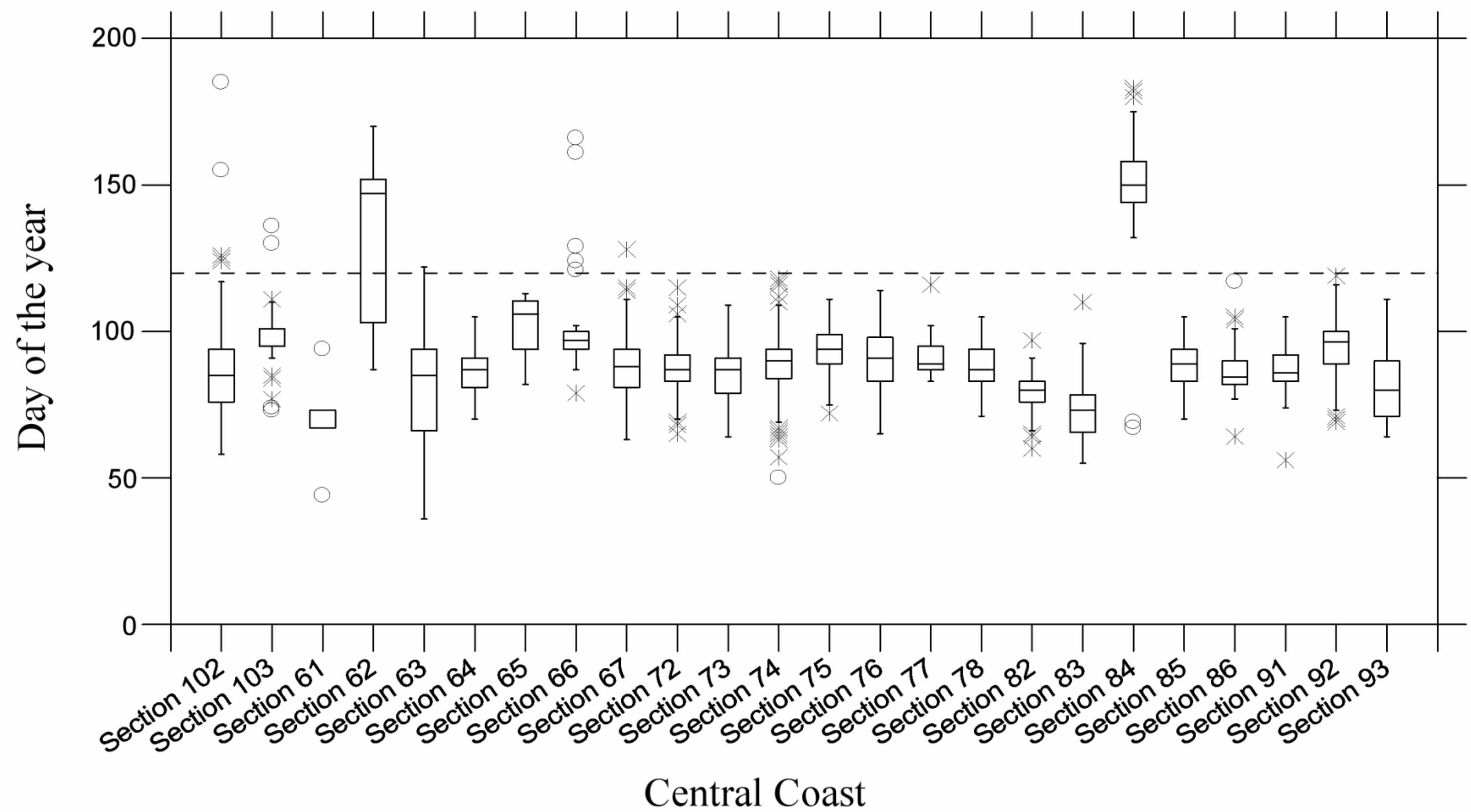

Figure 8. Pacific herring spawn timing observations (Julian Calendar day of the year corrected for leap years) by DFO herring sections in the British Columbia Central Coast herring management region from 1928 to 2004. Length of each box shows the range within which the central 50% of the values fall, and the center line in each box marks the median of the sample. Circles represent far outside values and Xs represent outside values. Horizontal line indicates the 120th day of the year (approximately 1 May). See Figure 4 for geographical location of sections. Data from http://www-sci.pac.dfo-mpo.gc.ca/herspawn/default.htm (DFO 2004).

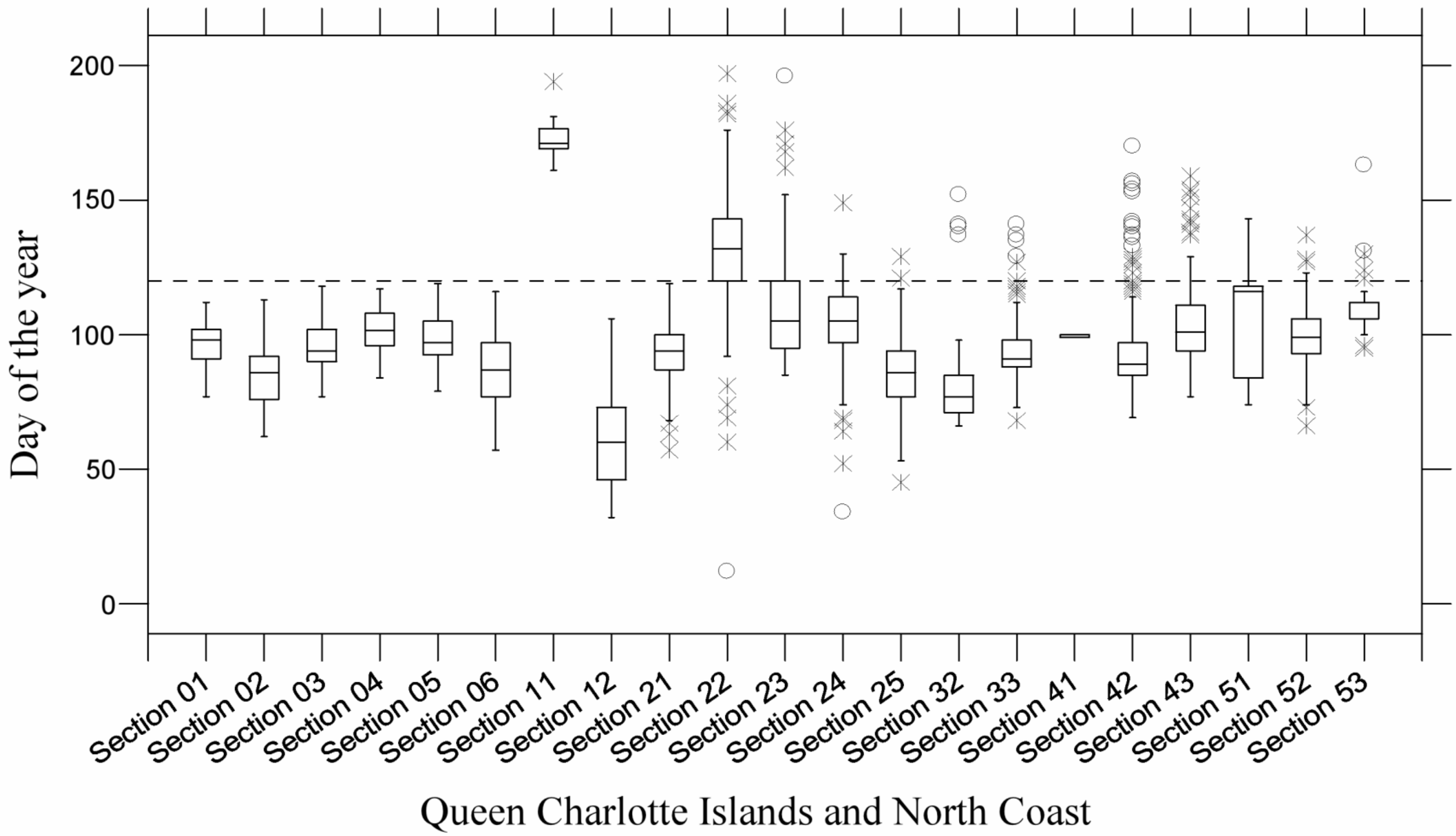

Figure 9. Pacific herring spawn timing observations (Julian Calendar day of the year corrected for leap years) by DFO herring sections in the British Columbia Queen Charlotte Islands (Sections 1–25) and North Coast (Sections 32–53) herring management region from 1928 to 2004. Length of each box shows the range within which the central 50% of the values fall, and the center line in each box marks the median of the sample. Circles represent far outside values and Xs represent outside values. Horizontal line indicates the 120th day of the year (approximately 1 May). See Figure 4 for geographical location of sections. Data from http://www-sci.pac. dfo-mpo.gc.ca/ herspawn/default.htm (DFO 2004).

Chapman et al. (1941) referred to an unpublished report of observations of Pacific herring spawning grounds in Puget Sound made in 1927 by Arthur S. Einarsen of the Washington Department of Fisheries. According to Chapman et al. (1941), the Einarsen report listed the spawn timing of the Birch Bay (Cherry Point) population as occurring from 1 May to 10 June in 1927. Chapman et al. (1941) does not indicate whether Einarsen recorded spring spawning Pacific herring at Hale Passage (Whatcom County), Point Roberts, or from Point Whitehorn south to Lummi Bay (Figure 2).

Although he does not address the specific spawn timing of different Pacific herring locations, Einarsen in another report (1928) in reference to the Puget Sound herring fishery stated that "the bulk are taken at Hales Pass [Hale Passage, Whatcom County], Holmes Harbor, Birch Bay, Poulsbo, and Discovery Bay" and that "all these areas are spawning beds" (1928, p. 132). Einarsen further noted that "herring are available here [in Puget Sound] in one district or another from October 15th to June 25th of each year" (1928, p. 133).

Chapman et al. (1941) recorded spawning in Birch Bay from 26 April to 22 May in 1936 and on 20 and 22 April in 1937. Chapman et al. (1941) reported that the spring run in Hales Pass (Hale Passage, Whatcom County) spawned on 20 April and from 5 to 10 May 1936. Chapman et al. (1941) indicated that two distinct runs occurred in the vicinity of Hales Pass (Hale Passage, Whatcom County), a winter run spawning in late February to early March (this is most likely a reference to Pacific herring currently defined as the Samish Bay-Portage Bay stock) and the spring run, spawning "in the latter part of April and in May" (Chapman et al. 1941, p. 10). Chapman et al. (1941) made no mention of Pacific herring spawning at Point Roberts or from Point Whitehorn south to Lummi Bay. Katz (1942, p. 28) also records time of spawning for Pacific herring at Birch Bay as "late April and early May."

Pasquale (1965, p. 19) reported a "light-to-medium (density) spawn deposition on eel grass in an area of approximately ¼ mile × 2 miles on the Pt. Whitehorn side of Birch Bay" that occurred on about 31 May 1962. Pasquale (1965, p. 19) estimated that spawning at Birch Bay normally occurred from "May 19 through 31." By the early 1970s, Meyer and Adair (1978, p. 39) reported that spring spawning Pacific herring in the Strait of Georgia region "utilize[d] four major geographical areas: Point Roberts, Birch Head, Point Whitehorn-Cherry Point, and Hale Passage."

In addition to spring-spawning Pacific herring at Birch Bay and Hales Pass (Hale Passage, Whatcom County), Chapman et al. (1941, p. 8) stated that "[i]n Echo Bay and Shallow Bay on Sucia Island there is a run of fish which in 1936 spawned in the middle of May" and "[i]n 1936 in the last week of May, a good spawning school of herring occurred in a small bay on the President Channel side of Waldron Island about two miles from the northeast point" (1941, p. 9). Sucia Island and Waldron Island are approximately 17 and 28 km southwest of Cherry Point (Figure 2). Einarsen (1928) also listed Waldron Island as the location of a spawning run of Pacific herring, although he did not note the time of spawning.

Both Thompson (1917) and Hay and Outram (1981) encountered an unusual group of large Pacific herring with anomalously reduced maturity states while conducting Pacific herring sampling off Point Grey, British Columbia and in the southern Gulf Islands, respectively (Figure 3). Several lines of evidence indicate that these fish were from the Cherry Point Pacific herring population. The mixed sample of small mature (ripe) and large immature (unripe) Pacific herring sampled by Thompson (1917, p. S53) in September and October at Point Grey off Vancouver, British Columbia (Figure 3), prompted him to postulate that these were "grounds for believing that there are summer spawning herring" in the vicinity. However, Thompson (1917, p. S53) stated that "there has been no opportunity of corroborating this by actual search for spawning herring during any particular season, nor by an examination of Point Grey herring during any other time of the year." Point Grey, British Columbia is approximately 57 km north of Cherry Point, Washington (Figures 2 and 3). Similarly, Hay and Outram (1981) reported upon Pacific herring samples taken in the vicinity of Porlier Pass (Figure 3) during 24–28 February 1975 that consisted of mixtures of Pacific herring with different degrees of sexual maturity. In these samples, similar to Thompson's (1917) samples, less mature Pacific herring were older and larger than the more mature Pacific herring. Hay and Outram (1981) and Hay and McCarter (1999) postulated that these larger immature fish were likely representative of a migratory stock, as differentiated from local smaller, mature Pacific herring. Both of these studies suggest that a population of fish with anomalous spawn timing was sampled, most likely representative of Cherry Point Pacific herring.

Barraclough (1967) reported on the occurrence of larval Pacific herring in surface trawls on 5–8 July 1966 in the southern SOG, between the Fraser River delta and Vancouver Island. Based on the size of these larval Pacific herring, Barraclough (1967) calculated that they were the result of spawning that had occurred between 22 May and 4 June, which was considerably later than any previously reported Pacific herring spawn timing in the British Columbia portion of the Strait of Georgia (Barraclough 1967). Based on the counterclockwise flow of currents in the Strait of Georgia, Barraclough (1967) postulated that these larvae had hatched from spawn deposition in the vicinity of Boundary Bay. Outram and Haegele (1969) further reported that:

> A survey was carried out by Biological Station personnel during 1969 to determine the origin of exceptionally small larval herring found in plankton tows made in June and July in the southern portion of the Strait of Georgia. The shoreline from Boundary Bay (Area 29) south across the International Boundary Line to the San Juan Islands was searched for evidence of late, unobserved herring spawnings with the MV *Caligus*. Two medium-intensity depositions were located, one at Birch Bay (3.2 mi), the other at Hale Passage (0.9 mi). These spawnings took place on May 17 and 22, respectively, and could be the source of the small larval herring found in June and July plankton hauls.

WDF (1971) listed Pacific herring spawning grounds in Puget Sound and provided a chart that documented numerous spawning events in April and May at Point Roberts, from Blaine to Birch Bay, from Point Whitehorn to Sandy Point, and at Hale Passage and Portage Bay. Spawning in the first few days of June was also recorded between Point Whitehorn and Sandy Point and at Hale Passage and Portage Bay.

In general, Pacific herring spawn from January to May in southern British Columbia and from mid-January to June in northern British Columbia (Taylor 1964, Hourston 1980) (Figures 5–9). Outram and Haegele (1969) found a difference of six weeks in the mean spawn timing (from 8–9 March to 20–21 April) occurred between spawning areas in extreme southern and northern British Columbia. However, several exceptions to these generalities occur (Outram and

Haegele 1969, Hay 1985, DFO 2004). For example, Pacific herring in two geographically adjacent spawning sections in the northern Queen Charlotte Islands, Masset Inlet (Section 011) and Naden Harbour (Section 012), exhibit some of the extreme latest and earliest spawn timings on the British Columbia coast, respectively (Figure 9) (Haegele and Schweigert 1985, Hay 1985). Masset Inlet spawnings have been documented in late-June to July with a mean spawn date of 20 June, while Naden Harbour spawnings occur in late-January or in early February with a mean spawn date of 2 March (Figure 9) (Hay 1985, 1990, Hay and McCarter 1999, Stout et al. 2001a, their figures 13c and 21, DFO 2004). Another local population in the Queen Charlotte Islands Region, Skidegate Inlet (Section 022), has a mean spawn date of 14 May while Pacific herring in other nearby sections spawn mainly in April (Haegele and Schweigert 1985, Hay 1985). Pacific herring in Burke Channel (Section 084), in the Central Coast Region of British Columbia, exhibit a mean spawn date of 1 June, which is consistently later than spawn timings for other Sections in the Region (Figures 8 and 9) (Scattergood et al. 1959, Haegele and Schweigert 1985, Hay 1985, Stout et al. 2001a, their figures 13c and 21, DFO 2004). Hay (1985, p. 124) noted that "even within the same general locations, such as the northern Queen Charlotte Islands or San Francisco Bay, the earliest and latest spawnings can be nearly 6 mo apart."

Sporadic past occurrence of Pacific herring spawning during May in the Canadian SOG has occurred in the following DFO Pacific Herring Sections: Section 142, Baynes Sound (particularly from 1974–1978); Section 173, Yellow Point (2 May 1955); Section 135, Cape Mudge (3 May 1969); Section 152, Powell River (15 May 1952); Section 293, Boundary Bay (7 May 1975); and Section 193, Victoria Harbour (29 May 1995) (Hourston 1980, DFO 2004) (Figure 10 and Table 2).

The adaptive value of spawn timing in the Pacific Northwest was articulated in the following quotation by Hay (1990, p. 2400):

> These extreme differences in spawning time must have evolved in the last 10,000 yr since glacial recession. The large spawning time differences between stocks are evidence of local and rapid selection, and such selection indicates that spawning time has significant survival value. An explanation for differences in spawning times is that the herring have spawning times that match local zooplankton production schedules, particularly the time of egg production by copepods because copepod eggs are, overwhelmingly, the dominant food organism of larval herring (Wailes 1936).

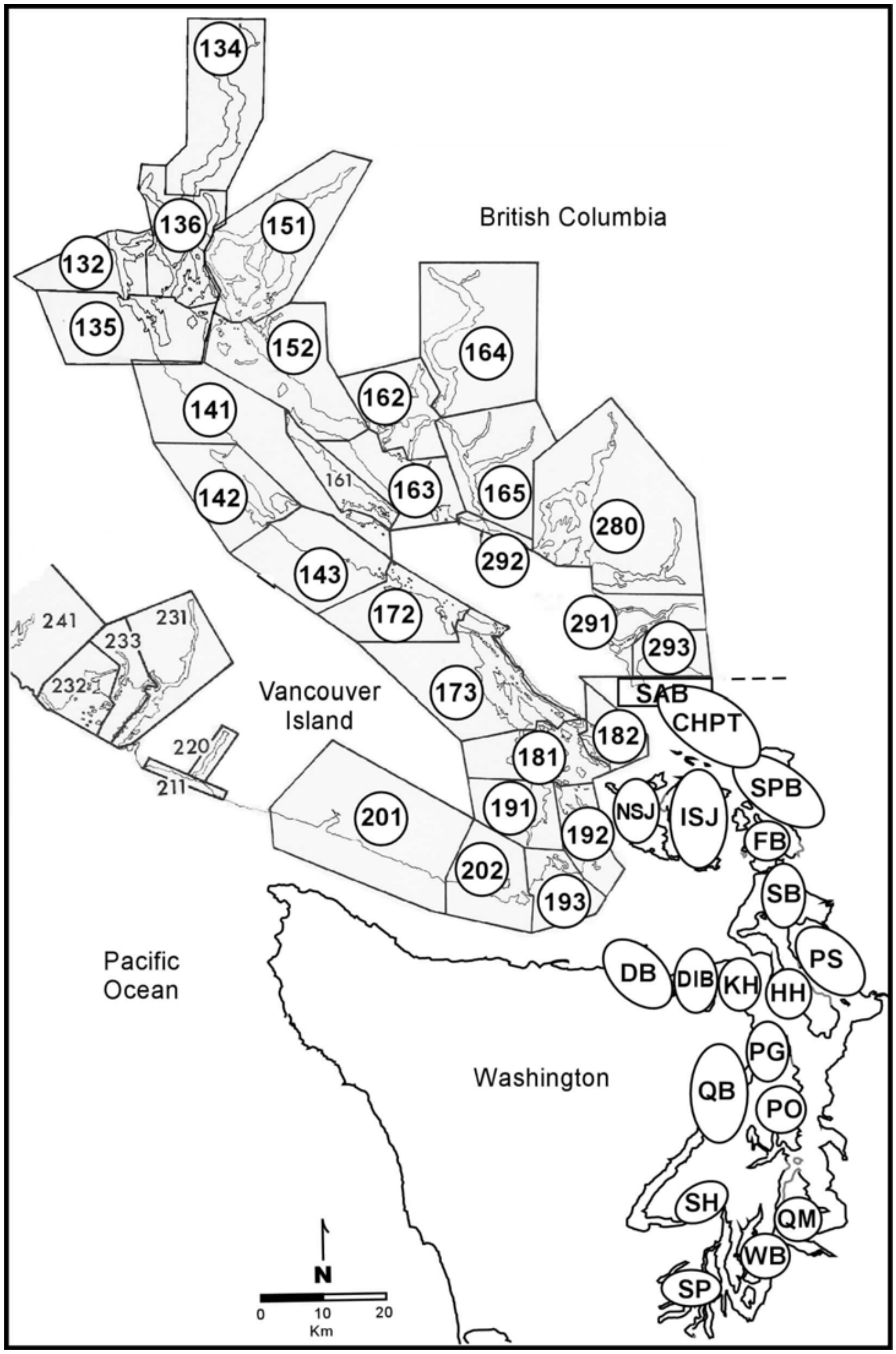

Figure 10. Geographic distribution of WDFW Pacific herring stocks (stock abbreviations as in Table 1) and herring sections in the Canadian SOG (132, Deepwater Bay; 134, Bute Inlet; 135, Cape Mudge; 136, Reed Island; 141, Oyster Bay; 142, Baynes Sound; 143, Qualicum; 151, Redonda Islands; 152, Powell River; 162, Hotham Sound; 163, Malaspina Strait; 164, Jervis Inlet; 165, Sechelt Inlet; 172, Nanoose Bay; 173, Yellow Point; 181, Swanson Channel; 182, Plumper Sound; 191-192, Saanich Peninsula; 193, Victoria Harbour; 202, Sooke Harbour; 280, Howe Sound; 291, Fraser River Foreshore; and 293, Boundary Bay). Unnamed sections 161 and 201 normally receive no appreciable herring spawn.

Table 2. Herring spawn records in the Strait of Georgia with a start date equal or greater than the 120th day of the year (approximately 1 May). DOY, Julian calendar day of the year; ND, no data. Data from DFO.*

Year	Herring section	Location name	DOY	Spawn length (m)	Spawn width (m)	Egg layers	Metric tons
1952	152-Powell River	Lund	136	274	27	2.96	73
1955	173-Yellow Point	Boat Harbour	122	274	2	2.15	116
1969	135-Cape Mudge	Heriot Bay	123	69	4	2.96	5
1969	162-Hotham Sound	Willingdon Beach	120	640	18	2.96	15
1974	142-Baynes Sound	Deep Bay	132	457	91	1.34	252
1975	142-Baynes Sound	Union Bay	132	366	23	2.96	85
1975	142-Baynes Sound	Hindoo Creek	132	914	23	2.96	212
1975	293-Boundary Bay	Boundary Bay	127	914	274	2.96	548
1976	142-Baynes Sound	Gartley Pt	131	27	5	1.34	16
1976	142-Baynes Sound	Union Bay	130	548	9	2.15	106
1976	142-Baynes Sound	Hindoo Creek	131	91	9	1.34	18
1977	142-Baynes Sound	Comox Bar	128	1,554	27	0.50	1,036
1977	142-Baynes Sound	Union Bay	134	640	69	3.00	136
1978	142-Baynes Sound	Willemar Bluff	148	137	137	1.00	94
1995	193-Victoria Harbour	James Bay	149	ND	11	2.00	ND

* D. E. Hay, Fisheries and Oceans Canada, Biological Sciences Branch, Nanaimo, B.C., Canada. Pers. commun., December 2004.

Spawning Location

Haegele and Schweigert (1985, p. 41) noted that Pacific herring almost exclusively spawn in "inlets, sounds, bays, and estuaries that are somewhat sheltered from the surf of the ocean." Selection of these areas is likely an adaptation to minimize egg loss from wave action that can dislodge marine vegetation upon which eggs are laid (Haegele and Schweigert 1985). Taylor (1955, p. 118) stated that "survival [of spawned eggs] is highest in locations partially protected from wave action and least in both exposed and well protected localities." This suggests that a moderate amount of wave action may improve hatching success (Taylor 1971, Leon 1993). In many areas in British Columbia, the bulk of Pacific herring spawn is deposited subtidally (Hay and Miller 1982) and is relatively protected from wave action.

The central core area of the Cherry Point Pacific herring spawning grounds is in a generally exposed location in close proximity to deep water (Stick 1995, O'Toole et al. 2000) and is "unlike other spawning grounds in Washington waters, which are typically protected, relatively small bays" (Stick 1995, p. 5) (Figure 2). However, historically, portions of the Cherry Point Pacific herring population spawned in the relatively protected waters of Hale Passage, Birch Bay, Drayton Harbor, and Semiahmoo Bay when abundance of the stock was much larger and spawning was laterally spread out both north and south of the core Cherry Point spawning area (Meyer and Adair 1978) (Figure 2).

Other examples of Pacific herring spawning in exposed shoreline areas subject to significant wave action at the time of spawning, although atypical, are not uncommon. Other documented spawning locations on relatively exposed locations, subject to significant storm-induced wave action, include 30 km on either side of French Creek in the Qualicum Beach area (Herring Section 143) (Hay and Miller 1982); Oyster Bay (Herring Section 141) (DFO 2004); Atrevida Reef in the Sliammon vicinity (Powell River Section 152) (Hay et al. 1989); Macoah Pass in West Barkley Sound (Herring Section 232) (Tester and Stevenson 1948); Bajo Point in the vicinity of Nootka Sound (Herring Section 252) (Hay et al. 1989) (Figure 11); and between Big Bay and Tugwell Point at Prince Rupert (Herring Section 042) (Hay et al. 1989, DFO 2004) (Figure 12), in British Columbia and at Kah Shakes-Boca de Quadra (Skud 1960, Blankenbeckler 1978, Blankenbeckler and Larson 1982) and Crab Bay (Leon 1993), in southeast Alaska. Leon (1993, p. 24) noted that "although the Crab Bay area [a Pacific herring spawning area on the east side of Annette Island, in Southeast Alaska] is not on the open ocean, and can be classified as inside waters, the southeast winds have over 10 km of fetch in which to generate waves, and seas can build to nearly two meters along the shore in a 30-knot wind."

Growth Rate and Body Size-At-Age

Scientific literature relating to differences in growth rate and body size-at-age among Pacific herring was previously reviewed in Stout et al. (2001a). In general, populations of Pacific herring exhibit a latitudinal cline in mean size-at-age, such that Pacific herring in southern locations (e.g., California) exhibit small size and Pacific herring in the north (e.g., Bering Sea) obtain a far larger size at a similar age. The following information specifically relates to Cherry Point Pacific herring.

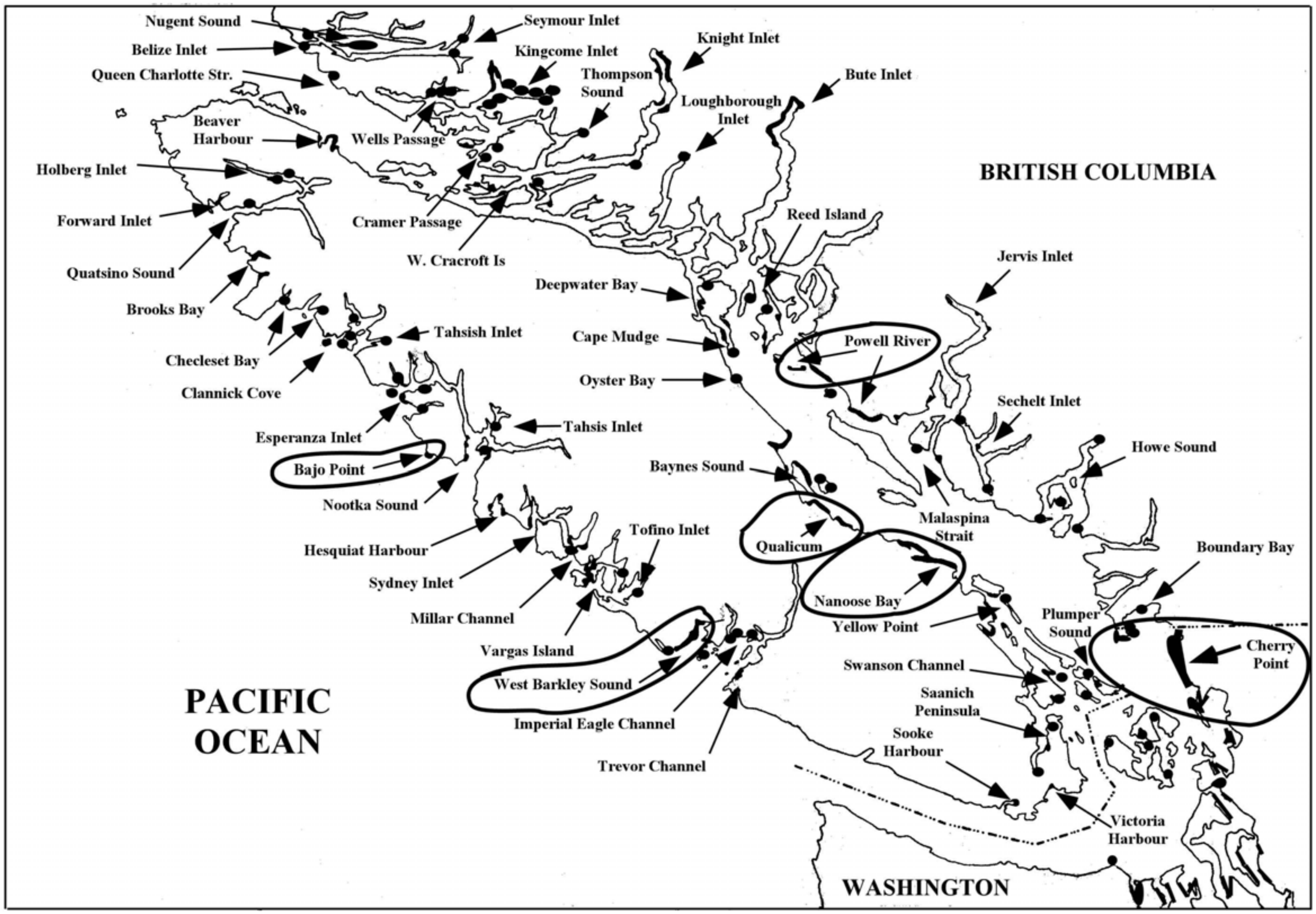

Figure 11. Geographical distribution of major Pacific herring spawning locations in southern British Columbia. Map modified from Hourston (1980) with additional information from DFO (2004). Named locations refer to DFO Pacific herring section designations and not necessarily to geographical locations. Circled locations indicate spawn sites on relatively exposed coastline.

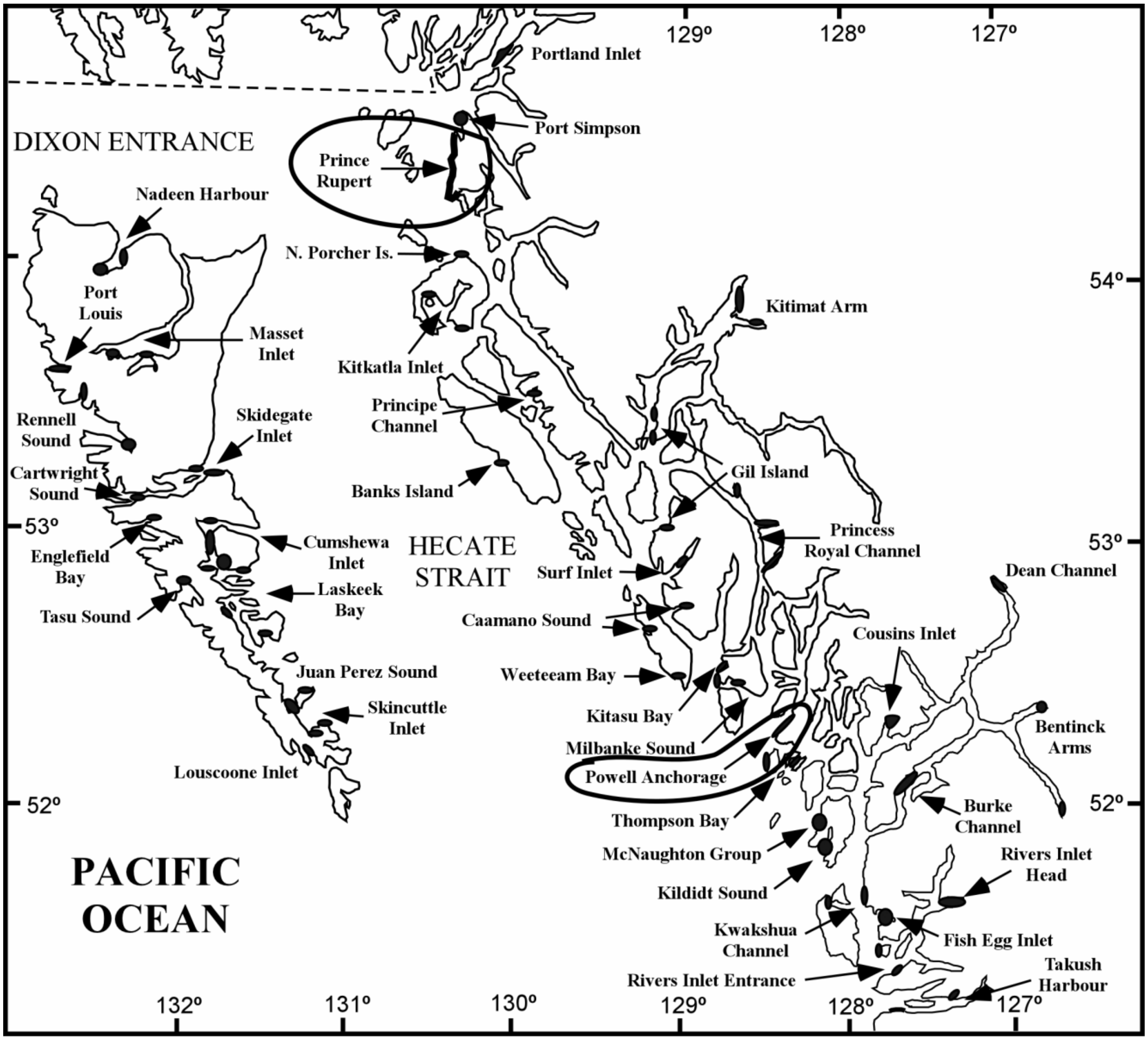

Figure 12. Geographic distribution of major Pacific herring spawning locations on the northern and north-central coast of British Columbia. Map modified from Hourston (1980) with additional information from DFO (2004). Named locations refer to DFO herring section designations and not necessarily to geographical locations. Circled locations indicate spawn sites on relatively exposed coastline.

Katz (1942, p. 33) examined length-at-age at nine locations in Puget Sound from samples taken in 1937 and determined that "the Birch Bay group, which is closest to the open sea, has the largest fish and the most rapid rate of growth." Trumble (1979, 1980), Gonyea and Trumble (1983), and O'Toole et al. (2000) described statistically significant differences in mean growth rate and length-at-age data for three populations of Pacific herring sampled in the mid-1970s in Puget Sound: 1) Case Inlet/Squaxin Pass, 2) Hale Passage (Pierce County)-Carr Inlet (South Sound), and 3) southern Strait of Georgia purse seine catch (Cherry Point Pacific herring). Trumble (1980) found that the Strait of Georgia (Cherry Point stock) Pacific herring were consistently longer at age than the other populations and continued to grow later in life. Herring from Case Inlet (Squaxin Pass stock) grew rapidly to age 3 and then growth slowed, culminating in a smaller size-at-age than was apparent for Pacific herring from the Strait of Georgia (Cherry Point) and Hale Passage (Pierce County)-Carr Inlet samples (Trumble 1980). Herring from Hale Passage (Pierce County)-Carr Inlet showed intermediate growth rate and size-at-age, and continued to grow as the fish aged (Trumble 1980). Day (1987, p. 9) concluded that "the exceptionally fast growth rate that characterizes the Strait of Georgia roe herring stock [Cherry Point] strongly suggests that the stock migrates to the open ocean after spawning." Likewise, Lassuy (1989, p. 6) suggested that growth and size-at-age differences between Squaxin Pass and Cherry Point Pacific herring "may result because the Strait of Georgia stocks [Cherry Point] are migratory while the Case Inlet [Squaxin Pass] stocks are resident."

The greater length- and weight-at-age of adult Cherry Point Pacific herring, after age 4, compared to Pacific herring at two sites on West Coast Vancouver Island (WCVI) and to other available locations in Puget Sound and the SOG from 1990 to 2002 are illustrated in Figures 13–29. Data for these comparisons were derived from midwater trawl samples[5] or seine gear samples (Hamer and Schweigert 1990, 1991, 1992, 1993, 1995, 1996, Hamer and Midgley 1997, 1999, Midgley and Hamer 1999, Midgley and Schweigert 2000, 2002a, 2002b, 2002c) obtained during the spawning season for each stock or Herring Section. All British Columbia data were from collections with a majority of the fish expressing a maturity index of four or higher. Length in all cases was recorded as standard length (Gonyea 1985, Hamer 1989).

At age 3, mean length (Figures 14 and 20) and weight (Figures 22 and 28) of Cherry Point Pacific herring, although greater than calculated means for most sites in Washington, are similar to mean lengths and weights computed for Pacific herring in the Canadian SOG and off WCVI. Tables 3 and 4 show pairwise comparison probabilities of length and weight, respectively, for 19 populations at age 3, over the 1990–2002 time period. By age 3, Cherry Point Pacific herring were significantly different ($P \leq 0.05$) in mean length from Interior San Juan Islands, Samish/Portage bays, Fidalgo Bay, Skagit Bay, Port Orchard-Port Madison, and Squaxin Pass but not from Semiahmoo Bay, Port Susan, Port Gamble, Kilisut Harbor, Quartermaster Harbor, and all of the Canadian Herring Sections with the exception of Baynes Sound, which had a significantly greater mean length (Table 3). Similarly, by age 3, Cherry Point Pacific herring had a significantly ($P \leq 0.05$) greater mean weight from Semiahmoo Bay, Interior San Juan Islands, Samish/Portage bays, Fidalgo Bay, Skagit Bay, Port Orchard-Port Madison, and Squaxin Pass but not from Port Susan, Port Gamble, Kilisut Harbor, Quartermaster Harbor, and all of the Canadian Herring Sections (Table 4).

[5] K. Stick, Washington Dept. Fish and Wildlife, La Conner, WA. Pers. commun., October 2004.

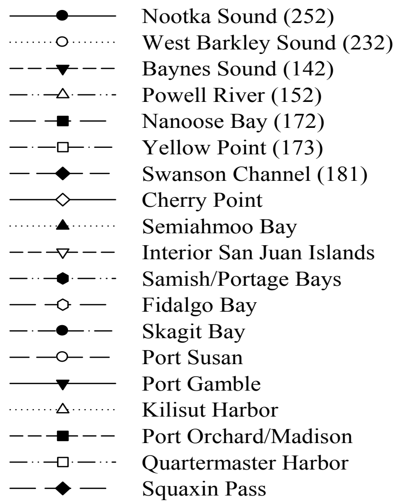

Figure 13. Pacific herring sampling sites and associated graphical symbols necessary for interpretation of Figures 14–19 and 22–27.

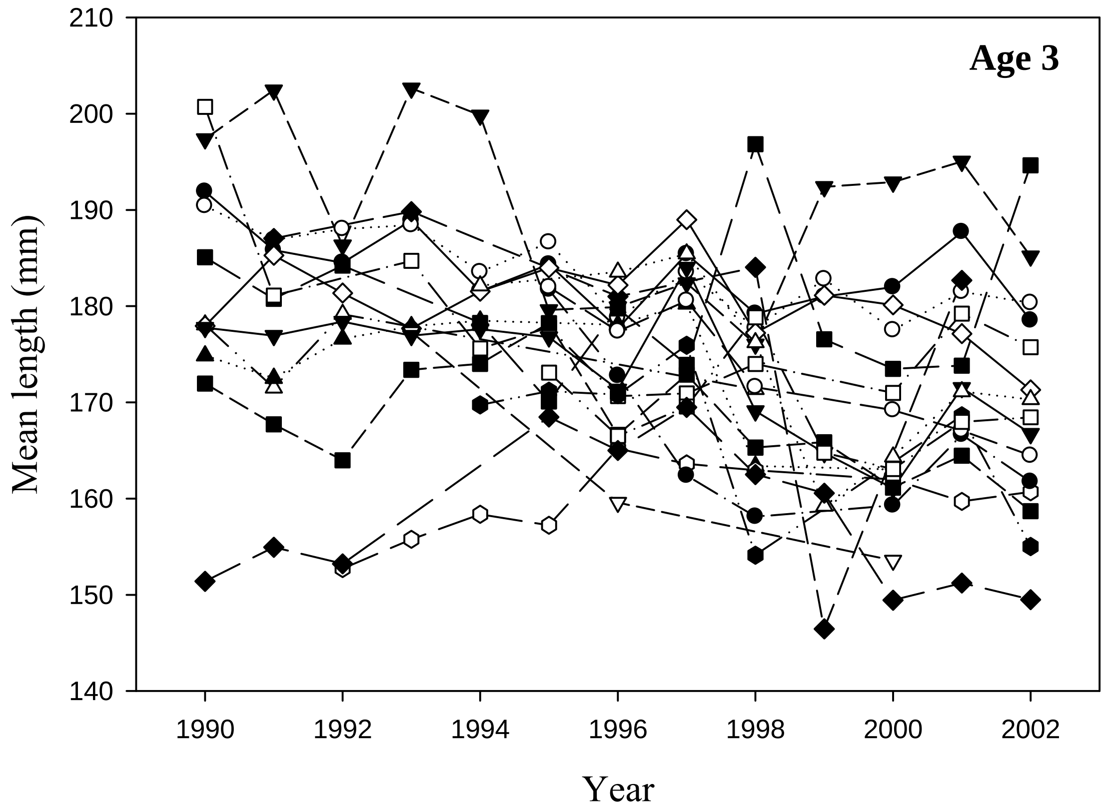

Figure 14. Mean length-at-age for 3-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[6]

[6] See footnote 5.

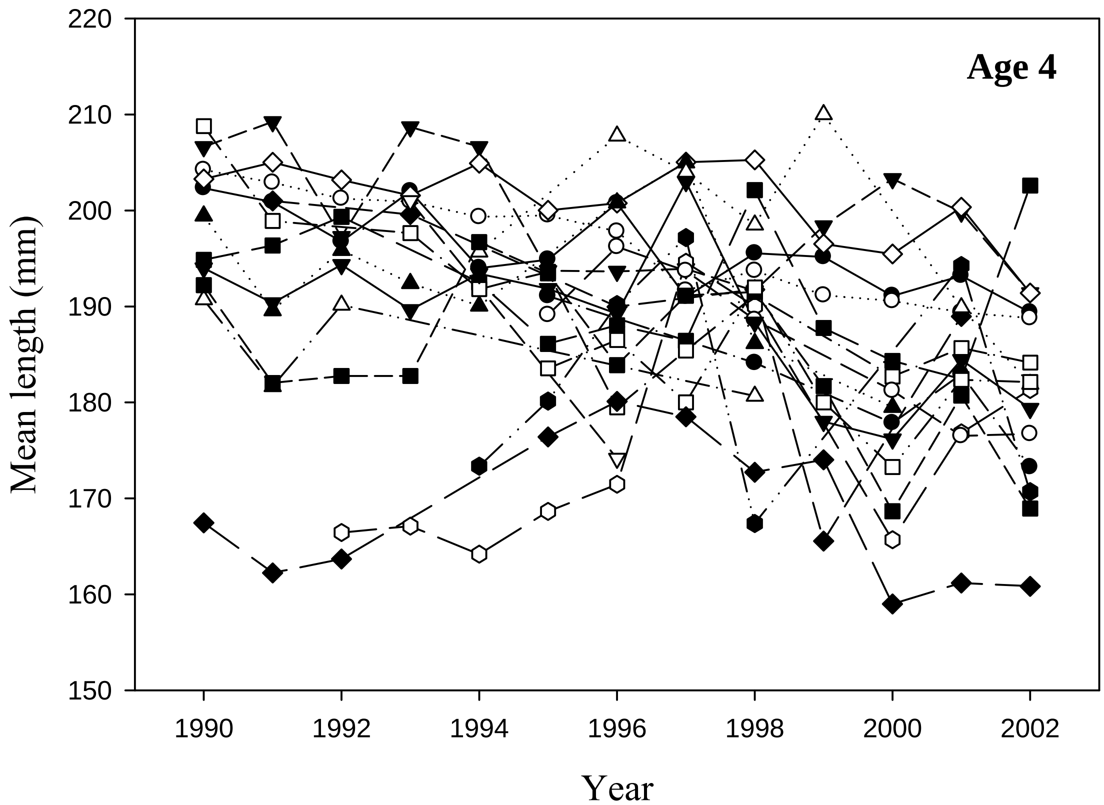

Figure 15. Mean length-at-age for 4-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[7]

[7] See footnote 5.

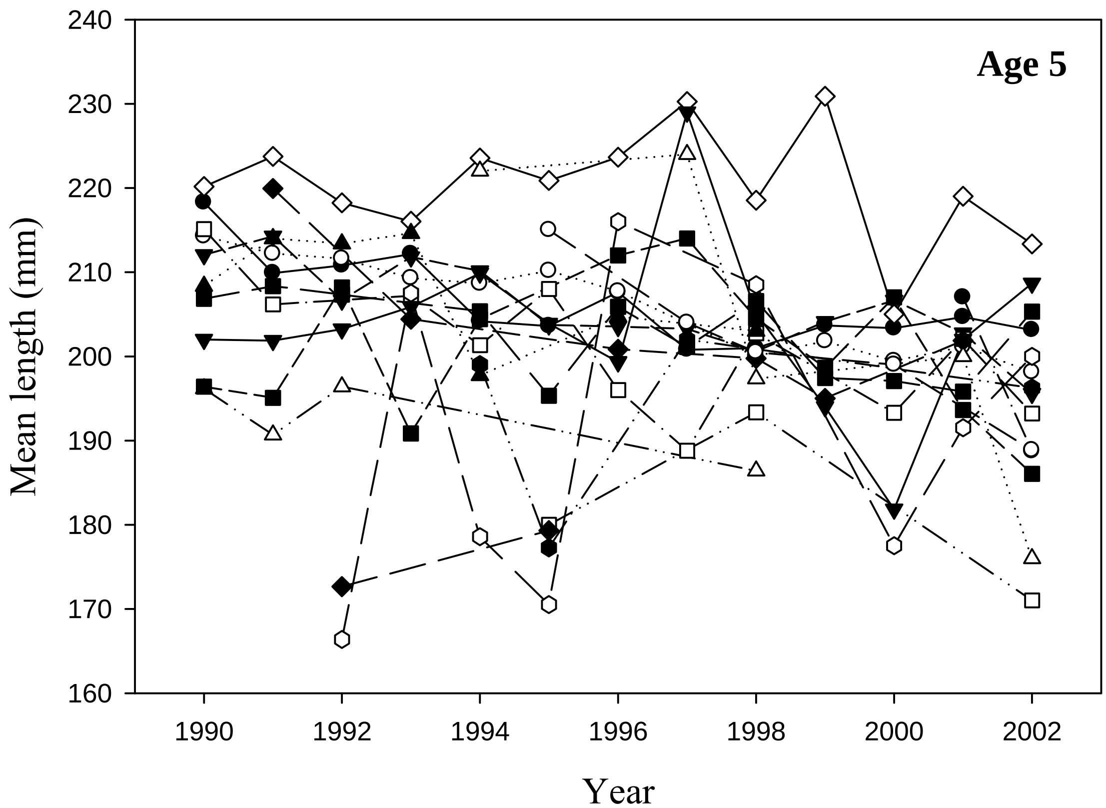

Figure 16. Mean length-at-age for 5-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[8]

[8] See footnote 5.

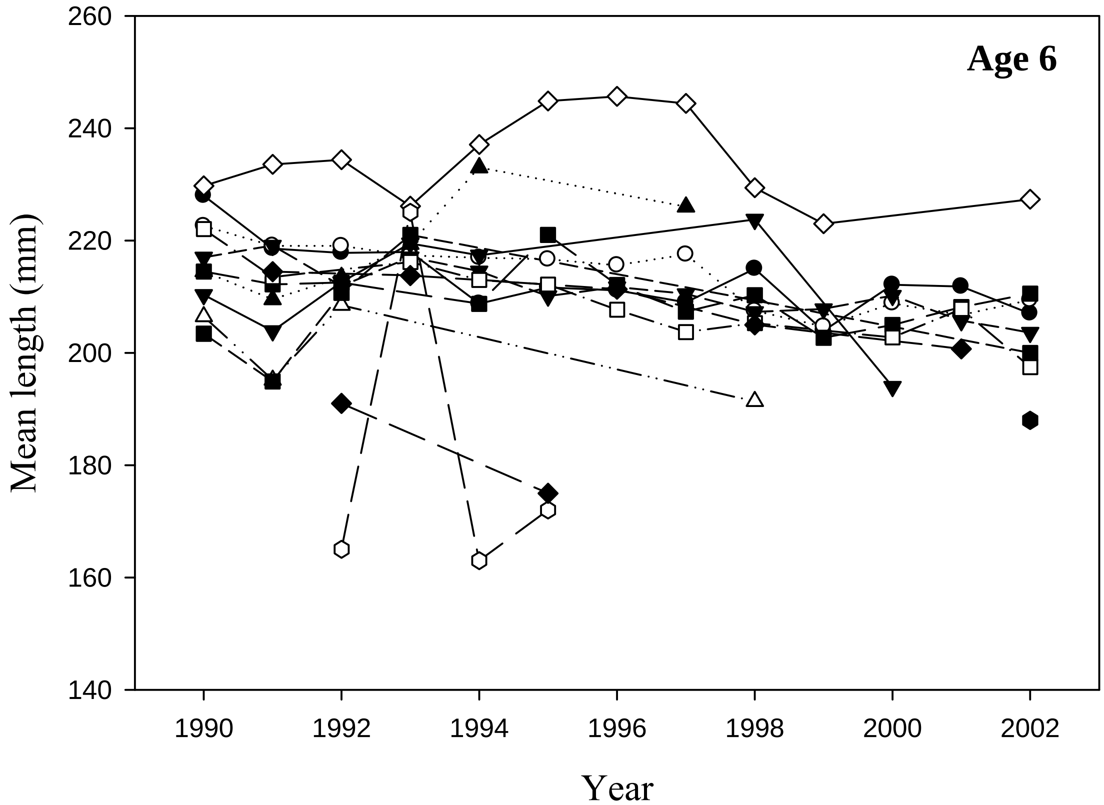

Figure 17. Mean length-at-age for 6-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[9]

[9] See footnote 5.

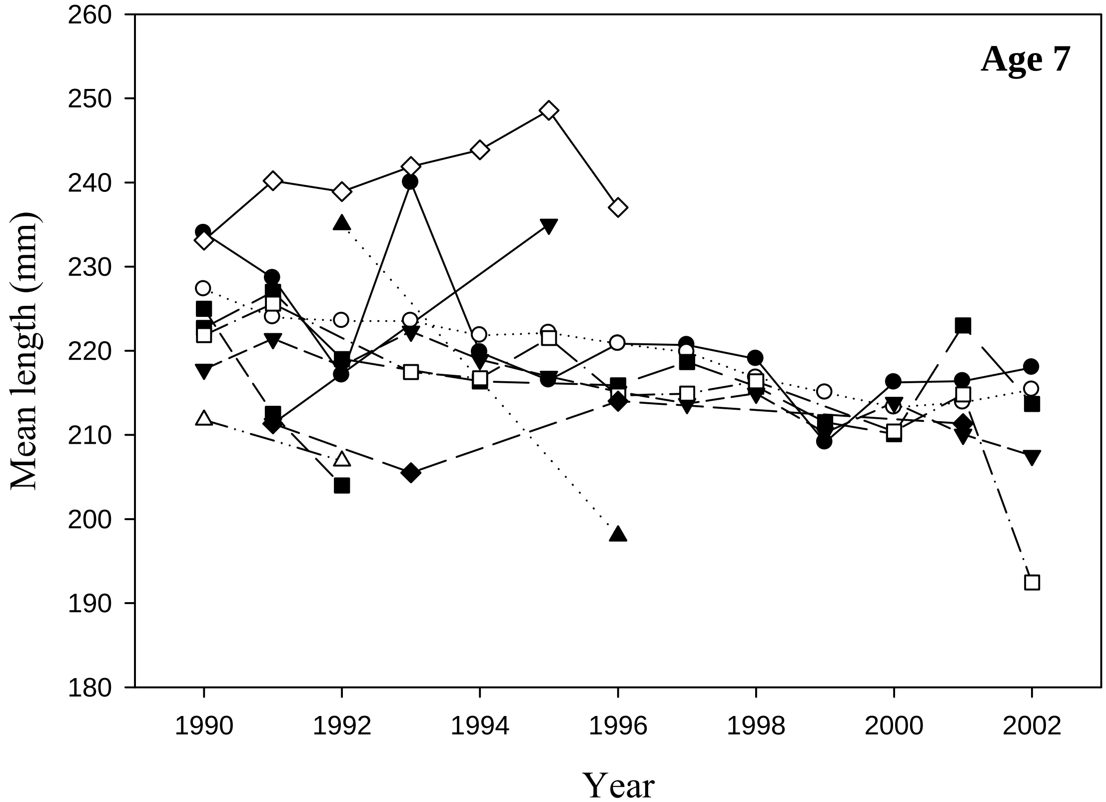

Figure 18. Mean length-at-age for 7-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[10]

[10] See footnote 5.

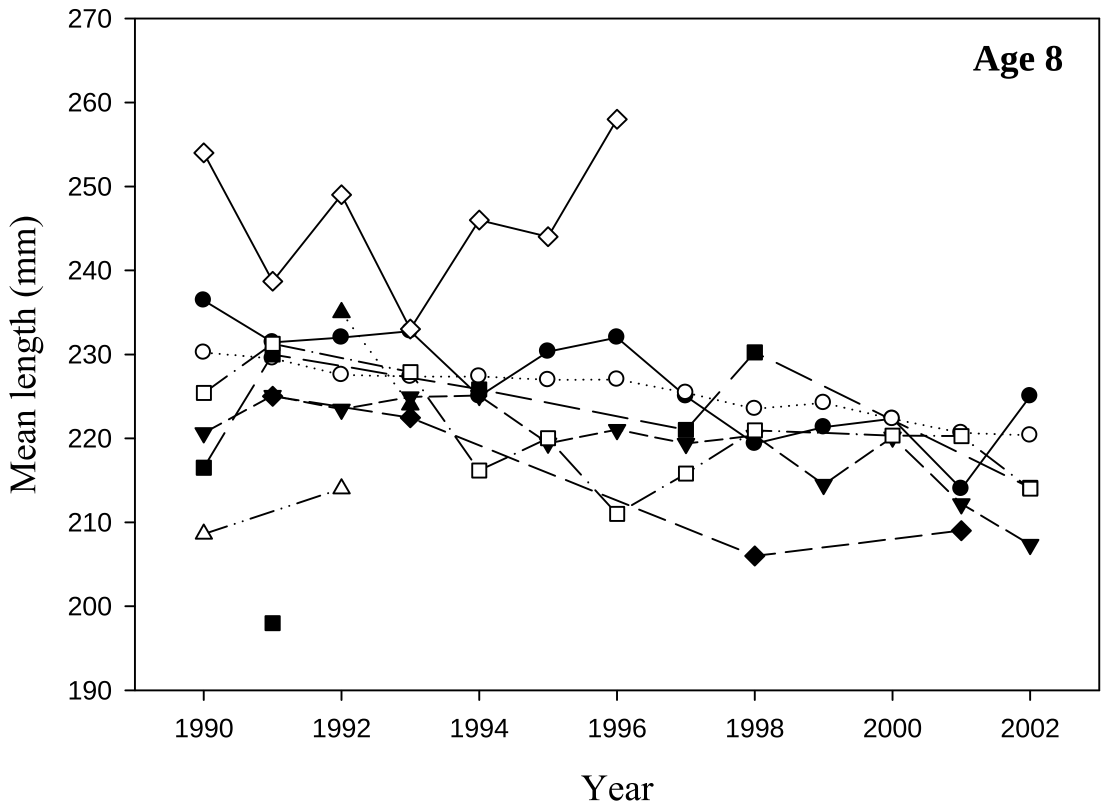

Figure 19. Mean length-at-age for 8-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[11]

[11] See footnote 5.

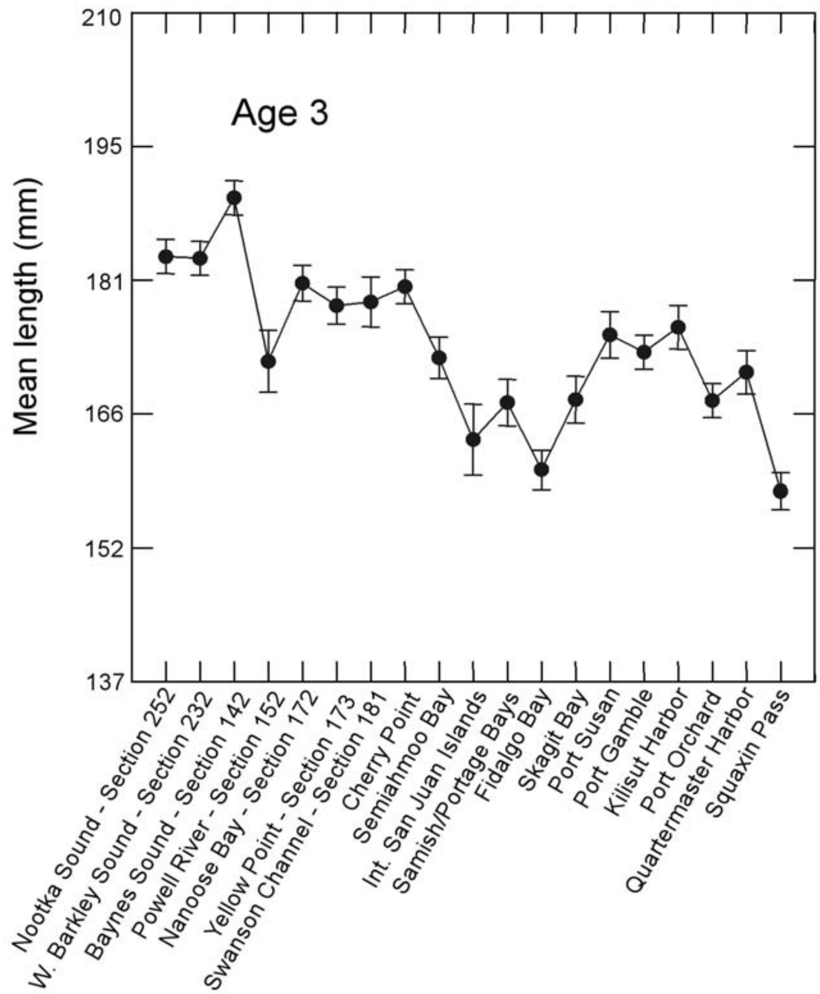

Figure 20. Comparisons of adjusted least squares means and standard errors of length for age-3 Pacific herring over the period 1990–2002 from West Coast Vancouver Island (Sections 232 and 252), Canadian SOG (Sections 142, 152, 172, 173, and 181), and Washington State. The interaction effect of population and year was not statistically significant for age 3 (P = 0.109). Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[12]

[12] See footnote 5.

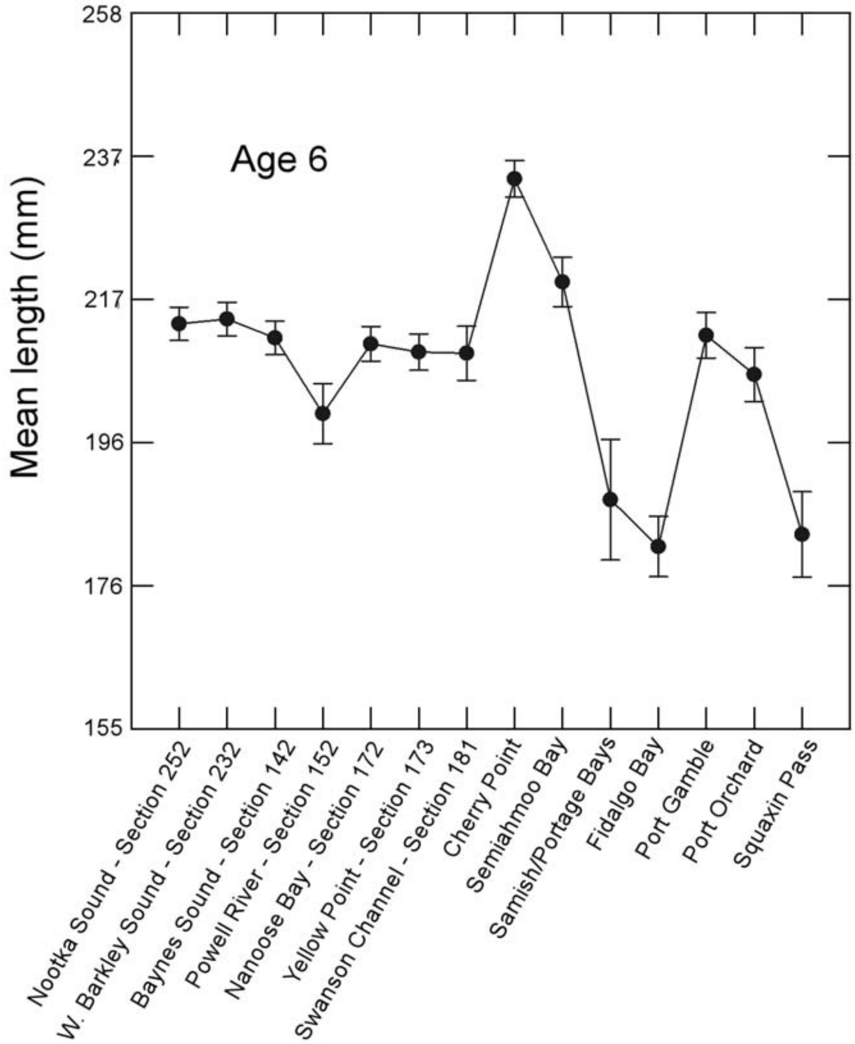

Figure 21. Comparisons of adjusted least squares means and standard errors of length for age-6 Pacific herring over the period 1990–2002 from West Coast Vancouver Island (Sections 232 and 252), Canadian SOG (Sections 142, 152, 172, 173, and 181), and Washington State. The interaction effect of population and year was not statistically significant for age 6 (P = 0.467). Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[13]

[13] See footnote 5.

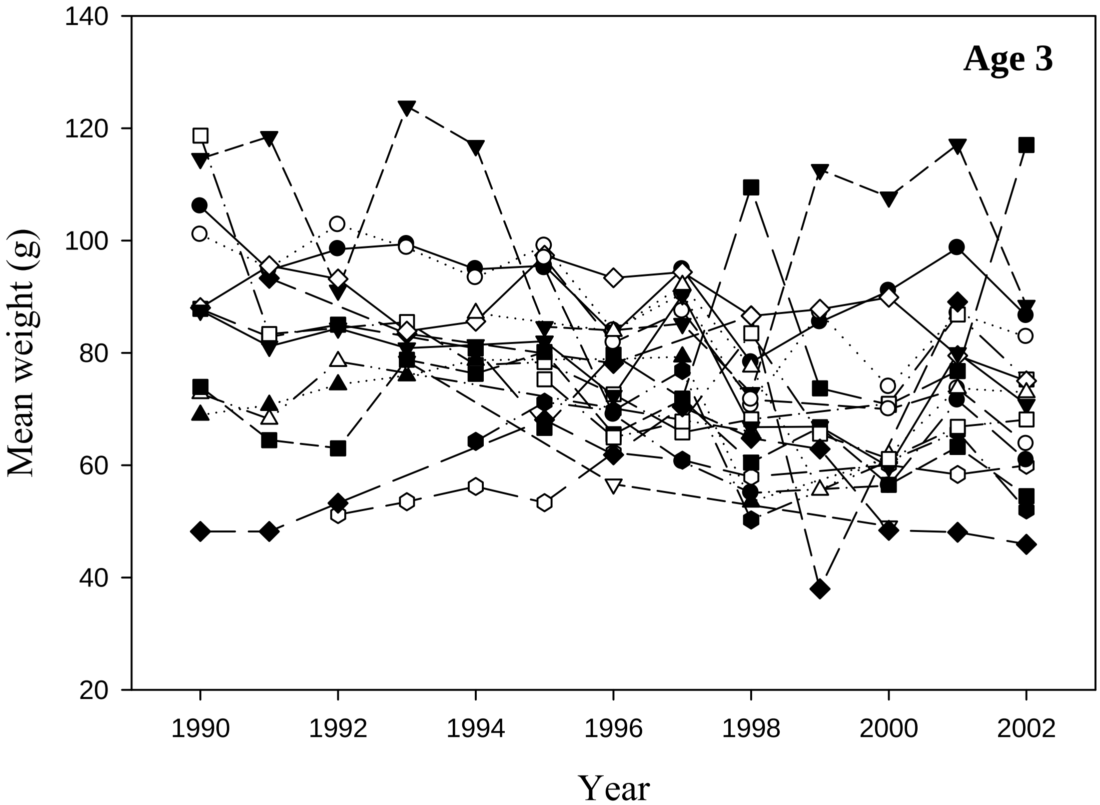

Figure 22. Mean weight-at-age for 3-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[14]

[14] See footnote 5.

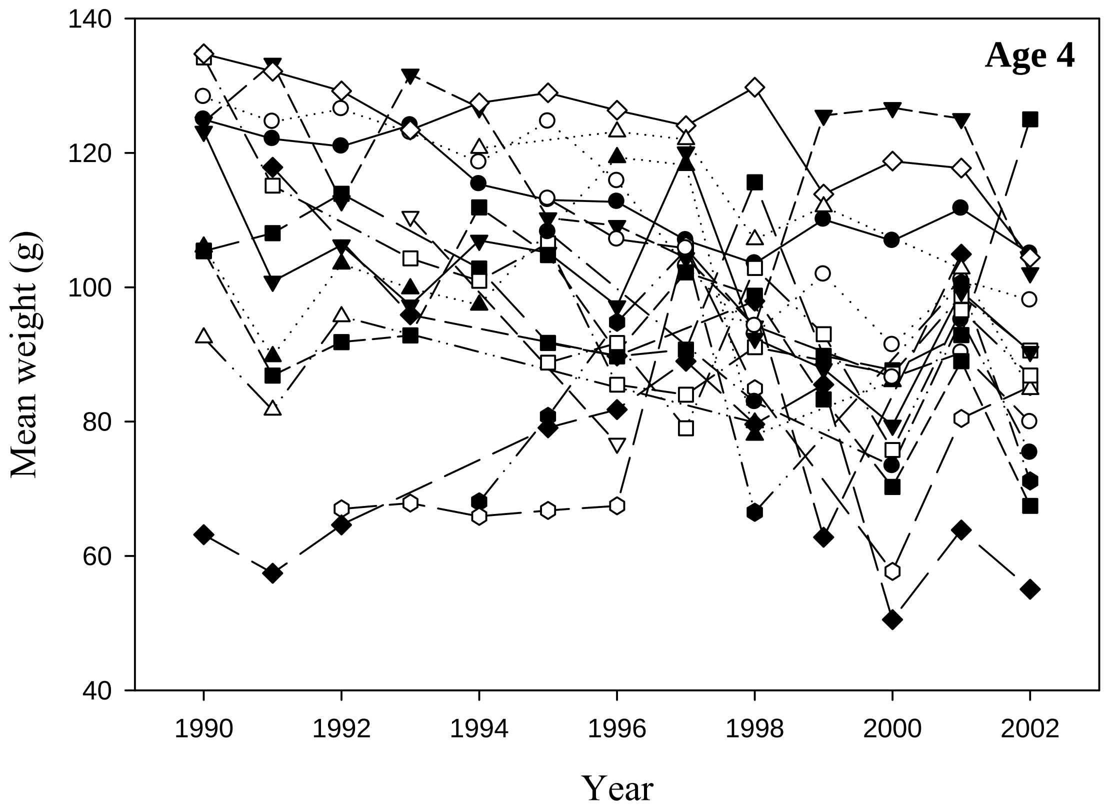

Figure 23. Mean weight-at-age for 4-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[15]

[15] See footnote 5.

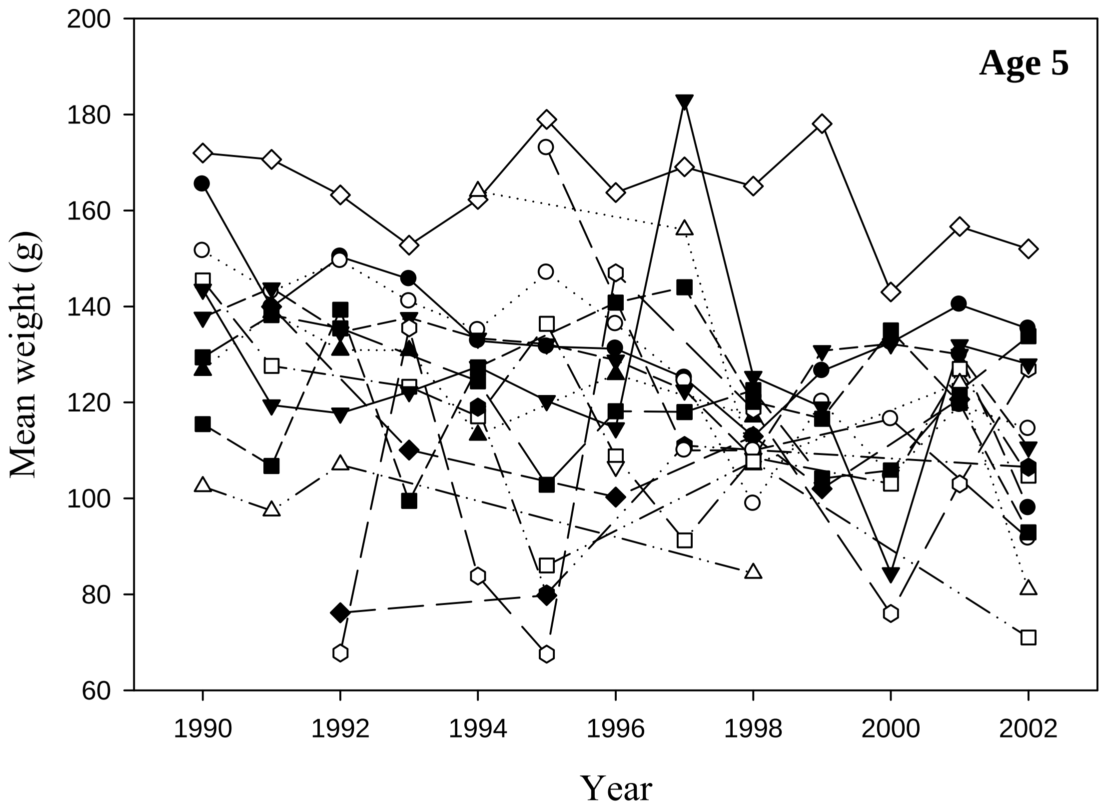

Figure 24. Mean weight-at-age for 5-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[16]

[16] See footnote 5.

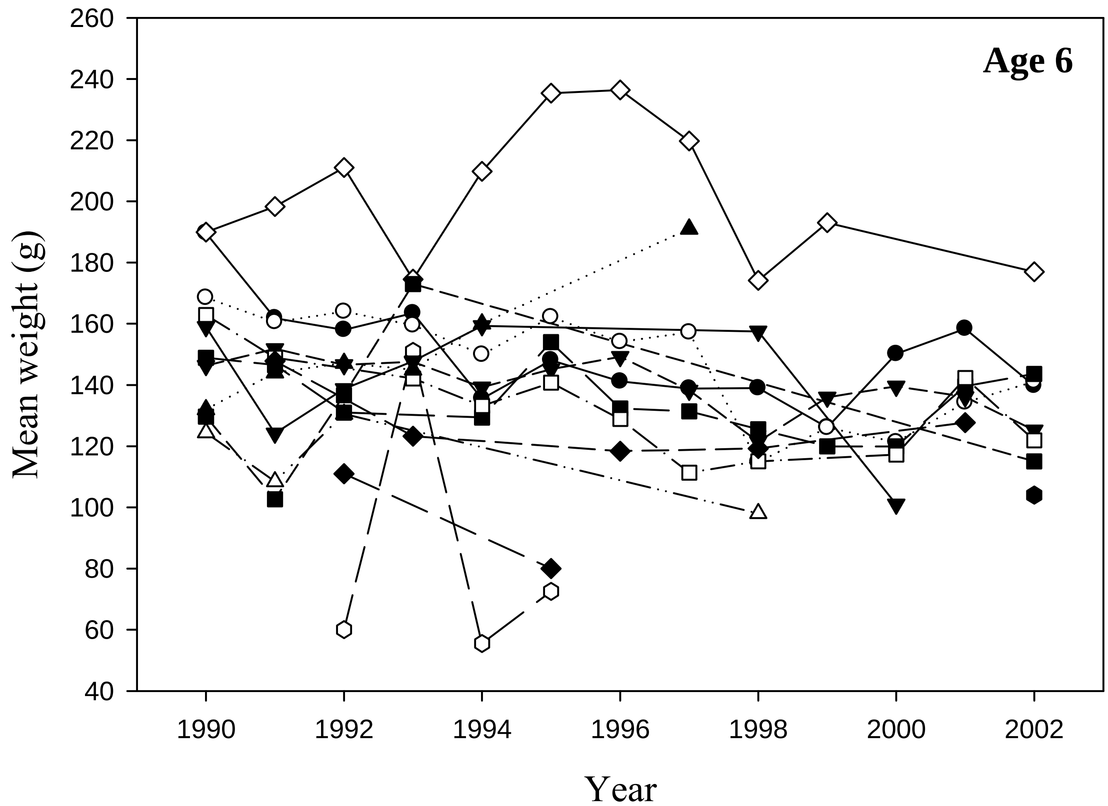

Figure 25. Mean weight-at-age for 6-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[17]

[17] See footnote 5.

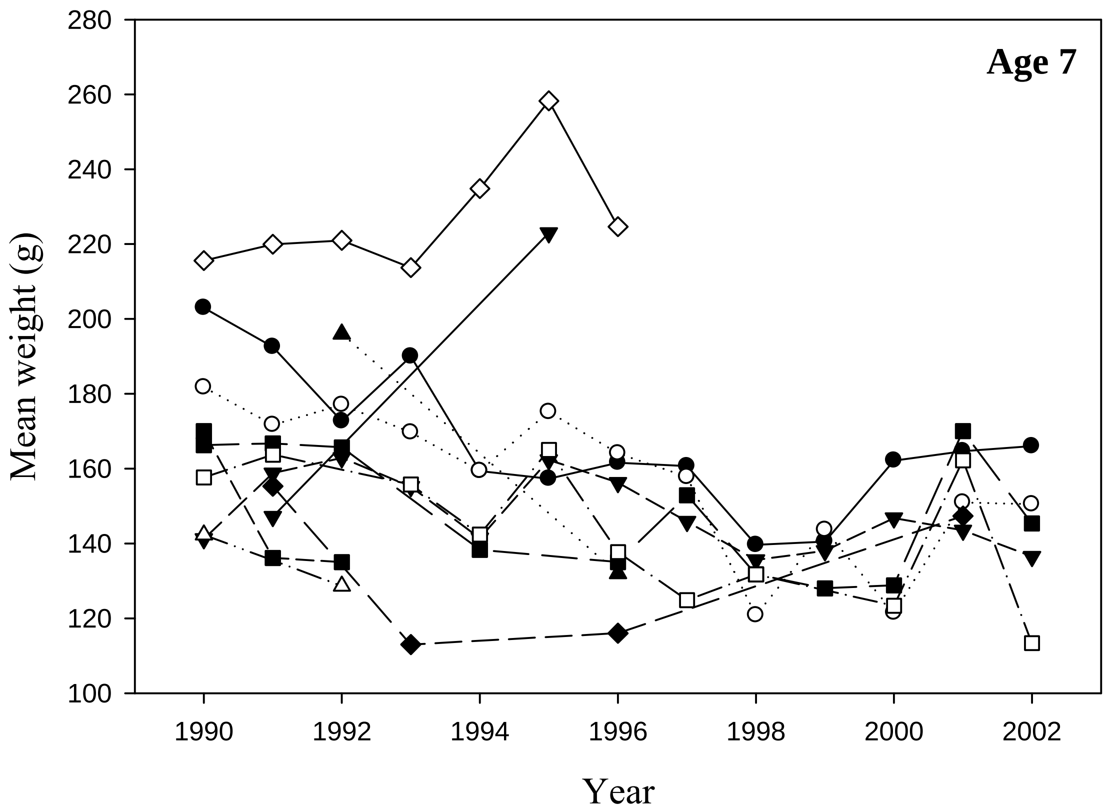

Figure 26. Mean weight-at-age for 7-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[18]

[18] See footnote 5.

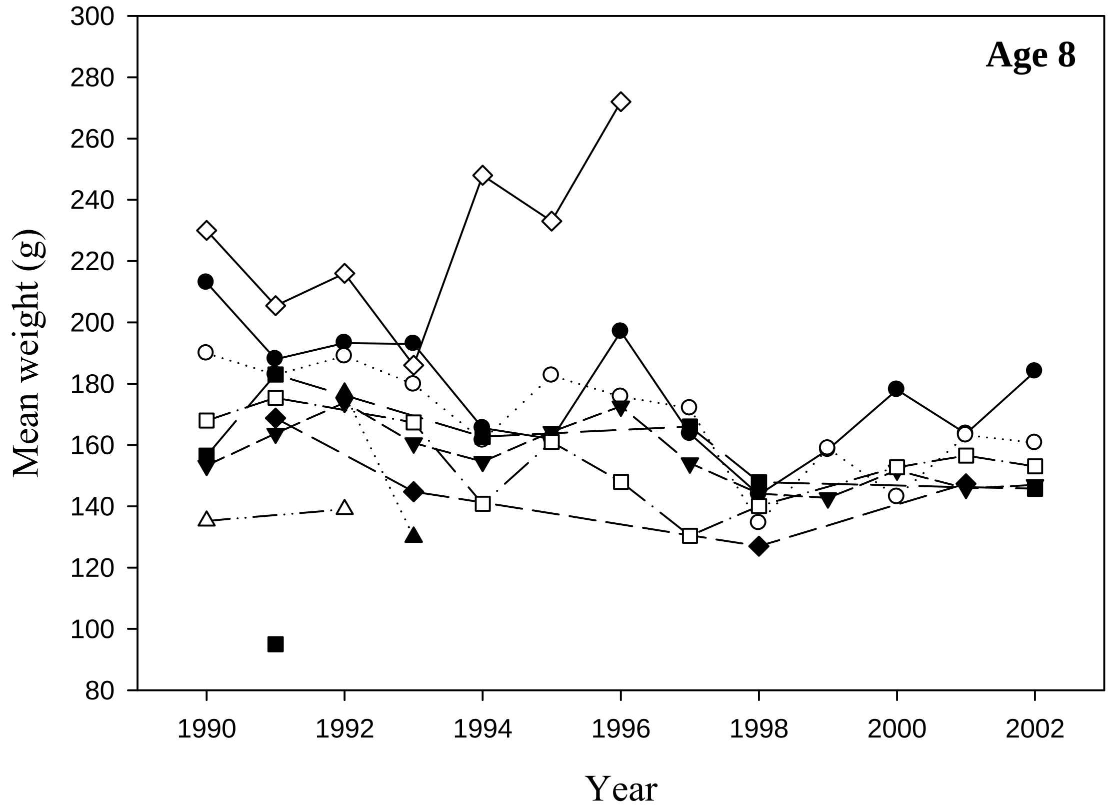

Figure 27. Mean weight-at-age for 8-year-old Pacific herring spawners sampled from 1990 to 2002 on spawning grounds with seine or trawl gear. Sampling sites and symbols as described in Figure 13. Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[19]

[19] See footnote 5.

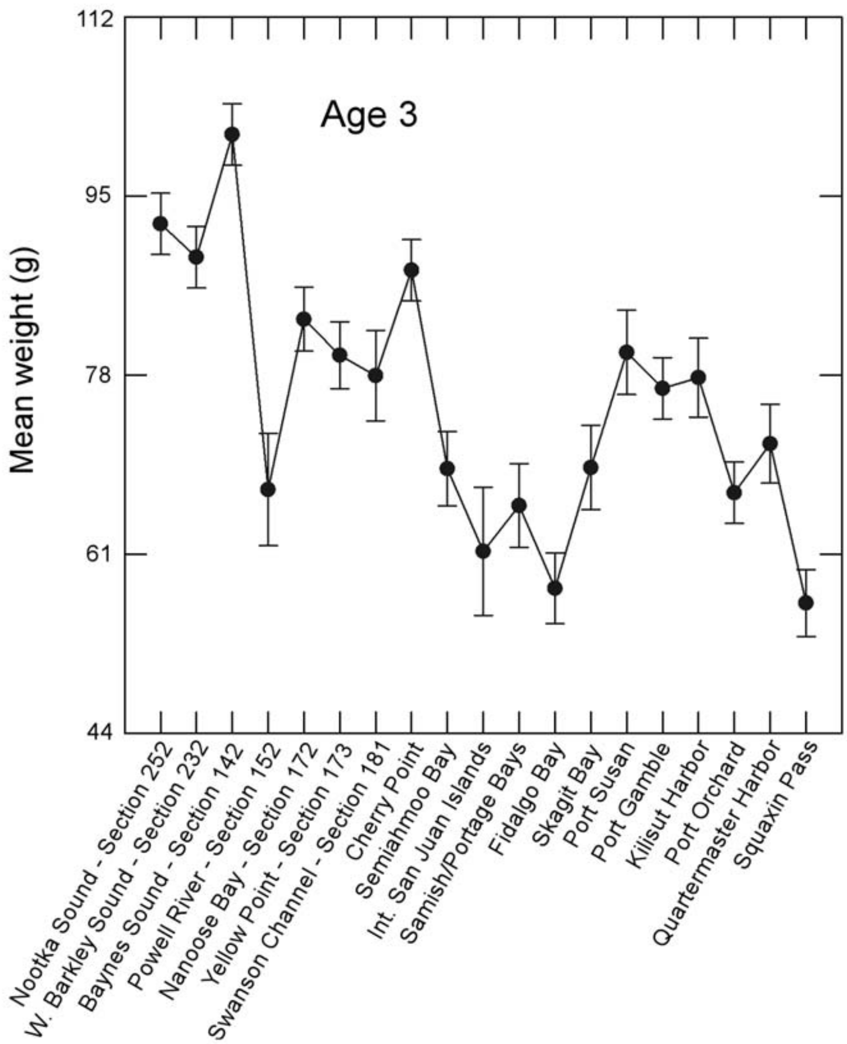

Figure 28. Comparisons of adjusted least squares means and standard errors of weight for age-3 Pacific herring over the period 1990–2002 from West Coast Vancouver Island (sections 232 and 252), Canadian SOG (Sections 142, 152, 172, 173, and 181), and Washington State. The interaction effect of population and year was not statistically significant for age 3 (P = 0.279). Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[20]

[20] See footnote 5.

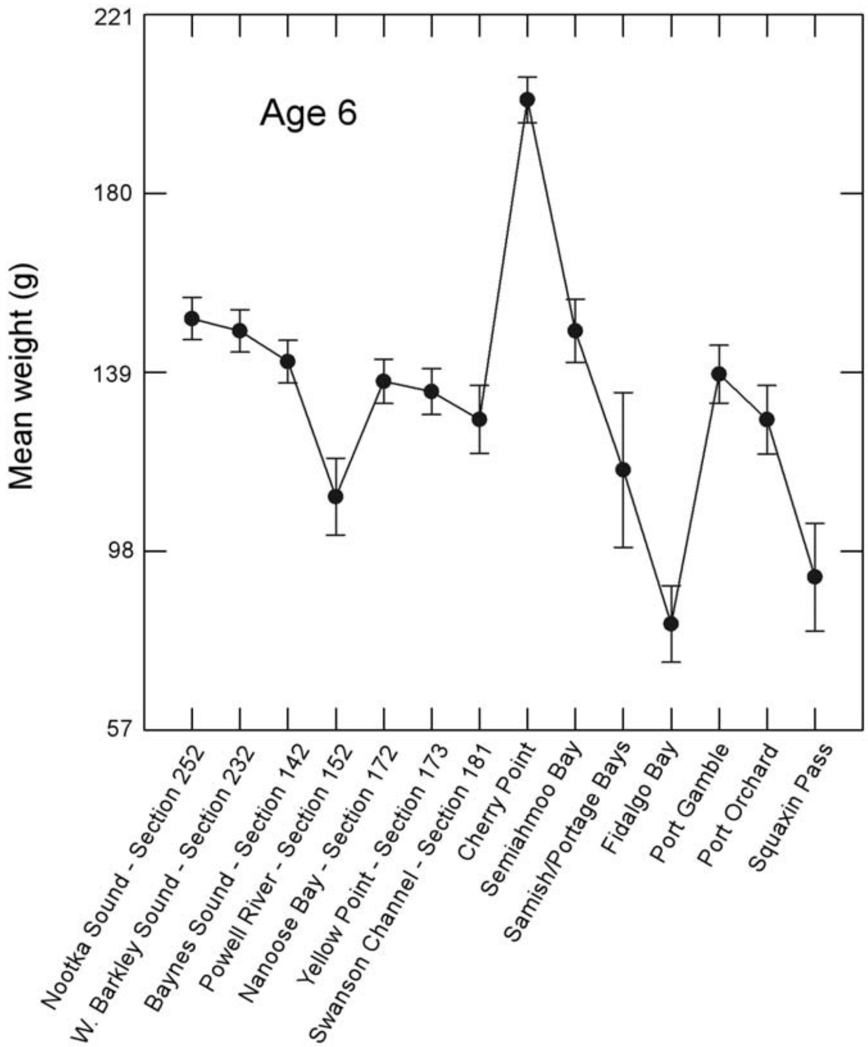

Figure 29. Comparison of adjusted least squares means and standard errors of weight for age-6 Pacific herring over the period 1990–2002 from West Coast Vancouver Island (Sections 232 and 252), Canadian SOG (Sections 142, 152, 172, 173, and 181), and Washington State. The interaction effect of population and year was not statistically significant for age 6 ($P = 0.312$). Data from Hamer and Schweigert (1990, 1991, 1992, 1993, 1995, 1996), Hamer and Midgley (1997, 1999), Midgley and Hamer (1999), Midgley and Schweigert (2000, 2002a, 2002b, 2002c), and WDFW.[21]

[21] See footnote 5.

Table 3. Matrix of pairwise comparison probabilities for age-3 length data from 1990 to 2002 as illustrated in Figure 20. Italic type indicates statistical significance ($P \leq 0.05$) after Bonferroni adjustment. Populations are: 1) Nootka Sound, Section 252; 2) West Barkley Sound, Section 232; 3) Baynes Sound, Section 142; 4) Powell River, Section 152; 5) Nanoose Bay, Section 172; 6) Yellow Point, Section 173; 7) Swanson Channel, Section 181; 8) Cherry Point; 9) Semiahmoo Bay; 10) Interior San Juan Islands; 11) Samish/Portage bays; 12) Fidalgo Bay; 13) Skagit Bay; 14) Port Susan; 15) Port Gamble; 16) Kilisut Harbor; 17) Port Orchard-Port Madison; 18) Quartermaster Harbor; and 19) Squaxin Pass.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1	1.00																		
2	1.00	1.00																	
3	1.00	1.00	1.00																
4	0.60	0.70	*0.00*	*1.00*															
5	1.00	1.00	0.11	1.00	1.00														
6	1.00	1.00	*0.01*	1.00	1.00	1.00													
7	1.00	1.00	0.13	1.00	1.00	1.00	1.00												
8	1.00	1.00	0.05	1.00	1.00	1.00	1.00	1.00											
9	*0.04*	0.05	*0.00*	1.00	1.00	1.00	1.00	1.00	1.00										
10	*0.00*	*0.00*	*0.00*	1.00	*0.02*	0.17	0.31	*0.03*	1.00	1.00									
11	*0.00*	*0.00*	*0.00*	1.00	*0.01*	0.23	0.63	*0.02*	1.00	1.00	1.00								
12	*0.00*	*0.00*	*0.00*	0.62	*0.00*	*0.00*	*0.00*	*0.00*	*0.02*	1.00	1.00	1.00							
13	*0.00*	*0.00*	*0.00*	1.00	*0.02*	0.33	0.83	*0.02*	1.00	1.00	1.00	1.00	1.00						
14	1.00	1.00	*0.00*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.00*	1.00	1.00					
15	*0.02*	*0.02*	*0.00*	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	*0.00*	1.00	1.00	1.00				
16	1.00	1.00	*0.00*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.00*	1.00	1.00	1.00	1.00			
17	*0.00*	*0.00*	*0.00*	1.00	*0.00*	*0.04*	0.23	*0.00*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
18	*0.01*	*0.01*	*0.00*	1.00	0.32	1.00	1.00	0.42	1.00	1.00	1.00	0.18	1.00	1.00	1.00	1.00	1.00	1.00	
19	*0.00*	*0.00*	*0.00*	0.08	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	1.00	0.59	1.00	0.44	*0.00*	*0.00*	*0.00*	0.08	*0.01*	1.00

Table 4. Matrix of pairwise comparison probabilities for age-3 weight data from 1990 to 2002 as illustrated in Figure 28. Italic type indicates statistical significance (P ≤ 0.05) after Bonferroni adjustment. Populations are: 1) Nootka Sound, Section 252; 2) West Barkley Sound, Section 232; 3) Baynes Sound, Section 142; 4) Powell River, Section 152; 5) Nanoose Bay, Section 172; 6) Yellow Point, Section 173; 7) Swanson Channel, Section 181; 8) Cherry Point; 9) Semiahmoo Bay; 10) Interior San Juan Islands; 11) Samish/Portage bays; 12) Fidalgo Bay; 13) Skagit Bay; 14) Port Susan; 15) Port Gamble; 16) Kilisut Harbor; 17) Port Orchard-Port Madison; 18) Quartermaster Harbor; and 19) Squaxin Pass.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1	1.00																		
2	1.00	1.00																	
3	1.00	0.91	1.00																
4	*0.01*	*0.06*	*0.00*	*1.00*															
5	1.00	1.00	*0.01*	1.00	1.00														
6	0.74	1.00	*0.00*	1.00	1.00	1.00													
7	1.00	1.00	*0.00*	1.00	1.00	1.00	1.00												
8	1.00	1.00	0.36	0.13	1.00	1.00	1.00	1.00											
9	*0.00*	*0.00*	*0.00*	1.00	0.46	1.00	1.00	*0.01*	1.00										
10	*0.00*	*0.01*	*0.00*	1.00	0.24	1.00	1.00	*0.02*	1.00	1.00									
11	*0.00*	*0.00*	*0.00*	1.00	0.09	0.98	1.00	*0.00*	1.00	1.00	1.00								
12	*0.00*	*0.00*	*0.00*	1.00	*0.00*	*0.00*	0.05	*0.00*	1.00	1.00	1.00	1.00							
13	*0.00*	*0.01*	*0.00*	1.00	0.98	1.00	1.00	*0.04*	1.00	1.00	1.00	1.00	1.00						
14	1.00	1.00	*0.01*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.00*	1.00	1.00					
15	*0.04*	0.51	*0.00*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.01*	1.00	1.00	1.00				
16	0.43	1.00	*0.00*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.02*	1.00	1.00	1.00	1.00			
17	*0.00*	*0.00*	*0.00*	1.00	*0.02*	0.49	1.00	*0.00*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
18	*0.00*	0.05	*0.00*	1.00	1.00	1.00	1.00	0.12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
19	*0.00*	*0.00*	*0.00*	1.00	*0.00*	*0.00*	*0.01*	*0.00*	1.00	1.00	1.00	1.00	1.00	*0.00*	*0.00*	*0.00*	1.00	0.42	1.00

However, at age 5 and after, mean length (Figures 16–19 and 21) and weight (Figures 24–27, and 29) of Cherry Point Pacific herring were greater than calculated means for all sites in Washington, the Canadian SOG, and off WCVI from 1990 to 2002. Tables 5 and 6 show pairwise comparison probabilities of length and weight, respectively, for 14 populations at age 6 over the 1990–2002 time period. Several populations had no fish that lived to age 6. Tables 5 and 6 illustrate that Cherry Point Pacific herring were significantly ($P \leq 0.05$) longer and heavier than all other stocks or herring sections included in the analysis.

Similar analyses were attempted for readily available length and weight data from the five-year period between 1976 and 1980, although lack of data from Washington State stocks other than Cherry Point limited the comparison to Cherry Point and several British Columbia herring sections (Figures 30 and 31). Again, data for these comparisons were derived from midwater trawl samples[22] or seine gear samples (Hourston 1981a) obtained during the spawn season for each stock or herring section. All British Columbia data were from collections with a majority of the fish expressing a maturity index of four or higher. Length in all cases was recorded as standard length (Gonyea 1985, Hamer 1989). During this time period, differences in mean length of Cherry Point Pacific herring were consistently greater after age 4 than in two WCVI herring sections and in six other SOG herring sections, although these differences were not always statistically significant (Figure 30). However, analysis of mean weight-at-age indicated that Cherry Point Pacific herring were statistically heavier than all the British Columbia herring sections included in the analysis from age 3 to age 8 (Figure 31).

Annulus Patterns

Trumble (1980, 1983) reported that Strait of Georgia (Cherry Point stock) Pacific herring typically had a small diameter first scale annulus compared to other Puget Sound Pacific herring stocks, but showed normal growth to continue after age 1. Trumble (1980, p. 108) also stated that Cherry Point Pacific herring could be "separated from other herring because scale quality is very bad in terms of clarity and reliability. False annuli are common and make age determination difficult."

Age Composition

Pacific herring age at first maturity ranges from 2 to 5 years (Hay 1985). However, along the west coast of North America, populations of Pacific herring exhibit a latitudinal cline in age-at-maturity, such that Pacific herring in southern locations (e.g., California) mature at an early age and Pacific herring in the north (e.g., Bering Sea) mature at later ages (Hay 1985, Schweigert et al. 2002). Ware (1985) emphasized that age at first maturity decreases with increasing exploitation. In other words, Pacific herring populations typically begin spawning at an earlier age when under stress from fishing pressure or other forms of mortality that act on older age classes (Ware 1985).

Markiewicz et al. (2001) and Landis et al. (2004) interpreted Cherry Point Pacific herring age composition data from the mid-1970s (Figure 32) as evidence of apparent immigration into

[22] See footnote 5.

Table 5. Matrix of pairwise comparison probabilities for age-6 length data from 1990 to 2002 as illustrated in Figure 21. Italic type indicates statistical significance ($P \leq 0.05$) after Bonferroni adjustment. Populations are: 1) Nootka Sound, Section 252; 2) West Barkley Sound, Section 232; 3) Baynes Sound, Section 142; 4) Powell River, Section 152; 5) Nanoose Bay, Section 172; 6) Yellow Point, Section 173; 7) Swanson Channel, Section 181; 8) Cherry Point; 9) Semiahmoo Bay; 10) Samish/Portage bays; 11) Fidalgo Bay; 12) Port Gamble; 13) Port Orchard-Port Madison; and 14) Squaxin Pass.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	1.00													
2	1.00	1.00												
3	1.00	1.00	1.00											
4	0.09	0.05	0.35	1.00										
5	1.00	1.00	1.00	0.58	1.00									
6	1.00	1.00	1.00	1.00	1.00	1.00								
7	1.00	1.00	1.00	1.00	1.00	1.00	1.00							
8	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	1.00						
9	1.00	1.00	1.00	*0.04*	1.00	1.00	1.00	*0.01*	1.00					
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.00*	1.00	1.00				
11	*0.00*	*0.00*	*0.00*	0.16	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	1.00	1.00			
12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.00*	1.00	1.00	*0.00*	1.00		
13	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.00*	1.00	1.00	*0.00*	1.00	1.00	
14	*0.00*	*0.00*	*0.00*	1.00	*0.00*	*0.00*	*0.01*	*0.00*	*0.00*	1.00	1.00	*0.00*	0.09	1.00

Table 6. Matrix of pairwise comparison probabilities for age-6 weight data from 1990 to 2002 as illustrated in Figure 29. Italic type indicates statistical significance ($P \leq 0.05$) after Bonferroni adjustment. Populations are: 1) Nootka Sound, Section 252; 2) West Barkley Sound, Section 232; 3) Baynes Sound, Section 142; 4) Powell River, Section 152; 5) Nanoose Bay, Section 172; 6) Yellow Point, Section 173; 7) Swanson Channel, Section 181; 8) Cherry Point; 9) Semiahmoo Bay; 10) Samish/Portage bays; 11) Fidalgo Bay; 12) Port Gamble; 13) Port Orchard-Port Madison; and 14) Squaxin Pass.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	1.00													
2	1.00	1.00												
3	1.00	1.00	1.00											
4	*0.01*	*0.03*	0.30	1.00										
5	1.00	1.00	1.00	1.00	1.00									
6	1.00	1.00	1.00	1.00	1.00	1.00								
7	1.00	1.00	1.00	1.00	1.00	1.00	1.00							
8	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	1.00						
9	1.00	1.00	1.00	0.11	1.00	1.00	1.00	*0.00*	1.00					
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.00*	1.00	1.00				
11	*0.00*	*0.00*	*0.00*	1.00	*0.00*	*0.00*	*0.01*	*0.00*	*0.00*	1.00	1.00			
12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.00*	1.00	1.00	*0.00*	1.00		
13	1.00	1.00	1.00	1.00	1.00	1.00	1.00	*0.00*	1.00	1.00	*0.01*	1.00	1.00	
14	*0.00*	*0.01*	*0.04*	1.00	0.12	0.23	1.00	*0.00*	*0.02*	1.00	1.00	0.13	1.00	1.00

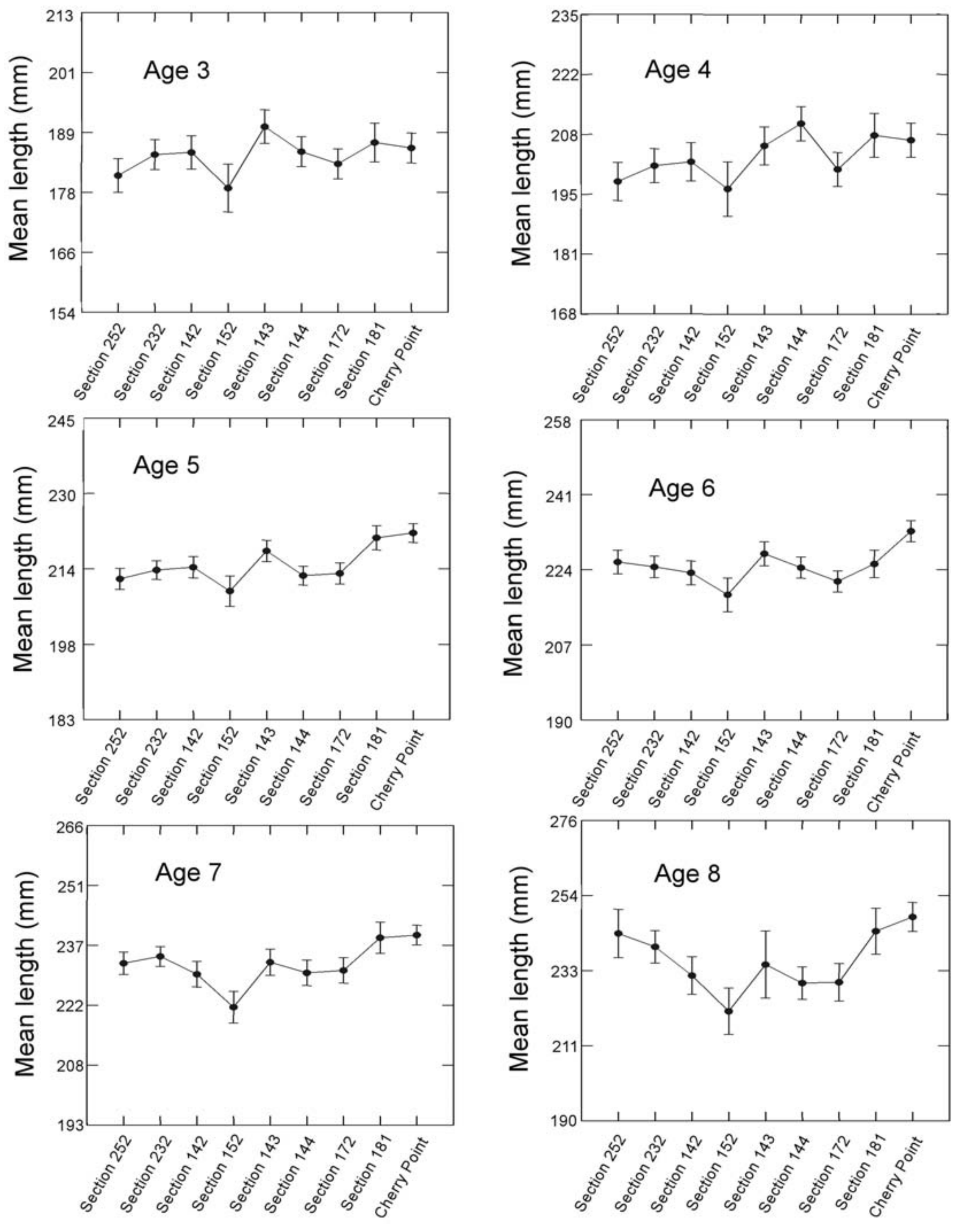

Figure 30. Comparisons of adjusted least squares means and standard errors of length for Pacific herring over the period 1976–1980 at Cherry Point, Washington, and in British Columbia (old Section designations) at Nootka Sound (Section 252), West Barkley Sound (Section 232), Baynes Sound (Section 142), Lund (Section 152), Qualicum (Section 143), French Creek (Section 144), Nanoose Bay (Section 172), and Other Area 18 (Section 181). The interaction effects of population and year were statistically insignificant ($P > 0.05$) for all ages. Data from Hourston (1981) and WDFW.[23]

[23] See footnote 5.

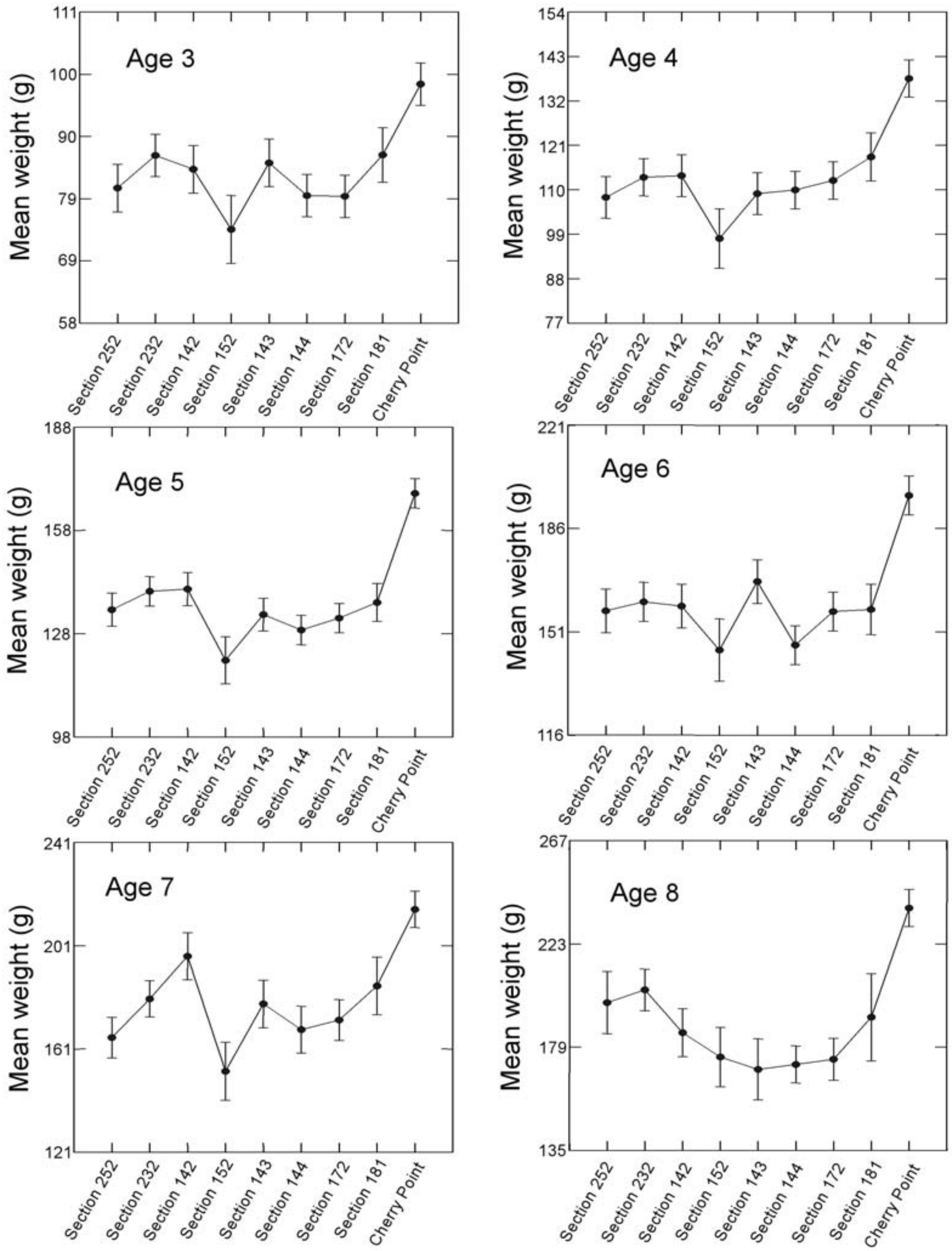

Figure 31. Comparisons of adjusted least squares means and standard errors of weight for Pacific herring over the period 1976–1980 at Cherry Point, Washington, and in British Columbia at Nootka Sound (Section 252), West Barkley Sound (Section 232), Baynes Sound (Section 142), Lund (Section 152), Qualicum (Section 143), French Creek (Section 144), Nanoose Bay (Section 172), and Other Area 18 (Section 181). The interaction effects of population and year were statistically insignificant ($P > 0.05$) for all ages. Data from Hourston (1981) and WDFW.[24]

[24] See footnote 5.

the Cherry Point stock from other sources and as evidence that Cherry Point Pacific herring may be part of a larger metapopulation. In particular, Landis et al. (2004, p. 281) stated that:

> From 1973 until 1979 there was an apparent greater number of Age 3 fish than could be accounted for from the previous years' numbers of Age 2 fish. Although the increase may be the result of sampling error, the increases were occasionally 30–70 times the expected number. This suggests that at one time there was immigration into the Cherry Point Pacific herring population that corresponded to the periods of high population numbers.

These conclusions are based on the assumption that age-at-maturity (or age of recruitment into the spawning population) has remained constant since the 1970s and that all age-2 Pacific herring were mature and part of the spawning population during the 1970s. Alternatively, it is possible that during the 1970s to the mid-1980s a large portion of the Cherry Point stock did not recruit into the spawning population until age 3 or perhaps age 4. Thus, a large percentage of the age-2 Pacific herring would not be present on the spawning grounds as they were still immature. The previous status review (Stout et al. 2001a, their table 12, p. 131) recognized the above relationship of age-2 and age-3 Pacific herring at Cherry Point and interpreted these data as evidence of "a reduction in the age at maturity." A similar situation obtains in northern British Columbia where Pacific herring are fully recruited into the spawning population at age 4 and there are typically more age-4 fish than age-3 fish in the catch. This has generally been interpreted as evidence that a large part of the age-3 cohort is immature and has yet to recruit into the spawning population and has been called the "age 3 immature hypothesis" (Hay and McCarter 1999, p. 4). However, alternative hypotheses invoke episodic migrations of mature Pacific herring from southern to northern areas to explain the apparent discrepancies between percent-at-age data and observed age-at-maturity (Hay and McCarter 1999). These competing hypotheses remain unresolved. Therefore age composition data cited in Markiewicz et al. (2001) and Landis et al. (2004) do not necessarily provide evidence of straying into the Cherry Point stock from other sources.

Parasite Incidence

Katz (1942) stated that Pacific herring collected in Willapa Bay in 1937 were heavily infested with nematodes, but that similar infestations were not present in Pacific herring collected in Puget Sound in 1936–37. Conversely, Trumble (1980, p. 108) stated that "infestation of the roundworm parasite *Anasakis* [sic] occurs much more heavily for the sac-roe herring [Cherry Point stock] than for herring elsewhere in Puget Sound." Similarly, O'Toole et al. (2000, p. 10) stated that "nonquantitative observations indicate body cavities of Cherry Point herring are normally full of the roundworm *Anasakis* [sic], which is uncommonly noted in adult herring from other areas in Puget Sound." According to MacKenzie (1987), the definitive host for adult *Anisakis simplex* are cetaceans such as whales and porpoises, and the first intermediate host(s) are euphausids. Pacific herring become infected with *Anisakis* larvae when they ingest infected euphausids. The implication is that Cherry Point Pacific herring may be feeding in a different region of the ocean than other stocks of Puget Sound Pacific herring.

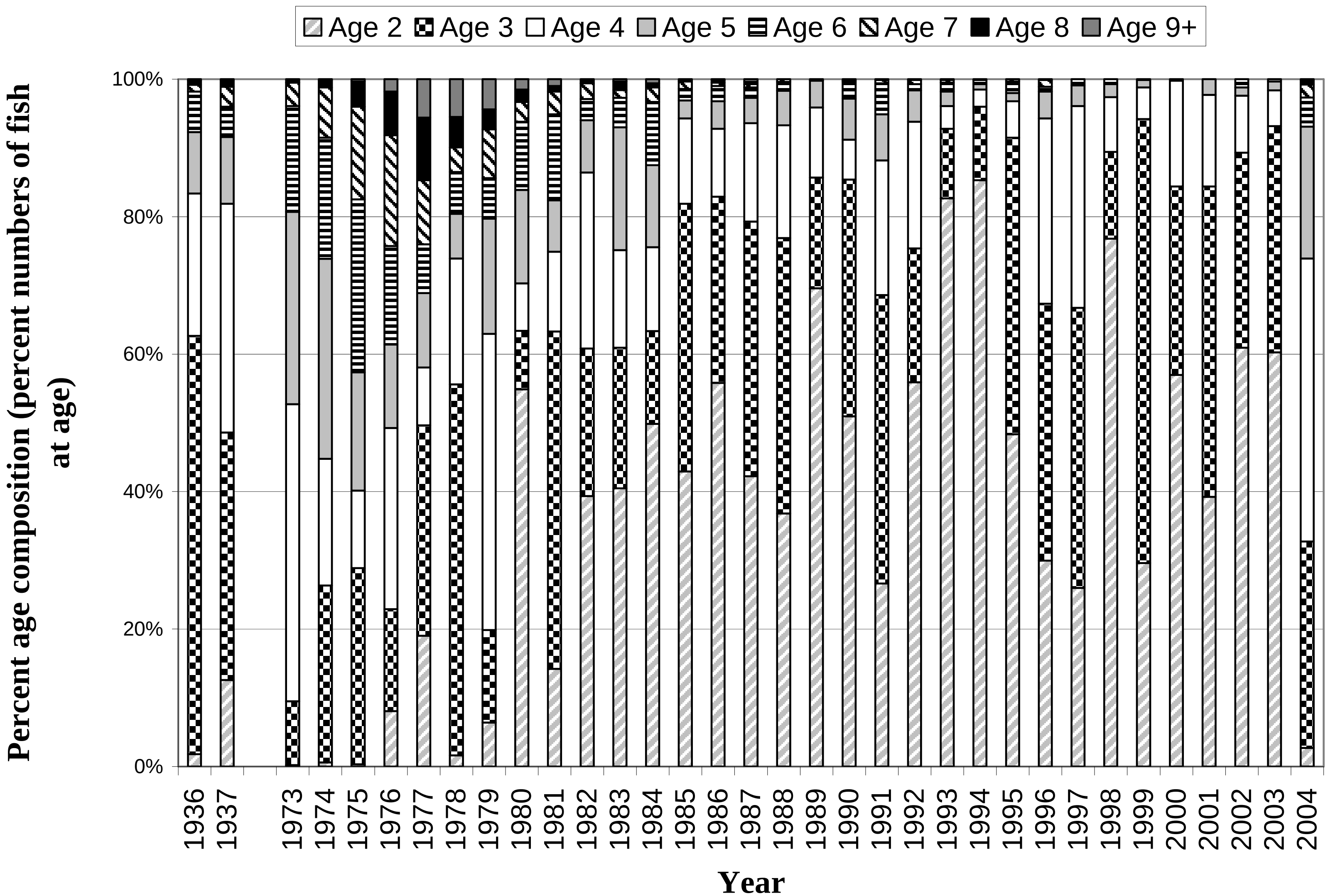

Figure 32. Cherry Point Pacific herring age composition of spawners in 1936–1937 (as Birch Bay) (Chapman et al. 1941) and 1973–2004.[25]

[25] See footnote 5.

Artificial Tagging

Much of the information on tagging of Pacific herring in British Columbia, utilizing metallic belly tags (1936–1967) and plastic anchor tags (1979–1991), that was reviewed by Stout et al. (2001a) has since appeared in the peer-reviewed literature in Hay et al. (2001a). In addition, Hay and McKinnell (2002) revealed that during the intensive Pacific herring tagging efforts that occurred between 1979 and 1992 in British Columbia, it was not unusual for "two or more tags from a single release session … [to be] recovered together" (Hay and McKinnell 2002, p. 1960). Statistical analysis of these recovery matches indicated that some adult Pacific herring appeared to associate in a nonrandom manner for months to years and over considerable distances (Hay and McKinnell 2002).

In recent years, DFO has begun applying coded-wire tags (CWT) to Pacific herring captured on the spawning grounds in British Columbia. Information on releases and recoveries of CWT Pacific herring from this study have been published in a series of technical reports (Schweigert and Flostrand 2000, Flostrand and Schweigert 2002, 2003, 2004). Although tag release and recovery efforts have not been uniform throughout the BC coast, recovery of strays at large for at least one year between the five regions (Figure 4) involved in the study (Queen Charlotte Islands, Prince Rupert District, Central Coast, Strait of Georgia, and West Coast Vancouver Island) amounted to 3 in 2000, 1 in 2001, 4 in 2002, and 41 in 2003 (Flostrand and Schweigert 2004). During 2003, about 3% of the recovered tags that had been applied in the SOG between 1999 and 2002 were recovered in the WCVI Region and 2% of the recovered tags that had been applied in the Central Coast in 2002 were recovered in the SOG. In addition to regional strays, reproductive straying was evidenced by straying between areas within regions including over 50 in 2002 and 196 in 2003 (Flostrand and Schweigert 2003, 2004).

Although not new since the previous status review, the following information is specific to tagging of Cherry Point Pacific herring. There have been two previous efforts to tag Cherry Point Pacific herring; a total of 797 fish were tagged with internal metal belly tags at Birch Bay (Figure 2) on 22 April 1938 (Hart and Tester 1938, 1939, 1940) (Figure 33) and 18,400 Pacific herring were tagged at Point Whitehorn (Cherry Point) during late April to early May in 1981 and 1982 (Buchanan 1986) (Figure 34). Hart and Tester (1938) reported that fish tagged at Birch Bay in 1938 were obtained from a herring-weir that was used for taking herring for bait. A total of 4 of the 797 Cherry Point fish tagged in 1938 were recovered. One fish was "recovered by a fisherman cutting up bait about five weeks after tagging…off the mouth of the Fraser River" (Hart and Tester 1939, p. Q66). The three additional tag recoveries occurred in Pacific herring reduction plants where magnet detectors were installed (Hart and Tester 1939, 1940). Two of these tags were recovered during the 1938–1939 fishing season and the other in 1939–1940. The first two recoveries were described by Hart and Tester (1939, p. Q78) as

> Birch Bay (2T): Two tags were recovered. One was recovered on the east coast [of Vancouver Island]. The other was reported from Barkley Sound [on west coast Vancouver Island], but may have originated with east coast fish.

Subsequently, the third tag recovery was described by Hart and Tester (1940, p. K52) as:

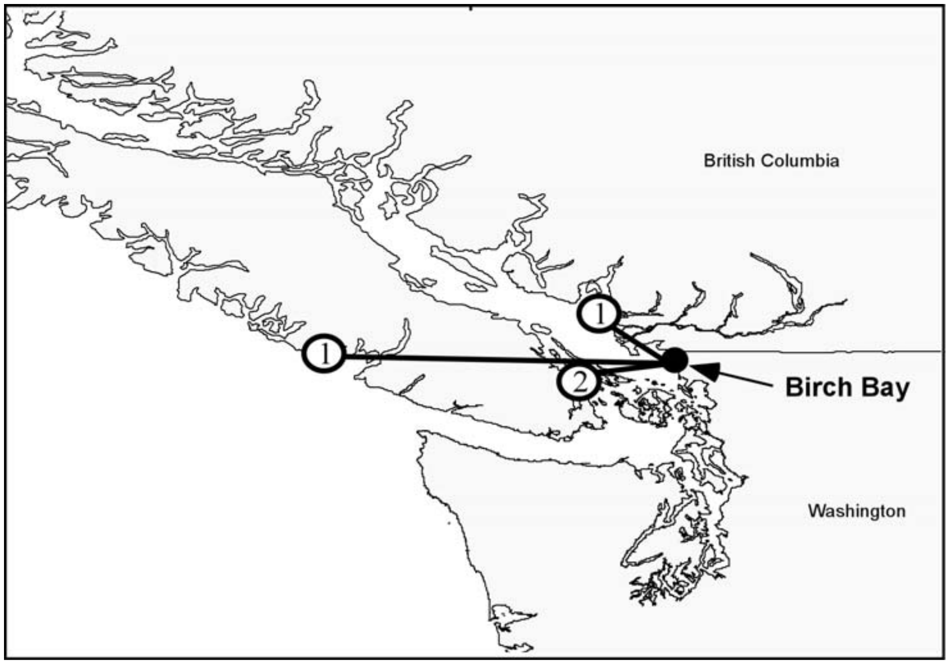

Figure 33. Recovery location of four of 797 herring tagged at Birch Bay on 22 April 1938. Black dot indicates site of tagging and circled numbers indicate number of recoveries at that site. Data from Hart and Tester (1938, 1939, 1940).

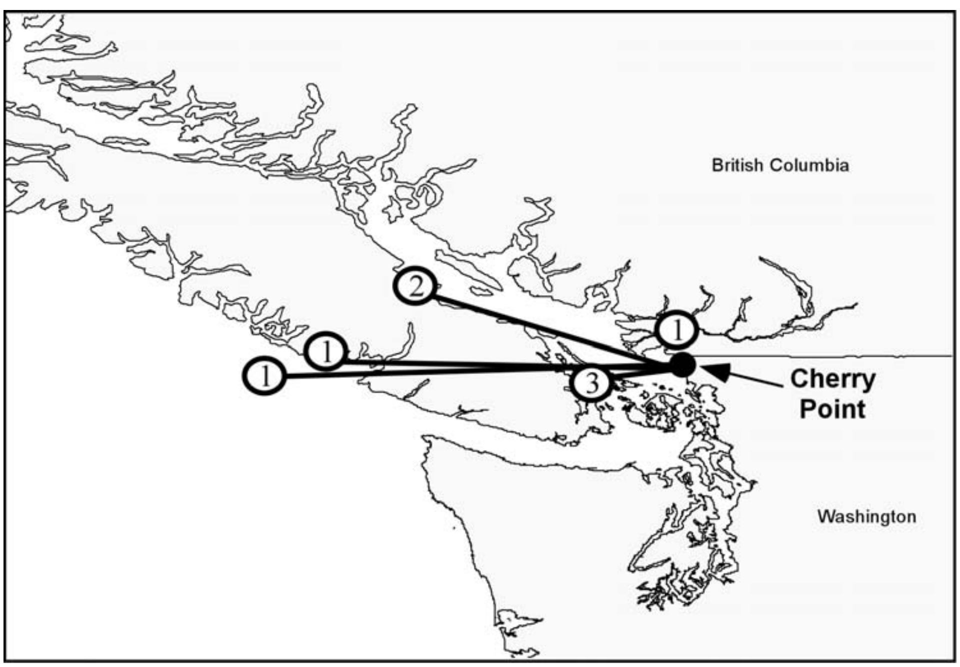

Figure 34. Approximate recovery locations of eight of the over 18,000 herring tagged at Cherry Point in 1981 and 1982. Black dot indicates site of tagging and circled numbers indicate number of recoveries at that site. Data from Buchanan (1986).

> Birch Bay (2T): One recovery was reported from east coast Vancouver Island fish. The reported locality of recovery is probably correct, although Queen Charlotte Sound is a possible source.

It is apparent from these descriptions that the locations of belly tag recoveries were not exact, as fish from many different regions were processed in certain reduction plants and often the tags were retrieved at the end of the season in reduction plant machinery (Hay et al. 1999).

Results of the 1981 and 1982 tagging efforts at Cherry Point were described by Buchanan (1986, p. 159) as follows:

> One tagged fish returned to the site of tagging exactly one year later. In addition, one fish was returned from a roe fishery in Barkley Sound, and one from offshore of Barkley Sound during the summer. Three were returned from the SEVI [southeast Vancouver Island] area from November through March in subsequent seasons. During the 1982 tagging, many well recovered spent fish were mixed in with maturing fish. Some of these spent fish got tagged. From this seasons tagging, two fish were returned from successive years roe fisheries in Lambert Channel [in the northwest SOG].

Buchanan (1986) also reported that three Pacific herring tagged in the southeast Vancouver Island region by Canadian researchers during November through March were recovered in early May at Cherry Point during the early 1980s (Table 7). Buchanan (1986, p. 159) stated that "it would appear that at least some of this late spawning U.S. stock [Cherry Point] spends some of the winter and spring in the channels of the Canadian Gulf Islands."

Otolith Chemistry

Gao et al. (2001) analyzed oxygen and carbon isotope ratios in otoliths from spawning Pacific herring collected at Cherry Point in north Puget Sound and at Port Orchard and Squaxin Pass in south Puget Sound. Isotope ratios from nuclei of otoliths from the two southern Puget

Table 7. British Columbia Pacific herring tag releases recovered in known Washington State location. Data from DFO (2004). SA, British Columbia statistical area.

Year	**Area released**	**Area recovered**	**Tags recovered**
1979	Porlier Pass SA 17, Strait of Georgia	Cherry Point, WA	1-anchor
1980	Beaver Point SA 18, Strait of Georgia	Point Whitehorn, WA	1-anchor
1980	Toquart Bay SA 23, W Coast Vancouver Is	Grays Harbor, WA	1-anchor
1980	Leclaire Pt SA 24, W Coast Vancouver Is	Cape Flattery, WA	1-anchor
1981	Porlier Pass SA 17, Strait of Georgia	Toleak Point, WA	1-anchor
1981	Ruxton Pass SA 17, Strait of Georgia	Cherry Point, WA	1-anchor

Sound samples were not significantly different from one another; however, Cherry Point otoliths were significantly different from the two southern Puget Sound samples. The Cherry Point isotope ratios suggested that Pacific herring from this location experience lower salinities as larvae and juveniles than Pacific herring from southern Puget Sound. However, Gao et al. (2001, p. 2117) noted that "there are some crossing samples in the database." Their Figure 2 shows that isotope ratios from 3 of the 32 Cherry Point fish fell well within the range of values shown for the other two sites. This overlap may indicate some degree of mixing of Pacific herring between the two areas or that water conditions characteristic of south Puget Sound may also occur in the areas frequented by Cherry Point Pacific herring during early life stages. Gao et al. (2001) also studied isotope ratios of second summer (1999) otolith rings in these three Pacific herring stocks. The results indicated that most south Puget Sound Pacific herring were rearing in high salinity conditions and were therefore "moving to the ocean" (Gao et al. 2001, p. 2115) (migratory stock) and that most Cherry Point Pacific herring with otolith isotope ratios indicative of lower salinities "might still remain in the spawning ground" (p. 2115) (nonmigratory stock). This result is surprising because nonmigratory Pacific herring would be expected to be slow growing and previous studies (based on tagging data and the relatively high growth rate of Cherry Point Pacific herring) had suggested that Cherry Point Pacific herring migrate to feed in offshore waters. Gao et al. (2001) did not consider the possibility that the fish they termed migratory may have been merely feeding deeper in the water column where salinity is higher than their nonmigratory fish.

Toxic Contaminants

It has been suggested that the differential accumulation of organochlorine contaminants in adult Pacific herring at Cherry Point compared to other local Pacific herring populations (O'Neill and West 2002) could be used as a stock distinguishing characteristic.[26] Different levels of total PCBs, DDTs, and hexachlorobenzene in Cherry Point Pacific herring were indicative of disparate rearing conditions compared to Pacific herring in Puget Sound proper and from one site in the northern SOG. These results are further discussed in the "Risk Factors" subsection on page 93.

Genetic Variation

Several genetic studies were reviewed by the BRT to assist in the determination of the significance of the Cherry Point Pacific herring population. Two studies, Beacham et al. (2001, 2002) and Small et al. (2004) compared microsatellite DNA allele variation at a number of loci within and between populations of Pacific herring. The Small et al. (2004) report was subsequently published, with some modifications, in the peer-reviewed literature as Small et al. (2005). A third study, Bentzen (2004), compared variation in mitochondrial DNA (mtDNA) haplotypes among several populations of Pacific herring and one population of Atlantic herring. The genetic information reviewed suggested that in general Pacific herring are characterized by high levels of gene flow among populations across fairly large geographic areas, consistent with the results of extensive tagging studies (Hay et al. 2001a). Overall, the genetic analysis of Beacham et al. (2001, 2002) supported the metapopulation view of Pacific herring populations in British Columbia, at least among the large migratory stocks. Several samples, including the

[26] See footnote 3.

single sample from a single year at Cherry Point, were identified in Beacham et al. (2001, 2002) as being somewhat more distinct. These included samples from later (spring-summer) spawning Pacific herring, samples from remotely sited "resident" Pacific herring in mainland inlets, and samples from sites that were geographically distant from British Columbia. Although these "outlier" samples appeared to cluster together in the Beacham et al. (2001, 2002) analysis, it was unclear whether this apparent similarity was an artifact of the analysis or an indicator of past or present genetic exchange.

The report by Small et al. (2004, 2005), suggests that a number of genetically discrete population aggregations may exist. Within Puget Sound, there was a small degree of genetic differentiation among sampling sites and in some cases between years within a site. Analysis of samples for microsatellite allele variation indicated small but significant levels of genotypic differentiation between Cherry Point and other sampling sites. The estimate of F_{ST} for six Puget Sound populations and one Strait of Georgia population was 0.003 (95% CI = 0.001–0.006), and samples from four consecutive years (1999–2003) from the Cherry Point population were differentiated in 18 of 32 pairwise comparisons (after Bonferroni corrections) from other Puget Sound/Strait of Georgia samples (F_{ST} ranged from ≈0.002 to ≈0.006). Based on these data, the BRT hypothesized that the Puget Sound Pacific herring populations, particularly in the South Sound and at Cherry Point, may be characterized by a degree of isolation similar to other "inlet" locations in British Columbia. In some cases it was possible for the BRT to hypothesize a mechanism for some level of demographic isolation. For example, temporal differences in spawning time (Cherry Point) or geographic isolation (Squaxin Pass) could result in the observed levels of genetic distinctiveness.

Determining the biological significance of this low level of differentiation is difficult. Several simple population genetic models have been developed that use estimates of F_{ST} to estimate biological parameters such as time of divergence or gene flow among populations. Assuming a large number of equal sized populations with equal rates of migration among them, Wright (1978) showed that the immigrant fraction of a population, m, could be estimated by the relationship $m = (1/4N_e)(1/F_{ST} - 1)$. Alternatively, assuming that a pair of populations diverged from a common ancestor t generations ago and have not subsequently exchanged migrants, the divergence time, t, can be estimated from the relationship $F_{ST} = 1 - (1\text{-}1/2N_e)^t$ (Weir 1996). Both models make many additional assumptions, such as discrete generations and selective neutrality of the loci used to estimate F_{ST}. In addition, particularly when estimates of F_{ST} are very small, results can be sensitive to problems such as nonrandom sampling of populations (Waples 1998). Under both models, the effective size of the population (N_e) is critical to the interpretation of the results. In particular, if N_e is small, F_{ST} increases relatively rapidly among isolated populations. Conversely, if N_e is relatively large, F_{ST} increases very slowly over time even if populations are completely isolated. For example, the value of F_{ST} estimated by Small et al. (2004, 2005) of 0.003 among herring populations in Puget Sound/Strait of Georgia is consistent with a divergence time of only ≈6 generations if N_e is ≈1,000, but is consistent with a divergence time of ≈600 generations if N_e is ≈100,000. A similar situation occurs when estimating immigration fraction; the same estimate of F_{ST} could imply either a large or small immigration fraction depending on the value of N_e. Clearly, without an estimate of N_e, it is hard to determine if an observed level of genetic differentiation is evolutionarily significant.

Herring populations, including Cherry Point, typically have spawning population sizes in the millions (Stout et al. 2001a), so it may be reasonable to expect that N_e could be relatively large. However, marine fish often have effective population sizes that are much smaller than the observed number of individuals in a population (e.g., Hauser et al. 2002). Several authors have developed methods for estimating N_e from temporal changes in allele frequencies (Nei and Tajima 1981, Waples 1989, Wang 2001). We used the data reported in Small (2004, 2005) to estimate N_e for the Cherry Point population using both Waples's (1989) moments method and Wang's (2001) likelihood method. In both cases, the point estimates of N_e for the Cherry Point population were ≈1000, but the 95% confidence intervals were extremely wide (≈200 – infinity).

Analysis of mtDNA variation by Bentzen (2004) failed to identify any significantly differentiated sampling sites ranging from California to the Bering Sea. In general, there was substantial variability in mtDNA both between samples and between years from the same sampling site. There were a number of mtDNA haplotypes that were unique to temporal samples within a sampling site. Conversely, there were a number of haplotypes that were common to a large proportion of the sampling sites. Given the large number of rare or unique mtDNA haplotypes, more extensive sampling is needed to provide a more discriminative analysis of Puget Sound and Cherry Point Pacific herring.

Given the observed genetic variability within and between Puget Sound sampling sites of Pacific herring (Beacham et al. 2001, 2002, Small et al. 2004, 2005, Bentzen 2004), the BRT concluded that the genetic distinctiveness observed for Cherry Point Pacific herring was not of a magnitude that could be characterized as evidence that Cherry Point Pacific herring "differs markedly from other populations of the species in its genetic characteristics" (USFWS-NMFS 1996, p. 4725).

Previous Marine Fish DPS Designations

It is also useful to briefly review the size and complexity of other designated DPS's of marine fish that have undergone the status review process and have thus been considered both discrete and significant to their respective biological species. DPSs have been designated for portions of the range of Pacific hake (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*) (NMFS 2000), copper rockfish (*Sebastes caurinus*), quillback rockfish (*S. maliger*), brown rockfish (*S. auriculatus*) (NMFS 2001), bocaccio (*S. paucispinis*) (NMFS 2002), and smalltooth sawfish (*Pristis pectinata*) (NMFS 2003). Several marine fish DPSs cover geographic areas larger than the Georgia Basin (e.g., Pacific cod and walleye pollock DPSs extend from Puget Sound to Southeast Alaska, two West Coast DPSs of the bocaccio rockfish were designated off Washington and Oregon [the northern DPS] and off California and Mexico [the southern DPS], and all smalltooth sawfish in U.S. waters were designated a separate DPS). At slightly smaller geographic scales, a Georgia Basin Pacific hake DPS was established as separate from coastal hake and three DPSs each of copper and quillback rockfish (Puget Sound Proper DPS, Northern Puget Sound DPS, and coastal DPS) and two of brown rockfish (Puget Sound Proper DPS and coastal DPS) were established. Many of these marine fish DPSs include a number of identifiable subpopulations with numerous isolated spawning locations and a substantial level of life history and ecological diversity (Gustafson et al. 2000, Stout et al. 2001b).

Final DPS Determination

To allow for uncertainty in identifying the boundaries of the DPS of Pacific herring that incorporates Cherry Point Pacific herring, the BRT adopted a "likelihood point" method, often referred to as the "FEMAT" method because it is a variation of a method used by scientific teams evaluating options under the Forest Plan (Forest Ecosystem Management: An Ecological, Economic, and Social Assessment Report of the Forest Ecosystem Management Assessment Team [FEMAT, http://www.or.blm.gov/ForestPlan/ NWFPTitl.htm]). This method has also been used in all recent status review updates for federally listed Pacific salmon and steelhead (*Oncorhynchus mykiss*) ESUs. In this approach, each BRT member distributes ten "likelihood" points among a number of proposed DPSs, reflecting their opinion of how likely that proposal correctly reflects the true DPS boundaries. Thus if a member were certain that the DPS that contains Cherry Point Pacific herring was Cherry Point alone, he or she could assign all 10 points to that proposal. A member with less certainty about DPS boundaries could split the points among two, three, or even more DPS proposals.

The BRT considered up to seven possible DPS configurations that might conceivably incorporate Cherry Point Pacific herring. Ultimately each BRT member distributed their 10 "likelihood points" amongst these possible configurations. Other possible configurations that encompassed either smaller or larger geographic areas were contemplated, but were not seriously considered. In order to try and capture the level of uncertainty on the BRT regarding the decision that Cherry Point Pacific herring was a discrete population, but not significant to the species as a whole, two of the DPS scenarios that were considered delineated Cherry Point Pacific herring as a DPS. The DPSs considered in this evaluation were:

1. Multiple DPSs for Puget Sound Pacific herring based on spawn timing.
    a) Late-spring spawning Pacific herring DPS (Cherry Point)
    b) Winter spawning Puget Sound Pacific herring DPS (all other Puget Sound populations)
2. Multiple DPSs for Georgia Basin Pacific herring based on spawn timing.
    a) Late-spring spawning Pacific herring DPS (Cherry Point)
    b) Winter spawning Puget Sound Pacific herring DPS (all other Georgia Basin populations)
3. Georgia Basin Pacific herring DPS (current boundaries and definition of DPS - Puget Sound/Strait of Georgia/ Strait of Juan de Fuca).
4. Pacific herring DPS incorporating Puget Sound, Strait of Georgia, and West Coast Vancouver Island spawning locations.
5. Puget Sound to Sitka, Alaska.
6. Puget Sound to Aleutian Peninsula.
7. San Diego to Sitka, Alaska.

There was very little support on the BRT for a separate Cherry Point DPS; less than 8% of the likelihood points were distributed amongst DPS scenarios 1 and 2. All remaining likelihoods points were distributed among scenarios supporting a DPS at the level of the Georgia Basin (a combination of Puget Sound and the Strait of Georgia) or greater. A majority of the BRT likelihood points supported retention of the current Georgia Basin Pacific herring DPS (scenario 3); however, over a third of the total likelihood points were distributed among scenarios that represented a DPS configuration that was larger than the Georgia Basin (scenarios 4–7). There was significant support on the BRT for a larger DPS than Georgia Basin based on tagging studies that indicate extensive straying at scales greater than the Georgia Basin (Heyamoto and Pasquale 1961, Buchanan 1986, Hay et al. 2001a); genetic studies of Grant and Utter (1984), Beacham et al. (2001, 2002), and Small et al. (2004) that indicate wide genetic homogeneity of the overwhelming number of Pacific herring populations in the Pacific Northwest and British Columbia; and evidence that most Pacific herring populations in British Columbia can be described as a metapopulation (Ware et al. 2000, Ware and Schweigert 2001, 2002, Ware and Tovey 2004). However, the BRT did not feel that these were reasons enough to modify the boundaries of the present DPS. The BRT noted that the ecological discreteness of the Georgia Basin (the inshore waters of Puget Sound and the Strait of Georgia) and concordance of age composition of Pacific herring among SOG and Puget Sound locations provided support for this decision. As currently defined, the Georgia Basin Pacific herring DPS (scenario 3) encompasses spawning locations of Pacific herring in all the marine waters of Puget Sound, the Strait of Georgia, and eastern Juan de Fuca Strait in both the U.S. and Canada (Figure 35).

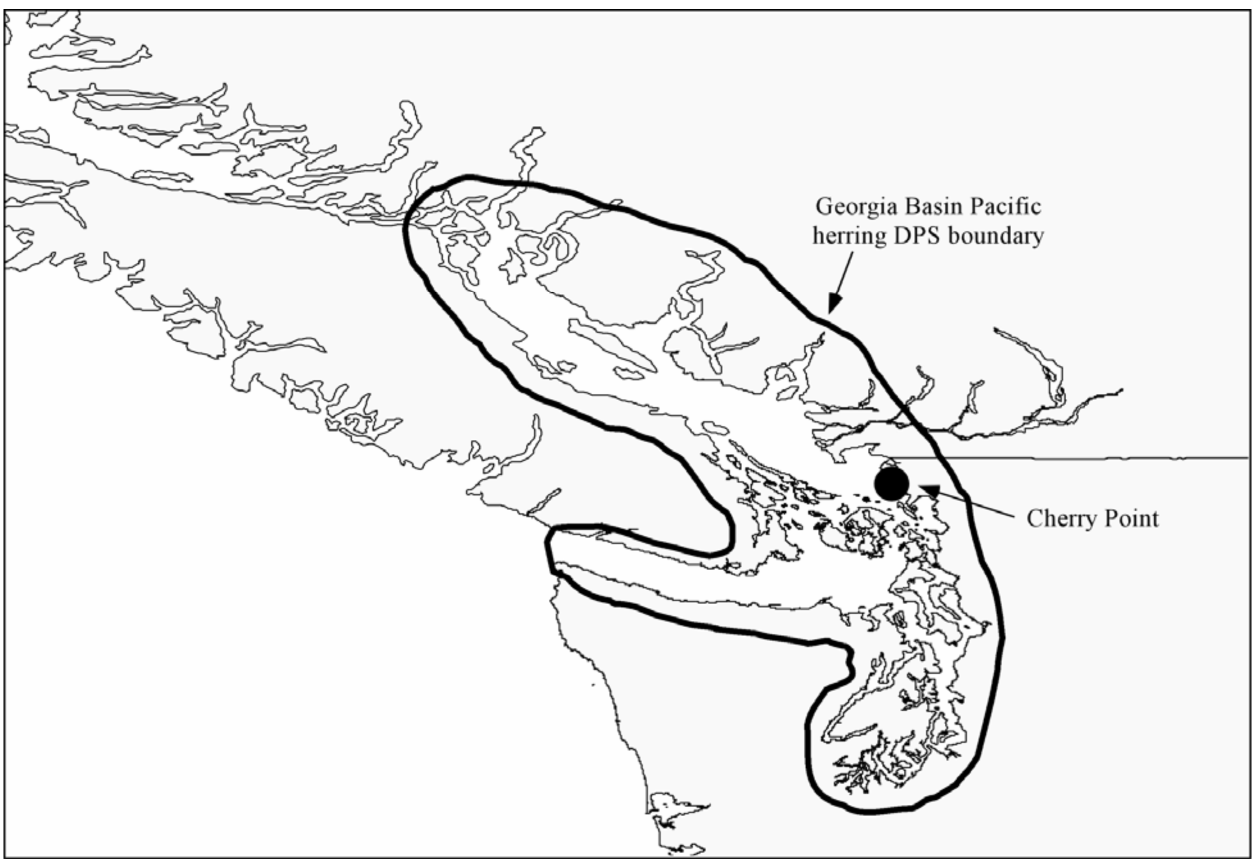

Figure 35. Generalized geographical boundary of the Georgia Basin Pacific herring distinct population segment.

Approaches to Evaluating Risk of Extinction

The “Extinction Risk” Question

After the composition of an ESA species is determined, the next question to address is, “Is the ‘species’ threatened or endangered?” The ESA (section 3) defines the term “endangered species” as “any species which is in danger of extinction throughout all or a significant portion of its range.” The term “threatened species” is defined as “any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.” Neither NMFS nor the USFWS have developed any formal policy guidance about how to interpret the definitions of threatened or endangered species in the ESA.

A variety of information is considered in evaluating the level of risk faced by a DPS. According to the ESA, the determination of whether a species is threatened or endangered should be made on the basis of the best scientific information available regarding its current status, after taking into consideration conservation measures that are proposed or are in place. During the biological status review process, the BRT does not evaluate likely or possible effects of conservation measures except to the extent they are reflected in metrics of population or DPS viability; these measures are taken into account in a separate process by the NMFS regional offices prior to making any listing determinations. Therefore, the BRT does not make recommendations as to whether identified DPSs should be listed as threatened or endangered species, because that determination requires evaluation of factors not considered by the team. Rather, the BRT draws scientific conclusions about the risk of extinction faced by identified DPSs under the assumption that present conditions will continue into the future (recognizing, of course, that existing trends in factors affecting populations and natural demographic and environmental variability are inherent features of “present conditions”).

Factors for Decline

According to Section 4 of the ESA, the Secretary (of Commerce or the Interior) shall determine whether a species is threatened or endangered as a result of any (or a combination) of the following factors: destruction or modification of habitat, overutilization, disease or predation, inadequacy of existing regulatory mechanisms, or other natural or man-made factors. Collectively, these are often referred to as “factors for decline.” In the previous status review, the BRT did not attempt a rigorous analysis of this subject, and the same is true for this report. There are several reasons for this.

1. The BRT chose to focus primarily on the question of whether a DPS is at risk rather than how it came to be at risk. Although the latter question is important, a population or DPS that has been reduced to low abundance will continue to be at risk for demographic and genetic reasons until it reaches a larger size, regardless of the reasons for its initial

decline. Furthermore, in some cases, a factor that was important in causing the original declines may no longer be an impediment to recovery.

2. Unlike many ESA-listed species that face a single primary threat, Pacific herring (like Pacific salmon) face numerous potential threats throughout every stage of their life cycle. It is therefore relatively easy to simply list current and past potential threats to Pacific herring populations, but it is much more difficult to evaluate the relative importance of a wide range of interacting factors.
3. Evaluating the degree to which historic factors for decline will continue to pose a threat in the future generally requires consideration of issues that are more in the realm of social science than biological science—such as whether proposed changes will be funded, and, if funded, will be implemented effectively.

Although this report does not consider factors for decline in a comprehensive way, the BRT did consider major risk factors that were identified in the previous status review and in the petition.

Previous Cherry Point Pacific Herring Risk Assessments

Previous formal risk assessments of Cherry Point Pacific herring include 1) the Cherry Point Screening Level Ecological Risk Assessment (EVS 1999), 2) the previous Pacific herring status review (Stout et al. 2001a), 3) the Regional Risk Assessment for the Cherry Point Herring Stock (Landis et al. 2000), and 4) Cherry Point Herring Regional Risk Assessment Phase II (Markiewicz et al. 2001). Aspects of the latter two studies have appeared in the peer-reviewed literature as Landis et al. (2004) and Hart Hayes and Landis (2004).

Results of the Environmental Consultants, Inc. (EVS) (1999, p. ES–4) analyses were that:

> The available data indicate that trends in the Cherry Point stock are likely due primarily, but not necessarily entirely, to increased mortality of adults. This increased mortality may be due to one or more of the following: changes in ocean conditions, particularly sea surface temperature, that appear to have led to increased predation by Pacific hake off southern Vancouver Island; changes in competition or food supply, also associated with trends in ocean conditions; and increased local predation on spawning adults by seals or other species.

The previous status review of Pacific herring concluded that "a combination of reduced recruitment of three-year-old herring and increased nonfishery related losses of older fish appeared to be the primary causes of the decline in biomass of [the] Cherry Point" population (Stout et al. 2001a, p. 143). Although the previous status review (Stout et al. 2001a) concluded that the Georgia Basin Pacific herring DPS was neither at risk of extinction nor likely to become so, the Cherry Point stock was noted to have declined to such an extent that it may meet the International Union for Conservation of Nature and Natural Resources (IUCN) criteria to be considered "vulnerable" (Stout et al. 2001a, p. 145) and by this definition was "considered to be facing a high risk of extinction in the wild" (IUCN 2001, p. 9). In addition, a quantitative analysis of trends in abundance at Cherry Point indicated that "there is greater than 50% chance that the Cherry Point population will decline to one ton or less in 100 years" (Stout et al. 2001a, p. 131) and that "a one ton population of herring would be sufficiently small to be considered very close to extinction and difficult to detect" (Stout et al. 2001a, p.129). On the other hand, Landis et al. (2000, their executive summary) concluded that

> over-harvesting coupled with a decline in the rate of recruitment of mature herring were responsible for the current low population levels. … The region with the highest potential risk encompasses south Birch Bay, Point Whitehorn and Cherry Point. … The potential risks to this area are very high due to construction and installation of new piers, inputs from industrial facilities, and other shoreline developments in the nearby vicinity.

The second phase of the Cherry Point Herring Regional Risk Assessment (Markiewicz et al. 2001) concluded "that climate change with concurrent changes in sea surface temperatures, exploitation, and habitat loss are still important risk factors to Cherry Point herring; similar to results of the original assessment" (Markiewicz et al. 2001, their executive summary, p. 1). In addition, Markiewicz et al. (2001, their executive summary, p. 1) stated that:

> Contaminants also received a high risk score, especially after taking into consideration the potential risk of exposure to contaminants while the herring are at feeding sites outside of the Cherry Point region. The lack of data, however, increases the uncertainty of the risk prediction and results in an overall lower score for contaminants as a major risk factor to herring.

Previous BRT Risk Assessment Methods

In the previous Pacific herring status review (Stout et al. 2001a) risk assessment was approached from several different directions. First, risk factors to Pacific herring as outlined in West (1997) were discussed in a qualitative manner without attempting to make a quantitative assessment of these factors. Second, the method used in early stages of the Pacific salmon and steelhead BRT process was adopted. Details of this risk approach are described in Wainwright and Kope (1999). Basically this is a risk matrix approach that includes information on abundance, population trends, productivity and variability, genetic integrity, and habitat condition/capacity. The risk matrix provides a way to organize and summarize the professional judgment of a panel of knowledgeable scientists. The third approach utilized criteria that define risk as presented in Musick (1999). These criteria are based on productivity measures such as intrinsic rates of increase, age-at-maturity, and maximum age. These criteria are similar to those examined in Wainwright and Kope (1999); however, they are organized somewhat differently. The criteria are rarity, small range and endemics, specialized habitat requirements and population decline. Decline thresholds are based on population resilience of the species. This method provided another way to examine and organize available information for the evaluation of risk and an opportunity to compare the results of the methods.

Risk Assessment Methods

Trends in Abundance

Short-term and long-term trends were calculated from time series of estimated adult Pacific herring spawning biomass, transformed to metric tons where appropriate. Short-term trends were calculated using data from 1990 to the most recent year, with a minimum of 10 data points in the 13-year span. Long-term trends were calculated using all data in a time series since 1973, the first year that data for U.S. portions of the DPS were available.

Trend was calculated as the slope of the regression of the biomass of spawners (natural log-transformed) over the time series; to mediate for zero values, one was added to natural spawners before transforming the data. Trend was reported in the original units as exponentiated slope, such that a value greater than 1 indicates a population trending upward, and a value less than 1 indicates a population trending downward. The regression was calculated as

$$\ln(N+1) = \beta_0 + \beta_1 X + \varepsilon, \tag{1}$$

where N is the spawner biomass, β_0 is the intercept, β_1 is the slope of the equation, and ε is the random error term.

Confidence intervals (95%) for the slope, in their original units of abundance, were calculated as

$$\exp(\ln(b_1) - t_{0.05(2),df}\, s_{b_1}) \leq \beta_1 \leq \exp(\ln(b_1) + t_{0.05(2),df}\, s_{b_1}), \tag{2}$$

where b_1 is the estimate of the true slope β_1, $t_{0.05(2)}$, df is the two-sided t-value for a confidence level of 0.95, df is equal to n–2, n is the number of data points in the time series, and s_{b1} is the standard error of the estimate of the slope, b_1.

Population Growth Rates and Parameters

In addition to analyses of trends in spawners, we estimated the annual long-term population growth rate, lambda (λ), of spawners as a measure for comparative risk analysis. Lambda more accurately estimates the long-term trend of a population than simple regression, as it incorporates sources of variation such as overlapping generations. An estimate of long-term population growth rate is important in viability assessment, as most population extinctions are the result of steady long-term declines (i.e., $\lambda < 1$). Methods of estimating lambda have been developed for data sets with high sampling error and age-structure cycles (Holmes 2001). These methods have been extensively tested using simulations for both threatened and endangered populations as well as for stocks widely believed to be at low risk (Holmes 2004), and cross validated with time series data (Holmes and Fagan 2002).

Time series of herring biomass were used to estimate population growth rates and risks by fitting a stochastic exponential decline model with observation errors to the data, also known as “the corrupted diffusion model” (Holmes 2004):

$$N_{t+1} = N_t \exp(\mu + \varepsilon) \tag{3a}$$

where ε is distributed Normal(0, σ^2),

$$O_t = N_t \exp(\varepsilon) \tag{3b}$$

where ε is distributed Normal (mean = $0,e^2$), and N_t are true population counts and O_t are yearly censuses. The σ^2 variance represents the variance of long-term population trajectories and affected both mainly by the environmentally-driven variability in year-to-year growth rates and the temporal correlation in those rates. The e^2 term represents variability due to lognormal measurement error and also short-term variability due to a variety of internal factors, for example density-dependent feedbacks, age-structure perturbations, and predator-prey feedbacks (cf Holmes 2001, 2004, Sabo 2005). The corrupted diffusion approximation has been shown to correctly describe the long-run statistical distribution of salmon populations (Holmes and Fagan 2002, Holmes 2004) and a wide variety of other species of conservation concern (Holmes et al. 2005).

The parameters of the corrupted diffusion model (Equation 3) were estimated via the Kalman filter, a widely used algorithm for maximum likelihood estimation for state-space models (Lindley 2003, Holmes 2004). The metrics, $\lambda = \exp(\mu)$ and probability of crossing a quasi-extinction threshold of $N_t/N_{current} = 0.05$, were calculated using the parameters of the diffusion model as described in Dennis et al. (1991). Under this model, lambda is the median observed growth rate. The expectation is that half the observed time series would grow faster than this and half would grow slower over some observed time period *t*. As the time series gets longer (*t* gets big), however, the variance in the observed average growth rate goes down and $(1/_t)\ N_t/N_{current} > \lambda$. Thus lambda is also the estimate of the long-run average growth rate of the population.

There is uncertainty in the estimated risk metrics given the uncertainty inherent in parameter estimation from finite time series. Risk metric uncertainty was expressed using posterior probability distributions calculated with a uniform prior on all parameters. The area within one area under the posterior probability distribution relative to another area gives the relative data support. Thus if the area under $\lambda < 1$ is 10 times greater than the area under $\lambda > 1$, the data support for a declining population ($\lambda < 1$) is 10 times greater than the data support for an increasing population. The prior odds on declining versus increasing were set to 1:1 (given the uniform prior on μ). This is a simple objective Bayesian analysis which makes a statement about the relative data support (area under the likelihood function) for different parameter values without making a judgment about whether some parameters are more plausible than others. If the uniform prior is considered very unreasonable, a test of the sensitivity to the prior is required.

Adoption of Risk Procedures Utilized in Recent Salmonid Status Assessments

The Georgia Basin Pacific herring DPS, similar to Pacific salmonid ESUs, is likely structured as a metapopulation—composed of multiple populations with some degree of interconnection, at least over ecological time periods. This makes the assessment of extinction risk difficult, especially since we have fairly solid evidence in the form of tagging studies that the Georgia Basin DPS is sharing relatively large numbers of migrants with populations outside the DPS. In the previous Pacific herring status review, as in the Pacific salmon status reviews prior to 1999, the BRT used a simple "risk matrix" for quantifying DPS-scale risks according to major risk factors (see discussion in Previous BRT Risk Assessment Methods subsection on page 71 and Stout et al. 2001a). In recent status review updates for Pacific salmon and steelhead, the BRTs adopted a risk assessment method that has been used for Pacific salmon recovery planning and is outlined in the viable salmonid populations (VSP) report (McElhany et al. 2000). In this approach, risk assessment is addressed at two levels: first, the population level, then at the overall ESU (or DPS) level. We have modified the previous Pacific herring BRT approach to DPS risk assessment to incorporate VSP considerations. For the purposes of the Pacific herring status review we will refer to these VSP criteria as population viability criteria.

In this approach, individual populations are assessed according to the four population viability criteria: abundance, growth rate/productivity, spatial structure, and diversity. The condition of individual populations is then summarized on the DPS level, and larger-scale issues are considered in evaluating the status of the DPS as a whole. These larger-scale issues include total number of viable populations, geographic distribution of these populations (to ensure inclusion of major life history types and to buffer the effects of regional catastrophes), and connectivity among these populations (to ensure appropriate levels of gene flow and recolonization potential in case of local extirpations). These considerations are detailed in McElhany et al. (2000).

The revised risk matrix (Table 8) integrates the four major population viability criteria (abundance, productivity, spatial structure, and diversity) directly into the risk assessment process. After reviewing all relevant biological information for the Georgia Basin Pacific herring DPS, each BRT member assigns a risk score (see below) to each of the four population viability criteria. The scores are tallied and reviewed by the BRT before making its overall risk assessment. Although this process helps to integrate and quantify a large amount of diverse information, there is no simple way to translate the risk matrix scores directly into an assessment of overall risk. For example, simply averaging the values of the various risk factors would not be appropriate; a DPS at high risk for low abundance would be at high risk even if there were no other risk factors.

Scoring population viability criteria: Risks for each population viability factor are ranked on a scale of one (very low risk) to five (very high risk):

1. *Very Low Risk.* Unlikely that this factor contributes significantly to risk of extinction, either by itself or in combination with other factors.
2. *Low Risk.* Unlikely that this factor contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors.
3. *Moderate Risk.* This factor contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future.
4. *High Risk.* This factor contributes significantly to long-term risk of extinction and is likely to contribute to short-term risk of extinction in the foreseeable future.
5. *Very High Risk.* This factor by itself indicates danger of extinction in the near future.

Recent events: The “recent events” category considers events that have predictable consequences for DPS status in the future but have occurred too recently to be reflected in the population data. Examples include a climatic regime shift or El Niño event that may be anticipated to result in increased or decreased predation in subsequent years. This category is scored as follows:

++ expect a strong improvement in status of the ESU,

+ expect some improvement in status,

0 neutral effect on status,

- expect some decline in status, and

-- expect strong decline in status.

Table 8. Template for the risk matrix used in BRT deliberations. The matrix is divided into five sections that correspond to the four VSP "parameters" (McElhany et al. 2000) plus a "recent events" category.

Risk Category	Score*
Abundance Comments:	
Growth Rate/Productivity Comments:	
Spatial Structure and Connectivity Comments:	
Diversity Comments:	
Recent Events	

* Rate overall risk of DPS on 5-point scale (1–very low risk, 2–low risk, 3–moderate risk, 4–increasing risk, 5–high risk), except recent events double plus (++, strong benefit) to double minus (--, strong detriment).

IUCN Criteria and Classification

The World Conservation Union (IUCN) published Red List categories and criteria for classifying species that are at high risk of extinction (IUCN 2001). These criteria can be applied to species or to lower taxonomic levels, such as distinct population segments. There are a range of quantitative IUCN criteria for placing a species in the relevant IUCN categories of Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), or Least Concern (LC), and meeting any one criterion is justification for listing at that threat level (IUCN 2001). The IUCN criteria fall into four main subject areas: 1) reduction in population size, 2) extent of geographic range, 3) population size, and 4) results of a quantitative analysis, such as a population viability analysis. In the current context, the reduction in population size criteria are most relevant to the available data for the Georgia Basin Pacific herring DPS. These criteria state that a species may be classified as Critically Endangered, Endangered, or Vulnerable when its population size has declined ≥80%, ≥50%, or ≥30%, respectively, over the last 10 years or three generations, whichever is longer, where the reduction or its causes may not have ceased, may not be understood, or may not be reversible (IUCN 2001). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has been using quantitative criteria similar to the IUCN criteria to assess risk of extinction in marine fish (COSEWIC 2003).

There has been controversy over using the IUCN decline criterion for some marine fish species, especially those still at high abundance despite large percentage declines (Matsuda et al. 1997, Musick 1999, Mace and Hudson 1999, Powles et al. 2000, Hutchings 2000, 2001a, 2001b, Dulvy et al. 2003, 2004). This debate was triggered by the IUCN listing in 1996 of several commercially valuable, widespread, and highly fecund marine fishes (Matsuda et al. 1997). Musick et al. (1999, p. 7) suggested the IUCN decline criteria "grossly overestimate the extinction risk for many if not most marine fish species" and proposed modified American Fisheries Society risk criteria that "better reflect population resilience" (p. 11). Powles et al. (2000, p. 672) also suggested that some "marine species have characteristics which should make them more resilient to extinction risk: 'opportunistic' life history characteristics (high fecundity, planktonic larvae, and highly mobile adults, low age at maturity), high abundance, and wide distribution." However, Hutchings (2000, 2001a, 2001b) and others (Dulvy et al. 2003, Mace and Hudson 1999, Hutchings and Reynolds 2004) cite empirical analyses indicating that marine fishes likely have similar extinction probabilities to those of nonmarine taxa. With the possible exception of some clupeids, which have a comparatively higher resilience to population declines, Hutchings and Reynolds (2004, p. 305) stated that "the decline-rate thresholds used by IUCN and COSEWIC to assign status are appropriate [for marine fishes], insofar as the probability of recovery is a reliable metric of extinction risk." In light of these discussions we applied the IUCN decline criteria to those portions of the Georgia Basin Pacific herring DPS that have exhibited a decline in abundance during the past three fish generations.

Risk Assessment

Abundance and Trends

New data acquired for this report since the previous status review (Stout et al. 2001a) include spawner biomass estimates through 2004 and length of coastline utilized for spawning for a number of Pacific herring spawning locations in Washington and herring sections in British

Columbia. New analyses include recalculation of previous BRT metrics with additional years of data and estimates of median annual growth rate (λ). Information is first presented for Cherry Point Pacific herring (the petitioned unit) and then for the Georgia Basin Pacific herring DPS.

Cherry Point Pacific herring

As noted earlier, Einarsen (1928, p. 132) stated that "the bulk [of Pacific herring in Washington State] are taken at Hales Pass [Hale Passage, Cherry Point population], Holmes Harbor, Birch Bay [Cherry Point population], Poulsbo, and Discovery Bay." In addition to this period of high abundance, evidence exists that Cherry Point Pacific herring went through a previous period of low abundance, similar to the present situation, in the late 1930s. Chapman et al. (1941, p. 3) stated that "three areas which formerly produced a great share of the catch (Discovery Bay, Hales Pass [Hales Passage] and Birch Bay) have scarcely enough fish left to support a fishery." Although Pacific herring abundance at Cherry Point was too low to attract a fishery in the late 1930s, fishermen reported that Birch Bay had previously been "one of the best herring producers of any of the spawning localities in Puget Sound" (Chapman et al. 1941, p. 8).

Washington State Pacific herring catch was reported intermittently from 1889 to 1920, annually from 1920, and by fishing locality from 1935 to date. Catch history and known stock biomass for Cherry Point Pacific herring are illustrated in Figure 36. Catch records for Birch Bay and Hale Passage were combined from 1935 to 1967, since Chapman et al. (1941, p. 10) noted that it was the spring run, in contrast to the February–March run, at Hale Passage that was the source of "the tremendous quantities of herring which were taken from Hales Pass [Hale Passage] in former years." By the late 1950s, Cherry Point Pacific herring had apparently recovered and Williams (1959, p. 28) stated that "formerly depleted stocks, such as those spawning in … Hale Passage and Birch Bay [Cherry Point population] have regained their productive levels after many years without exploitation."

Spawner biomass for Cherry Point Pacific herring (and other stocks in Washington's inside waters) since 1973 are presented in Tables 9 and 10. Since the previous status review (Stout et al. 2001a), the Cherry Point Pacific herring population has shown an increasing abundance trend (Figure 36). The 2004 spawner biomass estimate of 1,734 short tons (1,573 metric tons) (Table 9) was at its highest level since 1996. However, the estimate of total number of Pacific herring in the spawning population was at its second lowest level ever, just under 14 million fish (Table 11). This apparent discrepancy can be explained by examination of Figure 37, which illustrates that most of the apparent spawners that made up the Cherry Point population in 2004 consisted of 3–5-year-old fish with larger body mass; the 2-year-old fish were rare in the samples used for age composition determination in 2004 (see Table 11). There has also been an apparent temporal decline in size-at-age of Cherry Point Pacific herring (Figures 38 and 39). This is most evident in ages 3–7 (Figures 38 and 39). A similar decline in weight-at-age was also evident in SOG Pacific herring during the 1990s, but recent data have shown no obvious trend (Schweigert 2004).

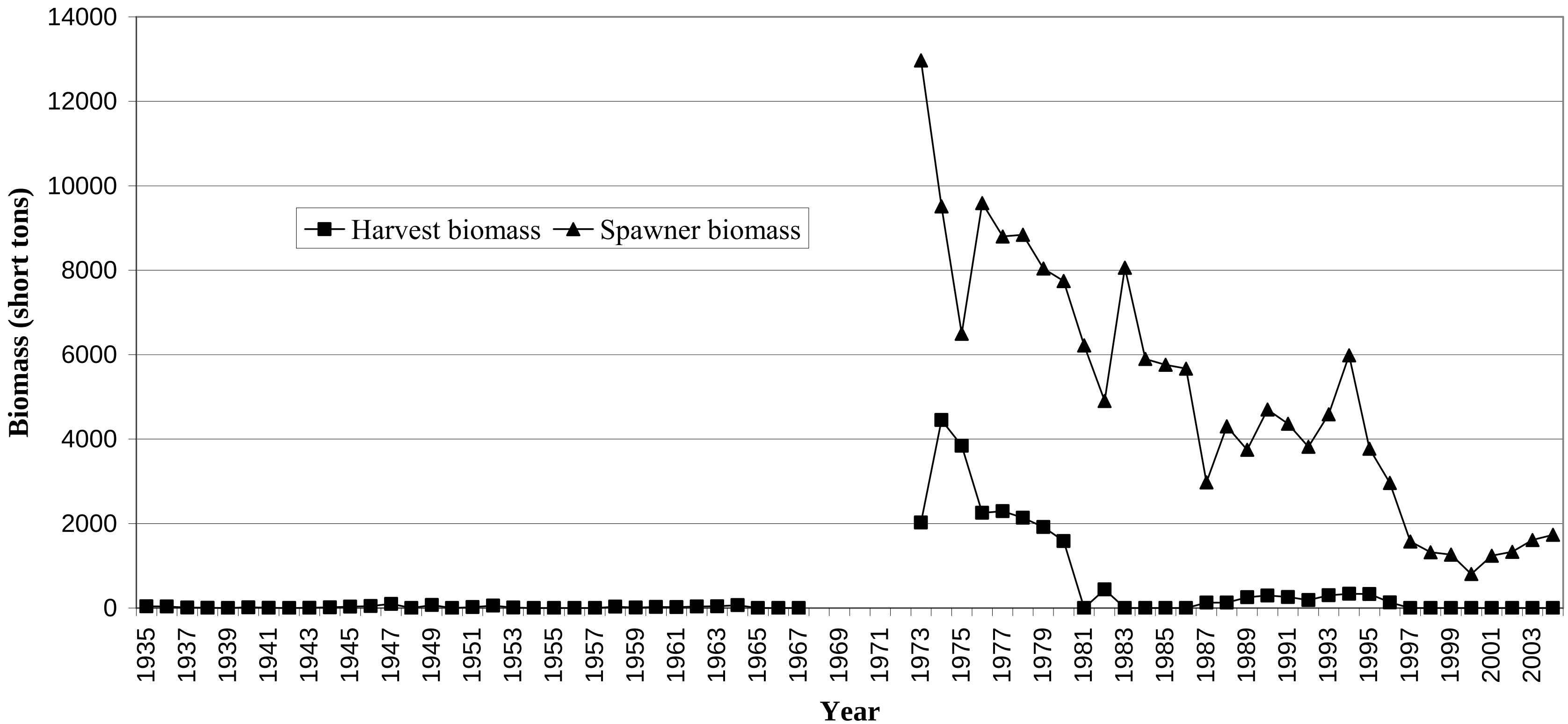

Figure 36. Cherry Point herring spawning stock and fishery catch biomass (short tons). Catch records for Cherry Point prior to 1973 are a combination of Birch Bay and Hale Passage records. Data from Williams (1959), WDF (1969), and WDFW.[27]

[27] See footnote 5.

Table 9. North Puget Sound herring biomass estimates (short tons). Estimates are from spawn deposition survey, except italic text, which indicates estimate is from acoustic trawl survey. Empty cell indicates no survey was done. DIB, Discovery Bay; SQB, Sequim Bay; DB, Dungeness Bay; FB, Fidalgo Bay; SPB, Samish-Portage Bay; ISJ, Interior San Juan Islands; NSJ, Northwest San Juan Islands; SAB, Semiahmoo Bay; and CHPT, Cherry Point. Data from WDFW.*

Year	DIB	SQB	DB	FB	SPB	ISJ	NSJ	SAB	CHPT
1973									14,998
1974									13,963
1975					109			772	10,337
1976	697	47			77	10	157	321	11,844
1977	1,488	94			32	18	29	634	11,097
1978	1,305	10							10,973
1979	882				333				9,957
1980	3,220	335	43	276	1,008				9,329
1981	3,070			456				1,008	6,219
1982	2,356			182	310			1,389	5,342
1983	2,578		197	640	159			874	8,063
1984	3,144	31		742	160			772	5,901
1985	1,447	18		761	78			2,325	5,760
1986	1,566		234	731	79			1,464	5,671
1987	1,593			887			400		3,108
1988	853							1,965	4,428
1989	1,225				58	541		1,701	4,003
1990	855					391	218	1,930	4,998
1991	925			1,079		60	298	2,061	4,624
1992	727			1,399	262	17		1,501	4,009
1993	737	11		1,417	198	*472*		1,902	4,894
1994	375	0		1,207	*459*			1,389	6,324
1995	261		287	1,173	*194*			1,245	4,105
1996	747	0	180	590	*636*	*277*	53	*1,219*	3,095
1997	199	0	158	929	509	*30*	79	621	1,574
1998	0	0	112	844	643		107	919	1,322
1999	307	0	352	1,005	555	197		868	1,266
2000	159	0	138	737	196	128	90	926	808
2001	137	6	87	944	470	219	62	1,098	1,241
2002	148	0	131	865	496	158	131	1,012	1,330
2003	207	0	44	569	299	72	13	1,087	1,611
2004	252	0	22	339	351	67	0	629	1,734

* K. Stick, Washington Dept. Fish and Wildlife, La Conner, WA. Pers. commun., October 2004.

Table 10. South/Central Puget Sound herring biomass estimates (short tons). Estimates are from spawn deposition survey, except italic text, which indicates estimate is from acoustic trawl survey. Empty cell indicates no survey was done. SP, Squaxin Pass; WB, Wollochet Bay; QM, Quartermaster Harbor; PO, Port Orchard/Port Madison; SH, South Hood Canal; QB, Quilcene Bay; PG, Port Gamble; KH, Kilisut Harbor; PS, Port Susan; HH, Holmes Harbor; and SB, Skagit Bay. Data from WDFW.*

Year	SP	WB	QM	PO	SH	QB	PG	KH	PS	HH	SB
1973											
1974											
1975	*298*			887				279			
1976	*2,138*		1,357	447	492	279	1,142	495		126	478
1977	20		1,413	1,348	444	232	2,525			135	227
1978	58		1,860			14	1,984	254			
1979	137		1,941	1,255			1,790				
1980	*683*		1,930	2,133			2,309	477		78	453
1981	*772*		1,777	891			1,753	324			
1982			1,778	1,214	177		1,463		1,391	78	
1983			909	1,651			2,407		1,398		
1984			1,386	1,293			2,685		1,555		
1985			667	1,415			2,387		1,321	914	
1986			1,181	1,926			2,050		934		
1987			924	2,538		68	2,046		1,216		1,552
1988			750	1,705			1,390		570		1,340
1989			898	1,739			2,395		345	693	
1990	566		681	1,795			2,969	364	291	380	
1991	943		580	722	357	204	2,259	613	245		
1992	771		518	314	144	97	2,270		545		
1993	596		1,075	304			1,521	538	1,693		
1994	225		1,412	424			2,857	292	365		
1995	157		2,001	863		817	3,158		363		891
1996	*374*		*805*	806	239	328	*2,058*	*380*	*110*	336	736
1997	149		1,402	*360*	226	465	*1,419*	*307*	*828*	530	*893*
1998	68		947	*489*	101	1,152	971	*311*	*2,084*	464	*209*
1999	*474*		*1,257*	*2,006*	516	2,464	1,664	*802*	545	175	905
2000	*371*	142	*743*	*1,756*	140	2,426	*2,459*	*107*	*785*	281	*646*
2001	*1,597*	133	*1,320*	*2,007*	187	2,091	1,779	*612*	*587*	275	*2,170*
2002	*3,150*	106	*416*	*878*	166	2,585	1,812	774	*775*	573	*2,215*
2003	*2,201*	152	930	1,085	207	916	1,064	448	*450*	678	*2,983*
2004	*828*	52	*727*	*700*	176	2,342	1,257	*184*	429	673	*1,245*

* K. Stick, Washington Dept. Fish and Wildlife, La Conner, WA. Pers. commun., October 2004.

Table 11. Age and year of millions of herring in the Cherry Point population. Data from WDFW.*

	Age (years)								
Year	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9+**	**Total**
1973	0.16	7.56	35.13	22.77	12.52	2.76	0.41	0.00	81.32
1974	0.54	23.21	16.62	26.28	15.90	6.59	0.99	0.09	90.32
1975	0.16	15.42	6.09	9.27	13.58	7.28	1.99	0.16	53.90
1976	5.53	10.17	18.09	8.33	9.83	11.06	4.37	1.23	68.25
1977	13.91	22.41	6.15	7.91	5.20	6.81	6.66	4.10	73.22
1978	1.24	41.75	14.15	5.03	4.72	2.78	3.40	4.25	77.32
1979	3.82	8.07	25.75	10.04	3.53	4.24	1.73	2.63	59.75
1980	40.16	6.22	5.05	9.95	7.24	2.12	1.32	1.10	73.14
1981	5.99	20.71	4.89	3.16	5.27	1.39	0.34	0.42	42.19
1982	16.41	8.96	10.67	3.17	1.29	0.96	0.25	0.00	41.66
1983	24.70	12.50	8.66	10.92	2.62	0.67	0.79	0.18	60.99
1984	23.95	6.49	5.87	5.72	4.43	1.01	0.29	0.29	48.10
1985	23.90	21.67	6.91	1.45	0.95	0.61	0.17	0.00	55.70
1986	30.80	14.96	5.46	2.21	1.21	0.28	0.22	0.06	55.20
1987	12.58	11.03	4.26	1.10	0.45	0.15	0.09	0.12	29.80
1988	14.79	16.12	6.59	2.01	0.52	0.16	0.00	0.00	40.20
1989	34.10	7.89	5.00	1.91	0.05	0.05	0.00	0.00	49.00
1990	27.18	18.39	3.09	3.20	1.28	0.11	0.11	0.00	53.30
1991	10.61	16.76	7.82	2.67	1.80	0.20	0.04	0.00	39.90
1992	23.76	8.29	7.82	1.96	0.38	0.26	0.04	0.00	42.50
1993	55.34	6.77	2.21	1.41	0.87	0.27	0.07	0.00	67.00
1994	73.72	9.25	2.16	0.69	0.52	0.09	0.00	0.00	86.43
1995	20.26	18.08	2.22	0.50	0.71	0.13	0.00	0.00	41.95
1996	8.65	10.79	7.79	1.13	0.20	0.29	0.03	0.00	28.85
1997	3.86	6.05	4.36	0.44	0.13	0.00	0.00	0.00	14.83
1998	13.06	2.14	1.36	0.32	0.12	0.00	0.00	0.00	17.01
1999	4.18	9.13	0.65	0.16	0.01	0.00	0.00	0.00	14.13
2000	5.22	2.51	1.41	0.02	0.00	0.00	0.00	0.00	9.18
2001	5.59	6.43	1.90	0.33	0.00	0.00	0.00	0.00	14.26
2002	11.17	5.20	1.52	0.22	0.22	0.00	0.00	0.00	18.32
2003	14.41	7.88	1.24	0.31	0.07	0.00	0.00	0.00	23.94
2004	0.38	4.17	5.72	2.67	0.58	0.26	0.11	0.00	13.89

* K. Stick, Washington Dept. Fish and Wildlife, La Conner, WA. Pers. commun., October 2004.

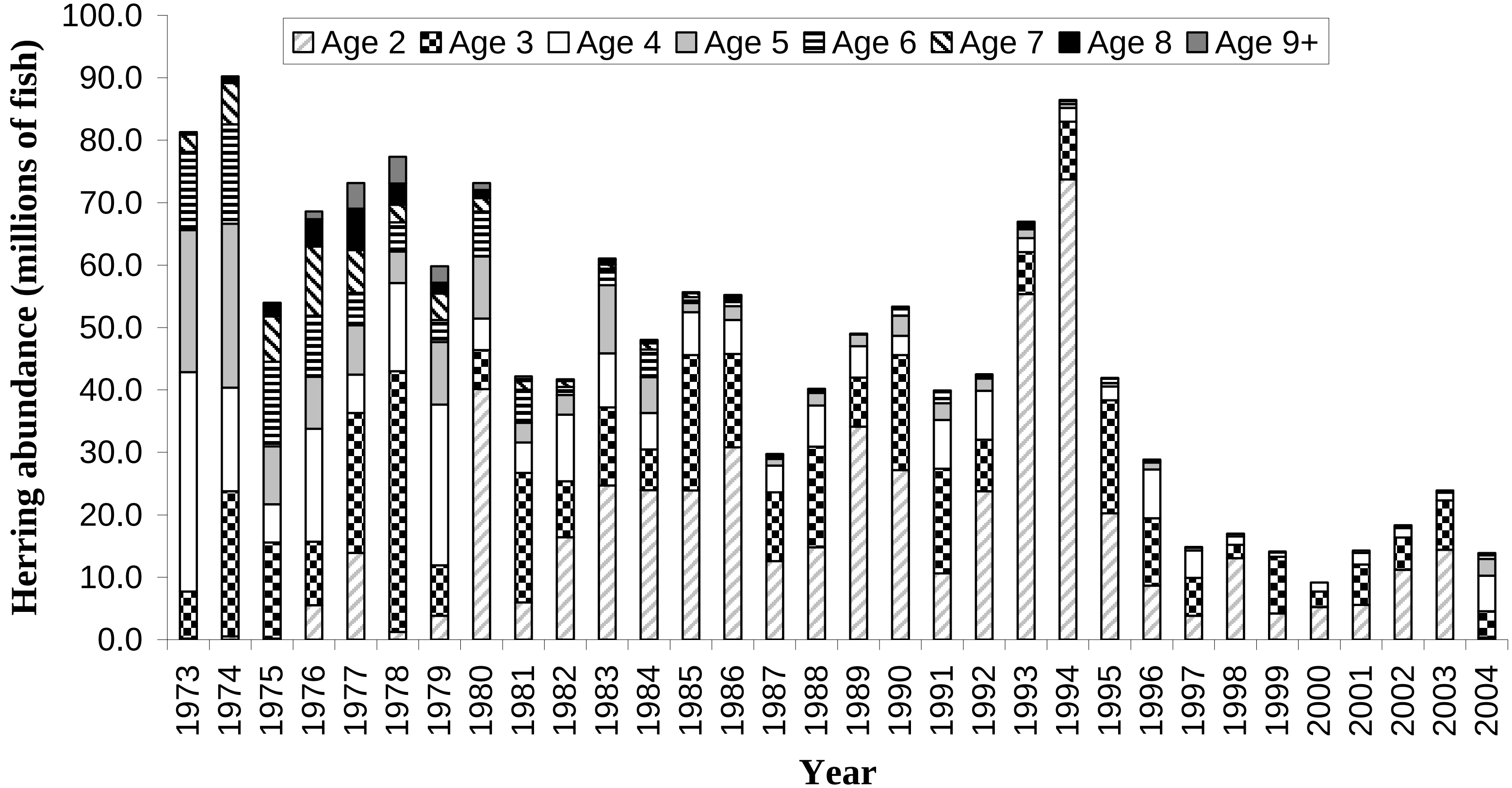

Figure 37. Number of Cherry Point Pacific herring at age from 1973 to 2004. Data from K. Stick.[28]

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[28] See footnote 5.

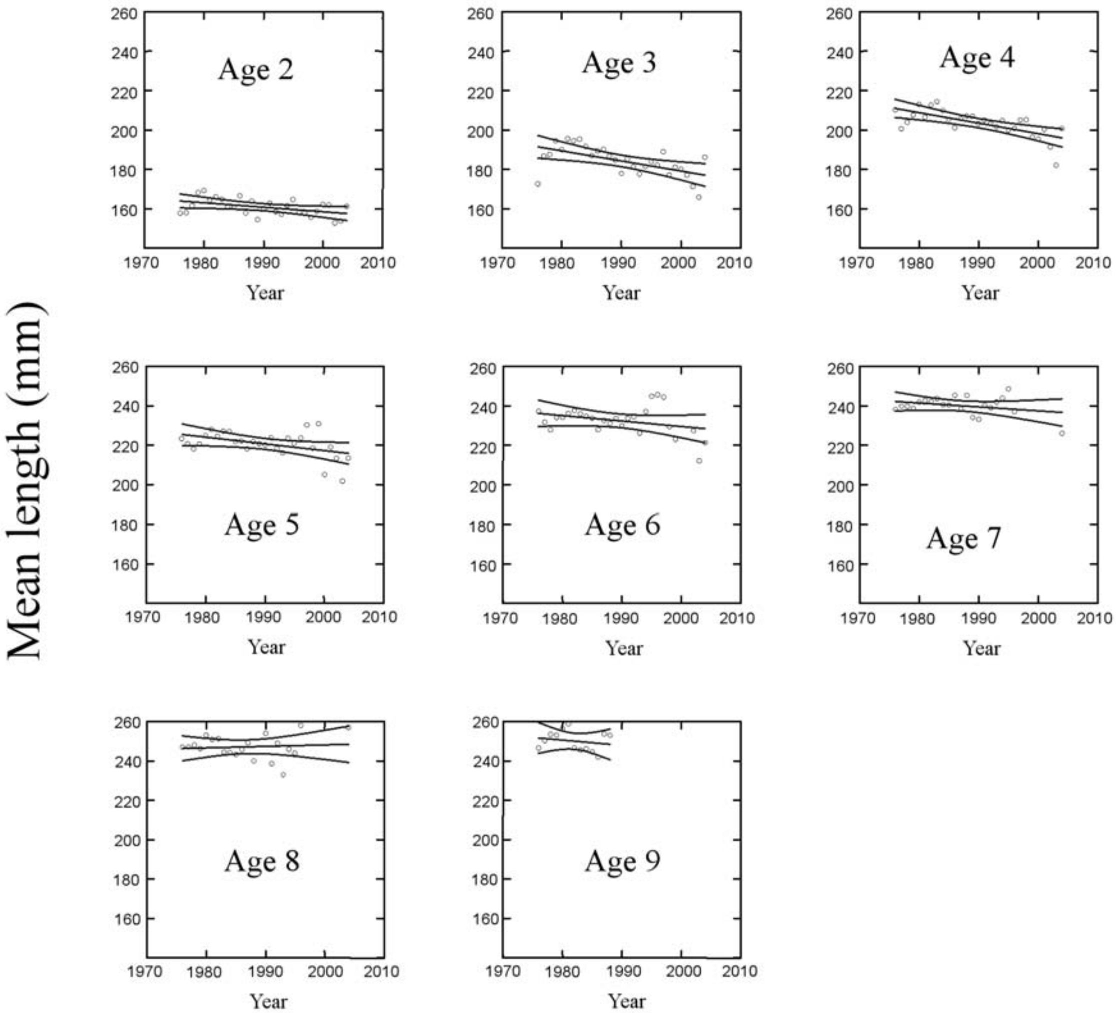

Figure 38. Cherry Point Pacific herring mean length-at-age for ages 2 through 9 from 1973 to 2004. Linear regression lines and 95% confidence intervals are included. Data from K. Stick.[29]

[29] See footnote 5.

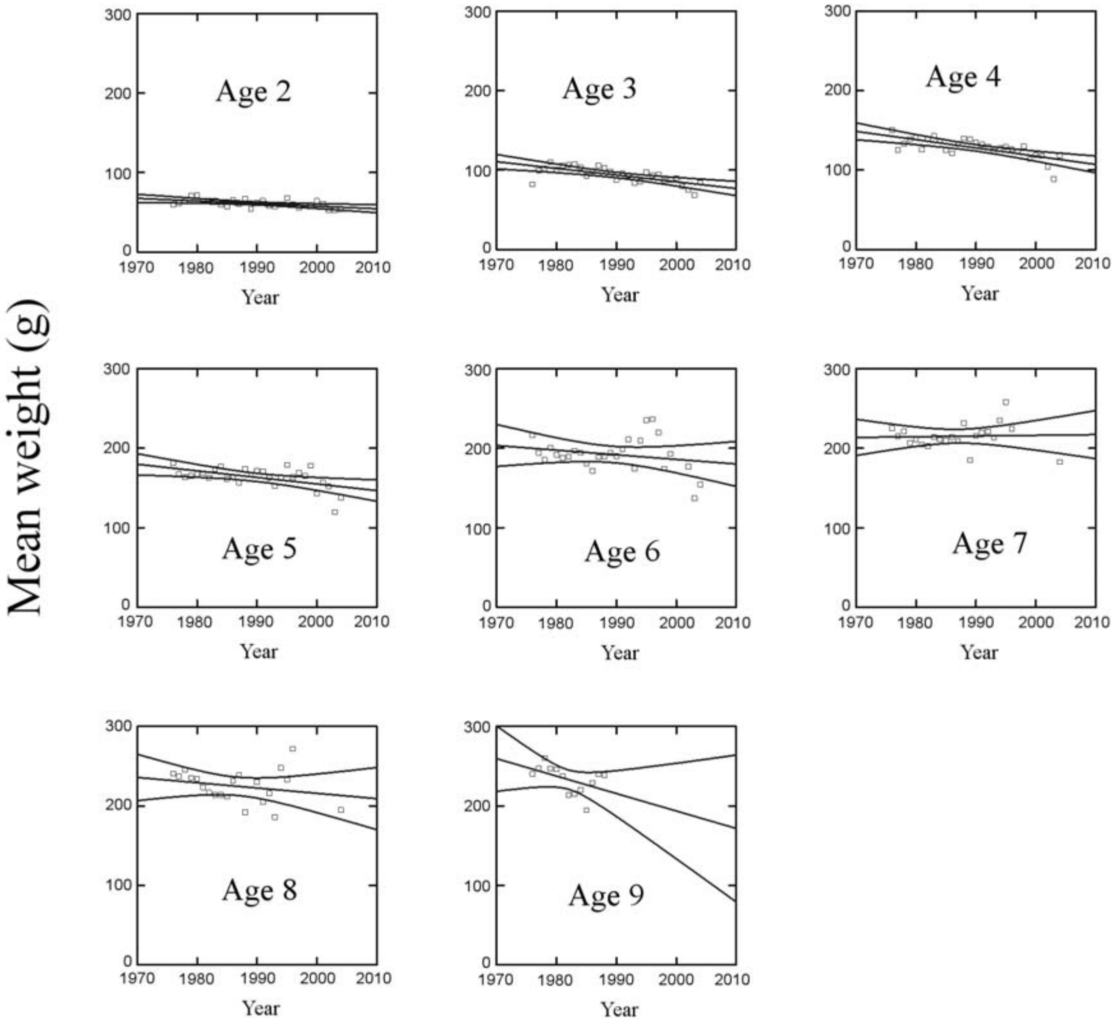

Figure 39. Cherry Point Pacific herring mean weight-at-age for ages 2 through 9 from 1973 to 2004. Linear regression lines and 95% confidence intervals are included. Data from K. Stick.[30]

[30] See footnote 5.

Short-term (1990–2004) and long-term (1973–2004) trends in biomass of Cherry Point Pacific herring are illustrated in Figures 40 and 41. Both the long-term trend of 0.92 (95% CI, 0.91–0.93) and the short term trend of 0.89 (95% CI, 0.84–0.93) (Table 12) indicate that Cherry Point Pacific herring have experienced severe declines in abundance over these time periods. Despite the slight positive increase in biomass since 2000 (Figures 36, 40, and 41), the spawner biomass has experienced a decline of about 87% since 1973. The current biomass estimate is at approximately half the level set by WDFW (Bargmann 2001) as necessary for the stock to maintain itself and provide harvest. The latest status classification by WDFW of the Cherry Point population is "Critical" (Table 13).

The length of coastline utilized by Cherry Point Pacific herring for spawning deposition (spawn length) since 1981 is illustrated in Figure 42. From 1973 to at least 1982, portions of the Cherry Point Pacific herring population spawned at Point Roberts, Birch Point, and Hale Passage, as well as at Cherry Point (Figure 42) (see Figure 2 for orientation). Since 1996 the Cherry Point Reach has been the only section of the coast receiving spawn deposition by the Cherry Point population. In 2004 less than 22 km of shoreline was utilized by Cherry Point Pacific herring for spawning, compared to over 60 km in 1981 (Figure 42). However, shoreline spawning was reported to be more extensive at Cherry Point in 2004 than it had been for a number of years.[31] Bargmann (2001) pointed out that this contraction of the utilized spawning habitat increases risks from anthropogenic stressors such as oil spills and contaminant releases near Cherry Point.

Georgia Basin Pacific herring DPS

The abundance time series information for the Georgia Basin Pacific herring DPS is presented in Figure 43. Summary statistics on population trends for the entire DPS as well as various subunits of the DPS are presented in Table 12. The methods for estimating trends are described in the general risk methods section. In 2004 the estimated total spawner biomass in the DPS of over 116,000 metric tons was only slightly lower than the all time high in 2003 of over 125,000 metric tons. The long-term trend (1973–2004) in abundance for the DPS is 1.01 (95% CI, 1.00–1.03) and the short term trend (1990–2004) in abundance is 1.04 (95% CI, 1.02–1.05) (Figures 44 and 45 and Table 12), indicating that Pacific herring in the DPS as a whole continue to increase in abundance.

Bargmann (1998) reported that, within Washington State, estimates of natural mortality rates for Pacific herring increased from less than 0.4 between 1976 and 1980 to more than 0.6 from 1990 to 1995. Some Pacific herring in Puget Sound formerly lived beyond age 10; however, fish older than 6 years are now rare (Bargmann 1998). Also during this time period, the number of age groups comprising the bulk of the populations decreased from five to two or three (EVS 1999).

The WDFW classifies populations into five status categories: 1) Healthy, recent two-year mean abundance above or within 10% of the 25-year mean; 2) Moderately Healthy, recent two-year mean abundance within 30% of the 25-year mean; or with high dependence on recruitment;

[31] K. Stick, Washington Dept. Fish and Wildlife, La Conner, WA. Pers. commun., June 2004.

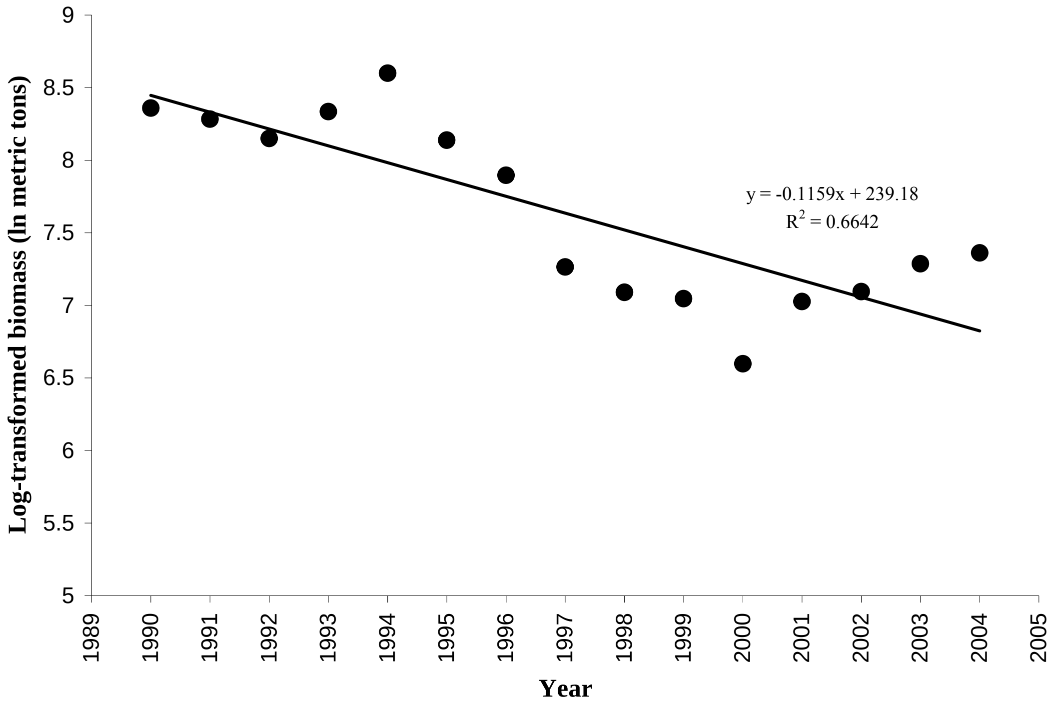

Figure 40. Short-term trend of Cherry Point Pacific herring spawner abundance (metric tons) from 1990 to 2004. Data from K. Stick.[32]

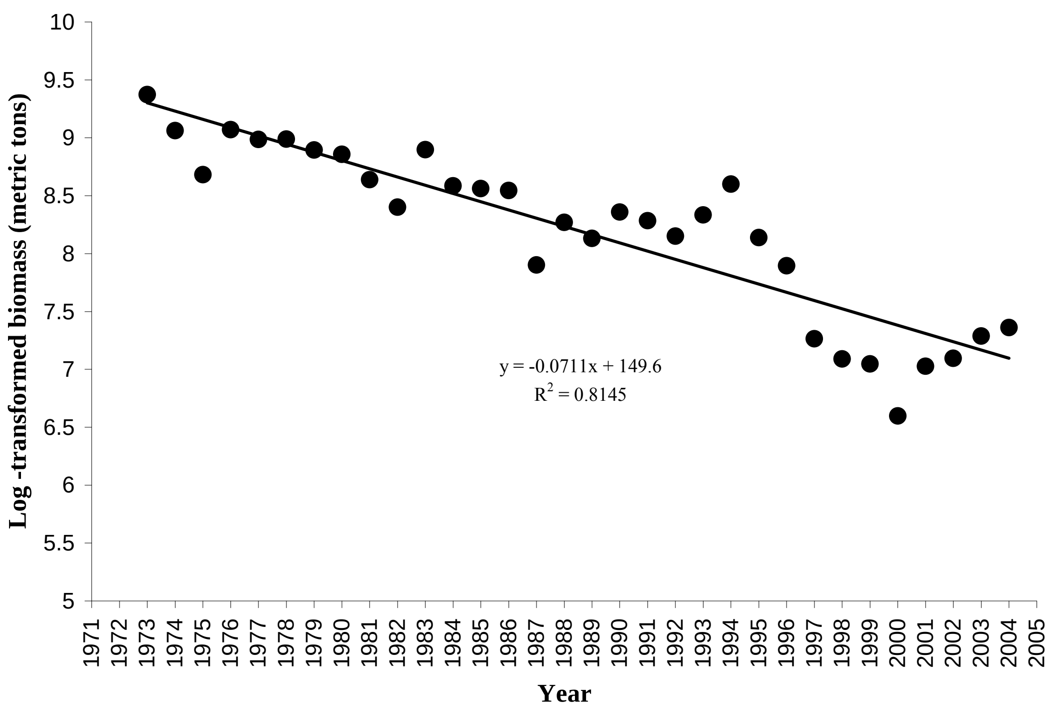

Figure 41. Long-term trend of Cherry Point Pacific herring spawner abundance (metric tons) from 1973 to 2004. Data from K. Stick.[33]

[32] See footnote 5.
[33] See footnote 5.

Table 12. Estimates of long- and short-term trends and their 95% confidence intervals for Pacific herring in the Georgia Basin Pacific herring DPS.

Herring stock/section	**Data years**	**LT trend (CI)**	**ST trend (CI) (1990–2004)**
North Puget Sound			
Cherry Point	1973–2004	0.92 (0.91–0.93)	0.89 (0.84–0.93)
Semiahmoo Bay	1975–2004[a]	1.01 (0.98–1.03)	0.94 (0.91–0.97)
Northwest San Juan Islands	1976–2004[a]	0.93 (0.84 1.03)	0.79 (0.64–0.96)
Interior San Juan Islands	1976–2004[a]	1.07 (0.98–1.15)	0.99 (0.85–1.15)
Samish/Portage Bay	1975–2003[a]	1.05 (1.01–1.09)	1.03 (0.95–1.10)
Fidalgo Bay	1980–2004[a]	1.02 (0.99–1.05)	0.93 (0.90–0.97)
South/Central Puget Sound			
Skagit Bay	1976–2004[a]	1.05 (1.00–1.09)	1.16 (0.98–1.37)
Holmes Harbor	1976–2004[a]	1.05 (1.01–1.09)	1.03 (0.95–1.12)
Port Susan	1982–2004	0.97 (0.92–1.01)	1.04 (0.94–1.14)
Quartermaster Harbor	1976–2004	0.98 (0.96–0.99)	1.00 (0.95–1.06)
Port Orchard–Port Madison	1975–2004[a]	0.98 (0.94–1.01)	1.05 (0.97–1.14)
Port Gamble	1976–2004	0.99 (0.98–1.01)	0.95 (0.92–0.99)
Kilisut Harbor	1975–2004[a]	1.00 (0.97–1.03)	0.98 (0.90–1.07)
Quilcene Bay	1976–2004[a]	1.13 (1.07–1.20)	1.25 (1.13–1.38)
South Hood Canal	1976–2004[a]	0.97 (0.95–1.00)	0.98 (0.90–1.06)
Squaxin Pass	1975–2004[a]	1.05 (0.99–1.11)	1.08 (0.94–1.23)
Strait of Juan de Fuca			
Discovery Bay	1976–2004	0.89 (0.84–0.94)	0.86 (0.70–1.06)
Dungeness Bay	1980–2004[a]	0.98 (0.91–1.05)	0.81 (0.70–0.92)
Canadian Strait of Georgia	1971–2003	1.02 (1.01–1.04)	1.05 (1.02–1.08)[c]
Georgia Basin DPS[b]	1973–2003	1.01 (1.00–1.03)	1.04 (1.02–1.05)[c]

[a] Missing several years of biomass estimates.
[b] Based on biomass estimates of a varying number of stocks per year.
[c] Data years 1990–2003.

Table 13. Comparison of WDFW classifications of status of inland water Pacific herring populations of Washington based on three stock assessments. Data from Stout et al. (2001) and WDFW.*

Stock name	Stock status 1996	Stock status 2000	Stock status 2004
Squaxin Pass	Moderately healthy	Healthy	Healthy: 185% of 25-yr mean spawning biomass
Quartermaster Harbor	Healthy	Healthy	Moderately healthy: 77% of 25-yr mean spawning biomass
Port Orchard/Port Madison	Depressed	Healthy	Moderately healthy: 72% of 25-yr mean spawning biomass
South Hood Canal	Unknown	Healthy	Moderately healthy: 87% of 25-yr mean spawning biomass
Quilcene Bay	Healthy	Healthy	Healthy: 133% of 25-yr mean spawning biomass
Port Gamble	Healthy	Healthy	Depressed: 58% of 25-yr mean spawning biomass
Kilisut Harbor	Unknown	Healthy	Moderately healthy: 73% of 25-yr mean spawning biomass
Discovery Bay	Critical	Critical	Critical: 21% of 25-yr mean spawning biomass
Dungeness Bay	Healthy	Healthy	Depressed: 24% of 25-yr mean spawning biomass
Port Susan	Depressed	Moderately healthy	Depressed: 54% of 25-yr mean spawning biomass
Holmes Harbor	Unknown	Depressed	Healthy: 154% of 25-yr mean spawning biomass
Skagit Bay	Healthy	Healthy	Healthy: 169% of 25-yr mean spawning biomass
Fidalgo Bay	Moderately healthy	Healthy	Depressed: 56% of previous 25-yr mean spawning biomass
Samish-Portage Bay	Healthy	Healthy	Moderately healthy: 78% of 25-yr mean spawning biomass
Interior San Juan Islands	Unknown	Depressed	Depressed: 34% of 25-yr mean spawning biomass
NW San Juan Islands	Unknown	Unknown	Critical: 5% of 25-yr mean spawning biomass
Semiahmoo Bay	Healthy	Depressed	Depressed: 66% of 25-yr mean spawning biomass
Cherry Point	Depressed	Critical	Critical: 41% of 25-yr mean spawning biomass

* K. Stick, Washington Dept. Fish and Wildlife, La Conner, WA. Pers. commun., October 2004.

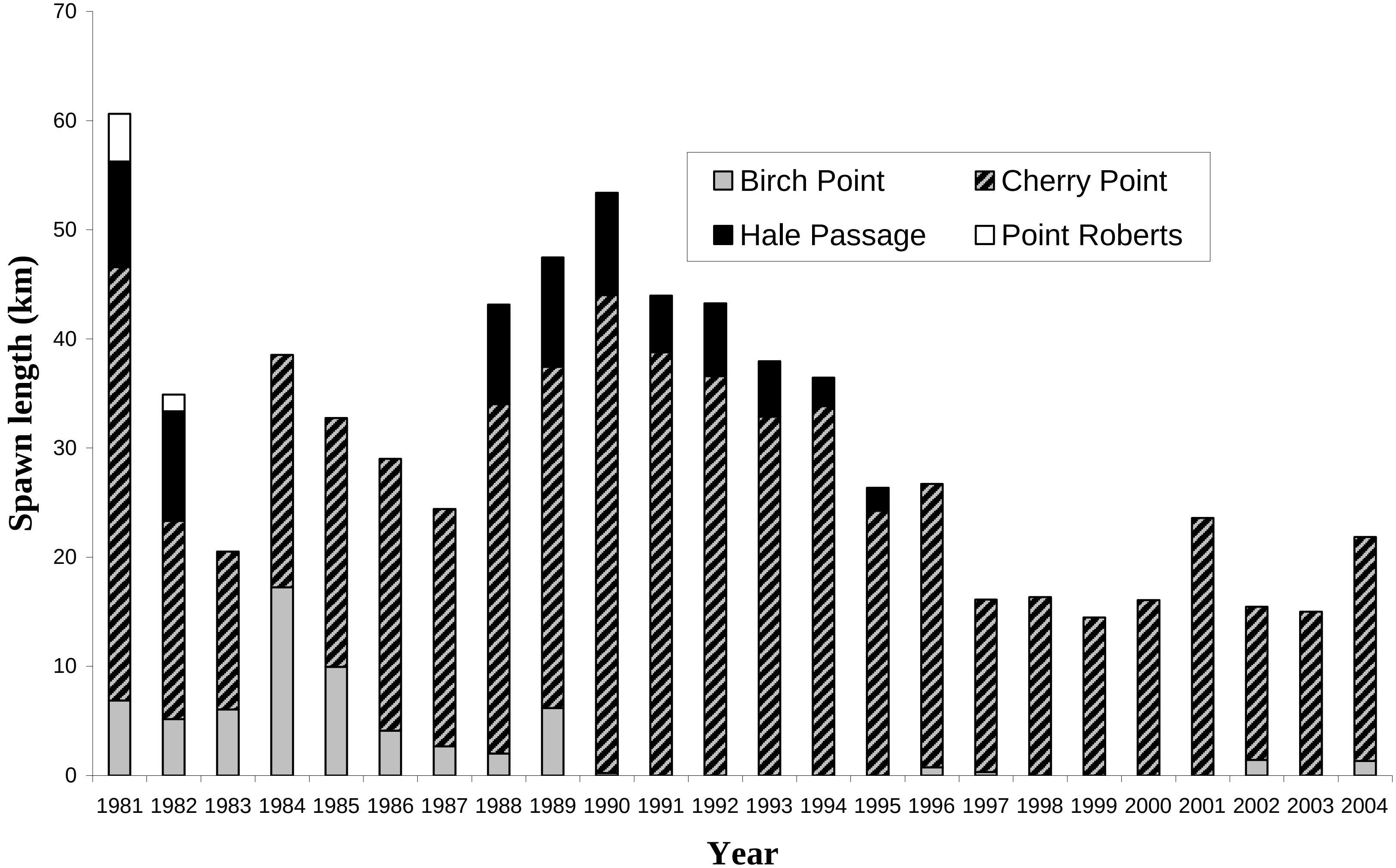

Figure 42. Kilometers of shoreline receiving late-spring Pacific herring spawn deposition at Point Roberts, Birch Point, Cherry Point, and Hale Passage (1981–2004). Data from WDFW.[34]

[34] See footnote 5.

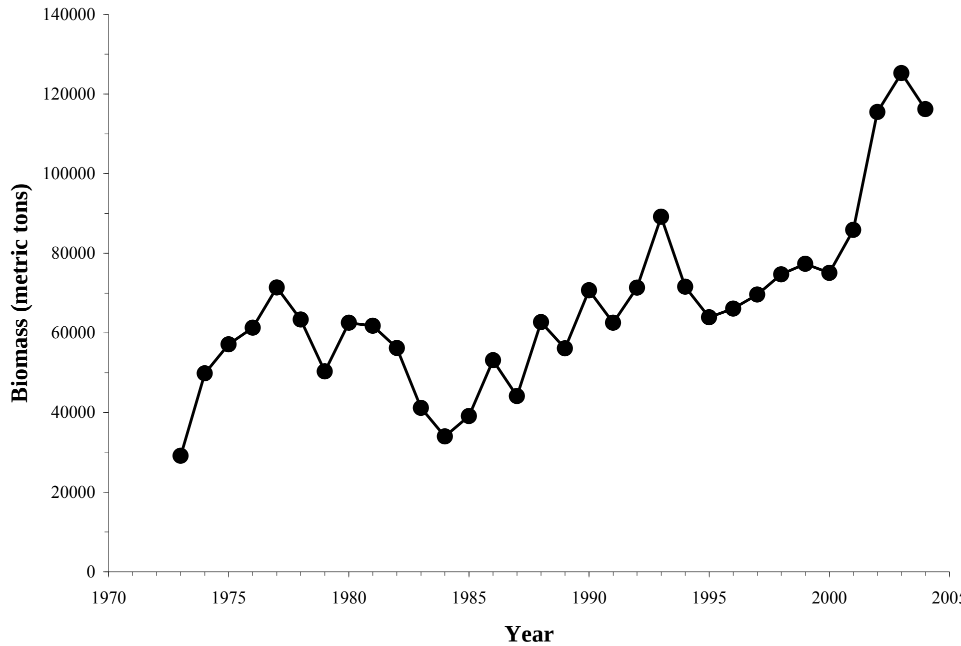

Figure 43. Georgia Basin Pacific herring DPS spawner biomass (metric tons) from 1973 to 2004. Data from WDFW[35] and DFO.[36]

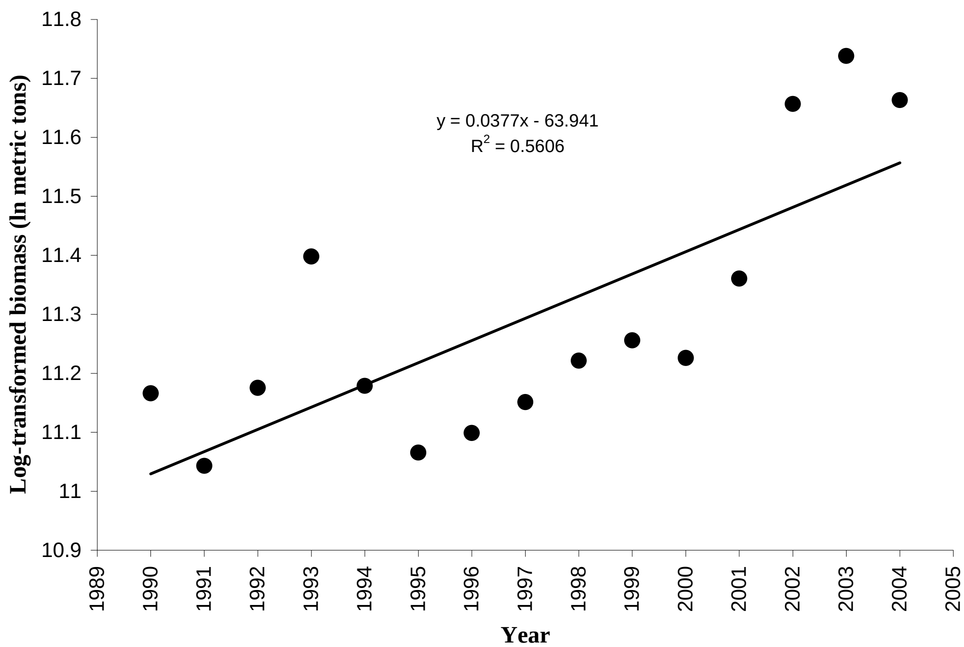

Figure 44. Short-term trend of Georgia Basin Pacific herring DPS spawner abundance (metric tons) from 1990 to 2004. Data from WDFW[37] and DFO.[38]

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[35] See footnote 5.
[36] D. Hay and J. Schweigert, Department of Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Canada. Pers. commun., December 2004.
[37] See footnote 5.
[38] See footnote 36.

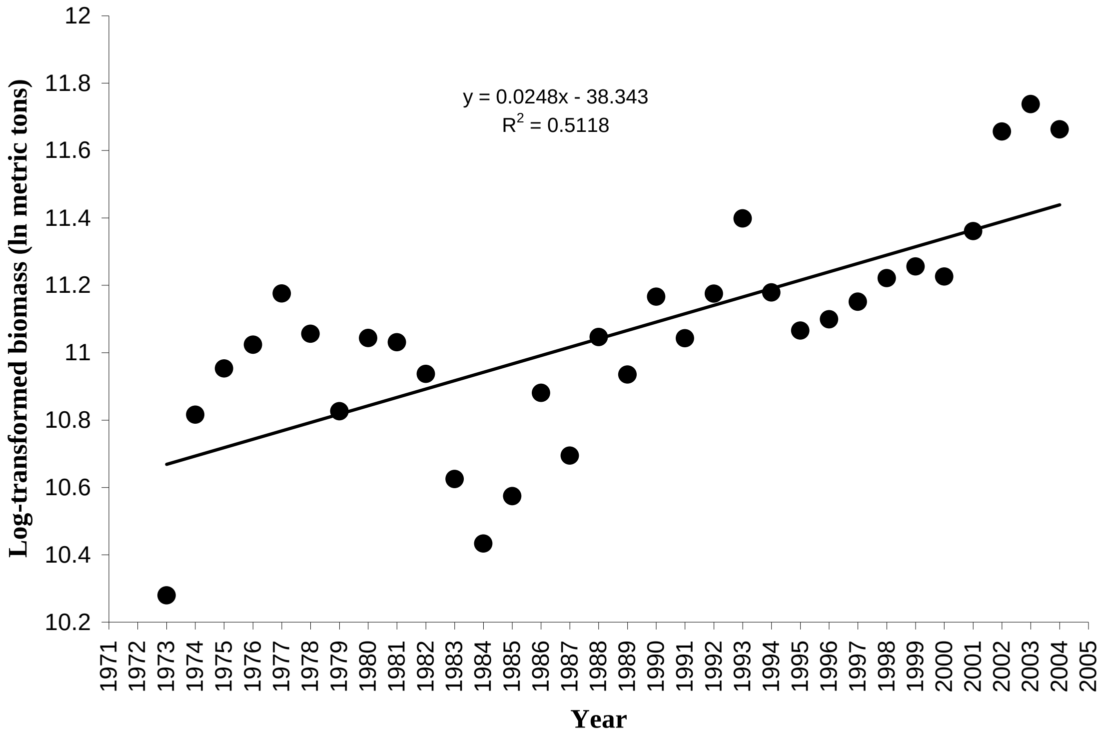

Figure 45. Long-term trend of Georgia Basin Pacific herring DPS spawner abundance (metric tons) from 1973 to 2004. Data from WDFW[39] and DFO.[40]

[39] See footnote 5.
[40] See footnote 36.

3) Depressed, recent abundance well below the long-term mean, but not so low that permanent damage to the population is likely (i.e., recruitment failure); 4) Critical, abundance low enough that permanent damage to population is likely or has already occurred; 5) Extinct, no longer can be found in a formerly consistently utilized spawning ground; and 6) Unknown, insufficient assessment data to identify stock status with confidence (Lemberg et al. 1997). In 1996, WDFW classified status of the 18 inland water stocks as 7 in healthy condition, 2 in moderately healthy condition, 3 depressed, 1 critical, and 5 unknown (Table 13). Washington Department of Fish and Wildlife has updated these classifications twice using data through 1998 and 2004 (Table 13). The recent update resulted in many changes in the classifications. Nine populations have been downgraded in status and one has increased since the 2000 status assessment (Table 13). The latest update classified status of the 18 stocks as 4 in healthy condition, 5 in moderately healthy condition, 6 depressed, and 3 critical. A new stock, Wollochet Bay, was added to WDFW assessments beginning in 2000, but time series of data are insufficient for analysis of the stock's status.

Population Growth Rates and Parameters

The methods for estimating the population growth rate λ are described in the Risk Assessment Methods subsection above. For the Cherry Point population, the data support is very high that the population is decreasing ($\lambda < 1$) (Figure 46). The data observed are much more likely to have been produced by an intrinsically declining population rather than an intrinsically increasing one.

For the Georgia Basin time series data, data support is very high that the population is increasing ($\lambda > 1$) (Figure 47). This means that the data are much more likely to have come from an intrinsically increasing population rather than an intrinsically decreasing population. Note that by chance, increasing time series can be observed from populations whose dynamics are intrinsically decreasing. However, for this time series, the observed rate of increase is high and the year-to-year variability is low. Such combinations are much more likely to be observed in intrinsically increasing populations.

Risk Factors

EVS (1999) provided a thorough overview of potential stressors to the Cherry Point Pacific herring population. Major risks to the survival of Pacific herring were summarized in detail in the previous Pacific herring status review under the topics of overharvesting, predation, loss or degradation of habitat, adverse climatic conditions, and pollution-related effects (Stout et al. 2001a). Risk factors identified in these two reports (EVS 1999, Stout et al. 2001a) are briefly reviewed in the following subsections, with particular reference to Cherry Point Pacific herring and to the Georgia Basin DPS.

Physical stressors

Climate—It is generally accepted that a climate shift occurred about 1977 that affected North Pacific marine ecosystems. Several studies have described decadal-scale oscillations in North Pacific climatic and oceanic conditions (Mantua et al. 1997). These changes have been associated with recruitment patterns of several groundfish species and Pacific herring

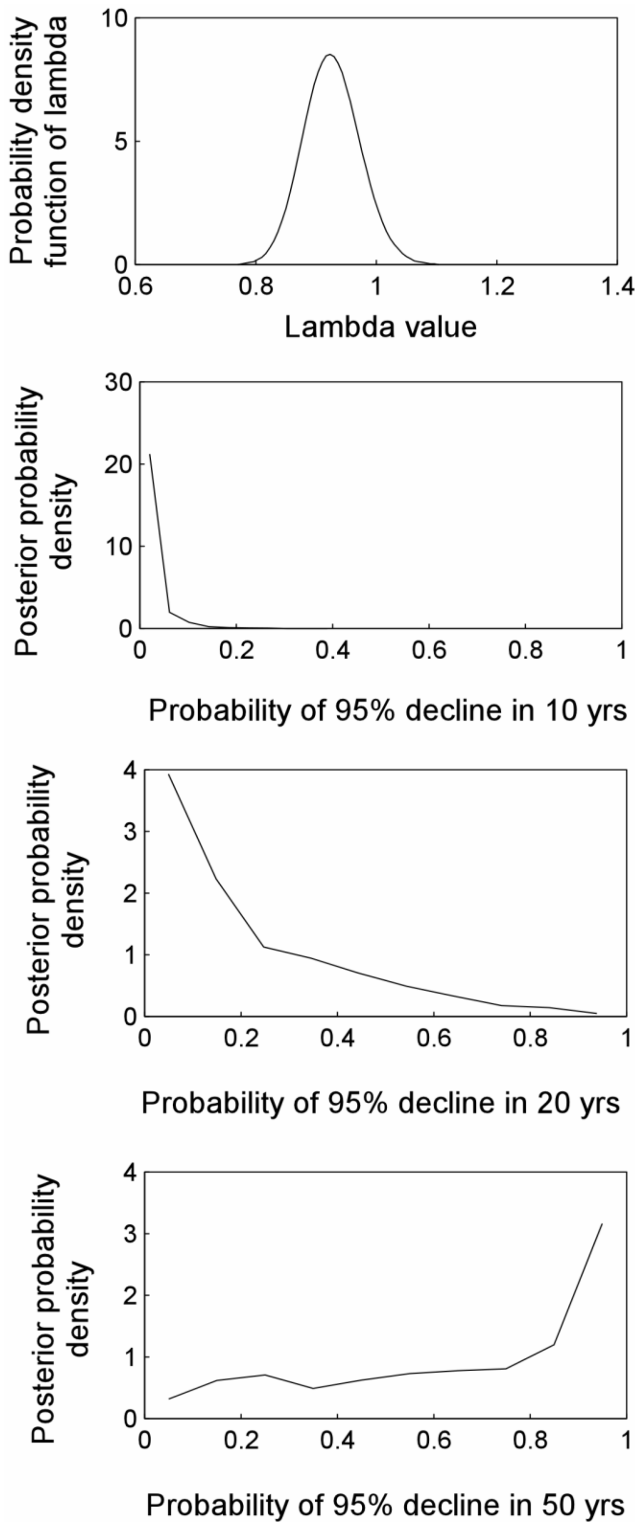

Figure 46. Lambda estimates for the Cherry Point Pacific herring population and the posterior probability that the subpopulation experiences a 95% decline in biomass within the next 10, 20, or 50 years.

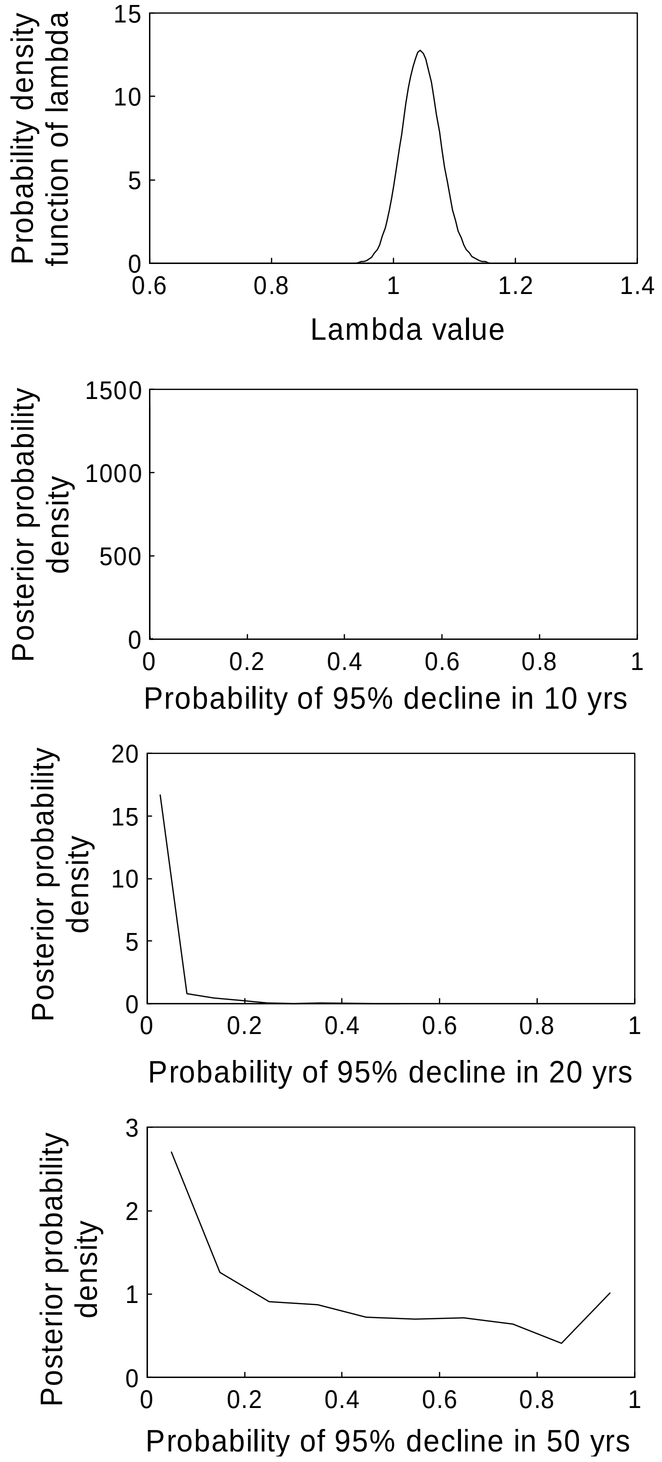

Figure 47. Lambda estimates for the Georgia Basin Pacific herring DPS and the posterior probability that the subpopulation experiences a 95% decline in biomass within the next 10, 20, or 50 years. Note that posterior probability of 95% decline within 10 years is essentially zero, as the line is up against the y-axis.

(McFarlane et al. 2000). Regional, long-term temperature regimes, such as El Niño climate events and the Pacific Interdecadal Oscillation (PDO), have been associated with declines in condition of certain Pacific herring stocks (Spratt 1987, Schweigert et al. 2002).

Schweigert et al. (2002) postulated that changing environmental conditions and resultant reduction in plankton availability may in part explain the decline in growth characteristics since 1977 that are evident for many Pacific herring stocks in Alaska and British Columbia. Similar temporal declines in size-at-age are evident for Cherry Point Pacific herring (Figures 38 and 39), and most other components of the Georgia Basin Pacific herring DPS.

Temperature—Temperature plays an important role in all stages of the life history of Pacific herring (Thornton 1995) and is an important risk factor to all life stages of Cherry Point Pacific herring (EVS 1999). Seasonal changes in temperature regulate the timing of spawning migrations, as well as metabolic and developmental rates. In addition, EVS (1999) indicated a potential interaction of temperature and increased predation on Cherry Point Pacific herring. Analyses of temperature trends for the U.S. part of the Pacific Northwest (Mote et al. 1999); the maritime portions of Oregon, Washington, and British Columbia (Mote 2003a); and the Puget Sound-Georgia Basin region (Mote 2003b) have shown that air temperature increased 0.8°C, 0.9°C, and 1.5°C, in these respective regions during the twentieth century. Warming in each of these areas was substantially greater than the global average of 0.6°C (Mote 2003b).

Scattergood et al. (1959) reported that water temperature at the time of Pacific herring spawning ranges from 3.0°C to 12.3°C on the Pacific coast of North America. Palsson (1984) recorded mean temperatures of 11°C and 11.5°C during two separate 1981 cohort incubation studies of Cherry Point Pacific herring at Birch Bay, substantially greater than the average temperature of 7–9°C at the time of spawning in British Columbia (Alderdice and Hourston 1985, Tanasichuk et al. 1993). Alderdice and Velsen (1971, p. 1545) determined that "maximum temperature for spawning is about 10°C" for Pacific herring in North American waters. Applied Biomonitoring (1999), Applied Biomonitoring and Boettner (2002), and Salazar and Salazar (2002, 2004) reported on temperature measurements associated with caged mussel toxic contaminants studies along the Cherry Point Reach from 1998–2000. Mean daily water temperature between mid-April and mid-June exceeded 11.5°C, the screening threshold for possible deleterious effects on Pacific herring development, on 14 days in 1998, 9 days in 1999, and 2 days in 2000 (Applied Biomonitoring and Boettner 2002). Brief temperature spikes as high as 17–18°C were recorded in 1998 and 1999 (Salazar and Salazar 2002). Salazar and Salazar (2002, p. 2) stated that "these data suggest that temperature is a potentially significant stressor for herring egg development" along the Cherry Point Reach.

EVS (1999) also analyzed the effects of temperature on Cherry Point Pacific herring and found an inverse relationship between the mean annual sea surface temperature (SST) and spawning biomass for the Cherry Point Pacific herring stock from 1973 to 1998. The significant correlations between temperature and spawning biomass, and between temperature and mortality, indicates that regional SST is a risk factor for Cherry Point Pacific herring.

Although temperature is not a direct cause of Pacific herring larval mortality except in extreme cases (Thornton 1995), SST has been correlated with the strength of year classes in Pacific herring (Nagasawa 2001). Temperature extremes have also been associated with larval mortality and abnormal development in laboratory studies and in the field. Wespestad and Gunderson (1991) reported that temperature and larval transport alone accounted for 50% of the recruitment variability seen in Pacific herring from the eastern Bering Sea. EVS (1999) considered temperature to be of moderate risk to egg and larval stages of Cherry Point Pacific herring.

Salinity—Salinity in the Cherry Point region is influenced by discharge from the Fraser and Nooksack rivers, as well as from industrial releases and surface water runoff. Pacific herring have a broad salinity tolerance, but lower survival and other effects have been observed at high and low extremes (Alderdice and Velsen 1971). The risks are greater for egg and larval life stages that are more sensitive to the extremes of salinity than other life stages (Alderdice and Hourston 1985). These life stages are also more likely to be exposed to changing salinity because they are present in nearshore intertidal and subtidal habitats.

Griffin et al. (1998) showed that initiation of sperm motility and progression to hatching were inhibited at higher and lower salinities than the optimum of 12–24‰ for sperm motility and 8–24‰ for development through hatching in San Francisco Bay Pacific herring. However, different Pacific herring populations may tolerate greater or lesser ranges of salinity (Griffin et al. 1998). EVS (1999) found evidence of little, if any, relationship between salinity and the decline of the Cherry Point Pacific herring population. Salinity in the Strait of Georgia and Bellingham Bay has been relatively constant over the years, even with the influence of the Nooksack and Fraser rivers. In contrast, the spawning biomass of Cherry Point Pacific herring has decreased dramatically and recruitment of new spawners has been highly variable.

Larval Pacific herring are euryhaline, surviving best in water of salinities that are less than oceanic, but greater than 0‰ (Thornton 1995). Larval condition is poor if incubation occurs at too high a salinity (Alderdice and Velsen 1971). However, larval Pacific herring are capable of withstanding, for a brief time, large changes in salinity. EVS (1999) found no study-area-specific data for salinity and instead relied on data from nearby Washington Department of Ecology monitoring stations. However, because it was not known whether those stations are representative of the nearshore, EVS (1999) was not able to draw conclusions about this risk factor, except to say that egg and larval life stages of the Cherry Point Pacific herring stock are potentially affected by salinity.

Spawn exposure—Heavy egg loss can occur when eggs are exposed at low tide and subjected to desiccation by sunlight and wind (Barton and Wespestad 1980). These exposure effects are influenced by beach height and by egg size and number of eggs per clump (Jones 1972). Jones (1972, p. 1123) noted that since smaller fish produce smaller eggs, any "reduction in mean spawner size … could put smaller eggs further up the beach where they are less able to survive." The reduction in mean size-at-age (Figures 38 and 39) and number (Figure 37) of adult Cherry Point Pacific herring has likely led to reduced mean egg size and clump size of spawned eggs, which could affect recruitment potential "if environmental factors operating in the intertidal zone are more detrimental to smaller eggs, eggs from smaller fish, or smaller clump sizes" (Jones 1972, p. 1119).

Wind and storms—The shoreline along Cherry Point is frequently exposed to wind and storms. Harsh overwintering conditions can weaken spawning fish, thus reducing egg production either in number or size, and thereby reducing recruitment (Zebdi and Collie 1995). In addition, eggs can be lost from storm damage—normally observed as windrows of washed up eggs and attached vegetation (Tester and Stevenson 1948, Haegele et al. 1981, Hay and Miller 1982). Hay and Miller (1982) estimated that about 25% of total Pacific herring egg deposition was lost in the vicinity of French Creek (near Qualicum Beach on the eastern shore of Vancouver Island) due to storm action in March 1980. Effects of this storm were felt along much of the east coast of Vancouver Island (Hay and Miller 1982). In addition, similar storm-induced changes in the physical environment during the incubation period could affect Cherry Point Pacific herring. That storm-induced egg mortality can occur at Cherry Point is evidenced by Meyer and Adair (1978, p. 53) who stated that:

> The northern Puget Sound sac-roe fishery began in 1973 after large amounts of herring spawn were found washed up on beaches along the eastern shore of the Gulf of Georgia in the spring of 1971 and 1972. The fishery was intended to harvest the apparent surplus.

Alderdice and Hourston (1985, p. 61) stated that "under exposed storm conditions at exposed spawning locations, extension of spawning into deeper waters where other conditions for egg survival are less promising may provide some net survival advantage."

Biological stressors

Lack of vegetation and substrate—Pacific herring have been reported to prefer native eelgrass (*Zostera marina*), rockweed (*Fucus distichus*), and the introduced Japanese seaweed (*Sargassum muticum*) in the intertidal zone for spawning (Taylor 1964). In addition to shallow eelgrass beds, subsequent studies indicated that egg deposition could occur to depths of negative 12 m mean lower low water (MLLW) (Outram and Humphreys 1974). Diver surveys have indicated that red algae may be the most commonly used spawning substrate in southern British Columbia (Haegele et al. 1981). In northern British Columbia, where giant kelp (*Macrocystis* sp.) is much more abundant, it is frequently used as a spawning substrate (Haegele and Schweigert 1985). Haegele et al. (1981) conducted dive surveys in Pacific herring spawning grounds to assess the relation between vegetation type and use as spawning substrate. Along transects with mixed vegetation, 52–77% of eggs were deposited on red algae species. More than half of the eggs were deposited on foliose red algae (*Cryptopleura* sp., *Prionitis* sp., *Gigartina exasperata*, and *Gymnogongrus leptophyllus*), except on gradual slopes with wide spawning areas where the majority was deposited on filamentous red algae (*Rhodomela larix* and *Odonthalia floccosa*). On steep slopes where kelp was a significant vegetation type, 36% of eggs were deposited on kelp (*Agarum* sp. and *Laminaria* sp.). Along transects with mixed vegetation, eggs also occurred on rockweed (*F. distichus*, to 17%), eelgrass (*Z. marina*, 6–15%), and other brown algae (*S. muticum*, to 11%). A similar pattern of vegetation utilization was found in approximately 200 ha of diving surveys in the Strait of Georgia, but in surveys 600 km (370 mi) north, red algae ranked second to eelgrass (Haegele and Miller 1979).

Eelgrass occurs in near shore areas of Puget Sound and the Georgia Basin where it provides spawning substrate for Pacific herring. Recent surveys in Puget Sound (Wyllie-Echeverria et al. 2003) found that submerged eelgrass habitat had disappeared from two documented Pacific herring spawning sites in the San Juan Islands, Washington. Eelgrass has also been monitored in Puget Sound by the Washington Department of Natural Resources

(WADNR) under the Submerged Vegetation Monitoring Project (Sewell et al. 2002). The Puget Sound Action Team (PSAT 2005) reported that WADNR detected a 4% decline in eelgrass between 2002 and 2003 that was mainly confined to Hood Canal and north Puget Sound, although the majority of the 76 monitored eelgrass beds had been stable since 2000.

Availability of suitable spawning and rearing habitat has been considered a potential risk factor for Cherry Point Pacific herring. EVS (1999) reported that since Pacific herring appear to be capable of utilizing a variety of vegetation types for spawning, at Cherry Point they could potentially spawn on vegetation along the entire stretch from Point Whitehorn to the Sandy Point Marina entrance (Figure 2). The width, slope, and exposure of the shelf along the Cherry Point reach that is used for spawning varies considerably from north to south and, consequently, vegetation used for spawning may vary from area to area or year to year (EVS 1999). However, EVS (1999) concluded that the width of the shelf, the availability of stable substrates for vegetation to attach to, and the distribution of vegetation with regard to shoreline zones could interact with environmental factors such as temperature, the amplitude of tidal cycles at the time of spawning, and predator abundance and distribution, to produce areas of the shoreline with different rates of egg survival. Overall, a lack of vegetation or substrate does not appear to be a factor limiting the areas that could potentially be utilized for spawning in the vicinity of Cherry Point (EVS 1999). EVS (1999) determined that impacts at the egg or juvenile life stage do not account for the overall stock decline

Food supply—One of the principal food sources for Pacific herring is *Neocalanus plumchrus,* a large and nutritious calanoid copepod. Marshall and Bargmann (in prep.) reported that the sharp decline in Cherry Point Pacific herring abundance was caused by a sharp reduction in *Neocalanus* sp., while populations of smaller copepods such as *Calanus marshallae* increased. They also speculate that Cherry Point Pacific herring spawn in late spring in order to synchronize larval hatch with the emergence of *N. plumchrus* as an available prey item. However, EVS (1999) analyzed ocean productivity (chlorophyll *a* and invertebrate biomass) and concluded that that was a lack of a relationship between recruitment to the Cherry Point Pacific herring stock and food supply. Therefore, although food supply is a potential risk factor that affects Pacific herring populations, there is no time series of data directly addressing Pacific herring food supply for the Cherry Point population, and data from other locations were not collected over a sufficient time scale to show any relationship (EVS 1999).

Competition—A temporal decline in size-at-age is apparent for Cherry Point Pacific herring since 1973 (Figures 38 and 39). A similar decline in size-at-age occurred in British Columbia and in Alaska (Schweigert et al. 2002). Much of this recent (since 1973) decline in size-at-age may be driven by a combination of poor ocean conditions (see above) for Pacific herring and perhaps competition for food (Schweigert et al. 2002), particularly with the very abundant migratory Pacific herring population that dominates the northern SOG. Naumenko (2002) examined temporal variations in size-at-age for 28 Pacific herring populations in the northwest Pacific Ocean and showed that these populations exhibit long-term cyclic growth dynamics that are influenced by stock abundance and food supply. Individual growth in these populations was reduced in periods of very large or very low stock abundance (Naumenko 2002). The decline in Cherry Point Pacific herring abundance and other segments of the Georgia Basin DPS may have allowed other forage fish species to move into the ecological niche once occupied by Pacific herring, resulting in increased competition for available food resources and a reduced ability for the populations to rebuild to previous levels.

Disease—Disease is a major risk factor that can significantly affect population abundance of Pacific herring (Marty et al. 2003) by reducing the lifespan of adult fish and causing mortality of juvenile fish before they mature. Pacific herring suffer from epidemic diseases such as viral erythrocytic necrosis virus (VENV) and viral hemorrhagic septicemia virus (VHSV) (Kocan et al. 1997). Several highly virulent, endemic pathogens persist in Puget Sound Pacific herring that, in combination with other stressors, can result in disease outbreaks (Hershberger et al. 2004). For example, Carls et al. (1998) found that adult Pacific herring, caught in the wild and experimentally exposed to weathered crude oil, exhibited increased mortality and histopathologic lesions in concert with activation of VHSV, in contrast to control fish. Kocan et al. (2001) concluded that it was highly probable that VHSV, or any other disease in age-0 Pacific herring, could have an important impact on recruitment success and ultimate year-class strength. However, Kocan et al. (2001) found low levels of VHSV-infected wild fish from Puget Sound and EVS (1999) found no evidence for long-term trends or increases in disease outbreaks in the Cherry Point Pacific herring population.

Parasites—A parasite of concern in risk analyses of Pacific herring is the protozoan *Ichthyophonus hoferi* (Kocan et al. 1999, Hershberger et al. 2002). This parasite infects many marine fish species, and has been shown in laboratory studies to be highly pathogenic for juvenile Pacific herring (Kocan et al. 1999), and therefore capable of causing mass mortality events. The prevalence of this parasite in wild populations of Pacific herring has been documented in coastal British Columbia (Jones and Dawe 2002), as well as in Puget Sound (Hershberger et al. 2002). Hershberger et al. (2002) found that prevalence of the parasite may be maintained in older fish in Puget Sound, noting that the parasite occurred in 12% of juveniles and 58% of the age-6 and older cohorts. Furthermore, the disease is maintained in the environment by other infected fish species (Kocan et al. 1999, Hershberger et al. 2002). Rates of infection by parasites in some Pacific herring stocks differ in El Niño years (Moser 1991), due to increased availability of prey. In addition to *I. hoferi*, 10 other species of parasites were recently identified in Pacific herring from Prince William Sound, Alaska (Marty et al. 1998).

Predation—Spawned Pacific herring eggs provide forage for a wide variety of birds and intertidal invertebrates (Schmitt et al. 1994). Bird predation is suspected as the greatest source of egg loss, since great numbers of birds often congregate on the spawning ground. Taylor (1955) reported bird predation could result in 30–90% egg mortality on individual spawnings. Large birds, mainly diving ducks and gulls, can account for up to 80% of Pacific herring egg loss rate over the incubation period (Palsson 1984). The waters of Puget Sound and the Strait of Georgia support large numbers of wintering seabirds, such as migratory sea ducks. These seabirds are known to concentrate in nearshore areas in association with spawning locations for Pacific herring (Bayer 1980, Haegele 1993a, Sullivan et al. 2002). At Birch Bay, Washington, Palsson (1984) reported that diving ducks congregated around spawning beds during the first three days after spawning in direct response to egg deposition. Palsson (1984) also reported that surf scoters were the dominant avian predators recorded at Cherry Point during the Pacific herring spawning migration. Haegele (1993a) estimated that seabirds consumed between 3.1% and 3.8% of the spawn deposited in the Strait of Georgia in 1989 and 1990, and noted that seabirds may consume most of the Pacific herring eggs when stocks are low. Furthermore, avian predation on

Pacific herring eggs also affects the macrophyta upon which eggs are deposited. Bayer (1980) observed 17 bird species (see Bayer 1980 for species list) grazing heavily on intertidal plants covered with Pacific herring eggs, which may have contributed to the patchiness and zonation of eelgrass. In addition to egg predation, Cleaver and Franett (1946) observed seabirds directly consuming juvenile Pacific herring. Logerwell and Hargreaves (1997) estimated that seabirds consumed between 11% and 21% of juvenile Pacific herring off Vancouver Island, Canada.

U.S. West Coast pinnipeds include the California sea lion (*Zalophus californianus*), Steller sea lion (*Eumetopias jubatus*), harbor seal (*Phoca vitulina*), northern elephant seal (*Mirounga angustirostris*), northern fur seal (*Callorhinus ursinus*), and Guadalupe fur seal (*Arctocephalus townsendi*). In Puget Sound and the Strait of Georgia, pinnipeds that potentially prey upon Pacific herring are limited to California sea lion (Schmitt et al. 1995) and harbor seals (Baraff and Loughlin 2000). Harbor seals are the most abundant pinniped in Washington (Jeffries et al. 1996), and are an important predator. Harbor seals are opportunistic feeders whose diet includes fish, cephalopods, and crustaceans. In Pacific Northwest waters, fish species commonly eaten by harbors seals include Pacific herring, northern anchovy (*Engraulis mordax*), and various salmon and codfish species. It is estimated that Pacific herring make up nearly 6% of the diet of California sea lions (Schmitt et al. 1995) and approximately 32% of that of harbor seals (Environment Canada 1998). Olesiuk (1993) reported that in the Strait of Georgia, Pacific hake and Pacific herring constituted 75% of the biomass consumed by harbor seals. Marine mammal predation remains an important risk factor to the Cherry Point Pacific herring population (EVS 1999).

River lamprey (*Lampetra ayresi*) is an important predator of Pacific salmon and Pacific herring. Mortality is mainly on 1-year-old Pacific herring, not the spawning 3-year-and-older fish. Beamish and Neville (1995) studied lamprey predation on Pacific herring in the Fraser River plume and estimated that mortality of Pacific herring amounted to 156 million in 1990 and 203 million in 1991. They concluded that lamprey predation could be an important source of marine mortality of Pacific herring in the Strait of Georgia.

Many species of invertebrates, including pelagic cnidarians, ctenophores, salps, and chaetognaths, prey on Pacific herring larvae (Schmitt et al. 1994). Purcell and Grover (1990) estimated zooplankton predation rates on Pacific herring larvae in Kulleet Bay, Vancouver Island, British Columbia. They concluded that predation, primarily by the hydromedusa *Aequorea victoria*, was a major source of Pacific herring larvae mortality.

A number of benthic marine invertebrate species also prey on Pacific herring eggs. In a study of epibenthic invertebrate predation of Pacific herring eggs in British Columbia, Haegele (1993b) estimated that egg loss due to invertebrate predation averaged 8%, with crabs comprising the major invertebrate predator, accounting for 60% of the egg loss. In an egg mortality study at two sites in Puget Sound, Palsson (1984) reported that invertebrate predators at Quartermaster Harbor included two mud snails (*Nassarius mendicus* and *Mitrella gouldi*). At Birch Bay, no snail predation was recorded but other invertebrate predators including crabs (*Cancer productus, C. magister,* and *Puggetia producta*), an amphipod (*Anisogammarus pugetensis*), the ochre sea star (*Pisaster ochraceus*), and unspecified sea anemones were present.

Herring larvae are eaten by juvenile fish of many species (Schmitt et al. 1994), including Pacific salmon, Pacific hake, and walleye pollock (West 1997). Likewise, adult Pacific herring, including spawning and post-spawning adults, are an important prey for many marine organisms in Puget Sound, including Pacific salmon, Pacific cod, Pacific hake, walleye pollock, lingcod (*Ophiodon elongates*), spiny dogfish (*Squalus acanthias*), Pacific halibut (*Hippoglossus stenolepis*), and rockfishes (*Sebastes* spp.) (West 1997). During May in Central Puget Sound, Pacific herring have been reported to make up 60% and 26% of the prey biomass of Chinook (*Oncorhynchus tshawytscha)* and coho salmon (*O. kisutch*), respectively (Fresh et al. 1981).

The predatory fish most likely to have contributed to the decline of Cherry Point Pacific herring is Pacific hake, a large demersal fish, which has declined in abundance in Puget Sound, but is suspected to be a major Pacific herring predator in open waters off the coast of Vancouver Island (EVS 1999). Several studies (Ware and McFarlane 1995, McFarlane et al. 1997) have hypothesized that a predator-prey mechanism can explain the interrelationship of rising sea surface temperatures, the biology of Pacific hake, and the decline of Pacific herring that utilize areas off southern Vancouver Island. The theory rests on the temperature-dependence of the northward extent of the annual summer migration of Pacific hake from California into the coastal waters of northern Washington and southern British Columbia. Because Pacific hake feed heavily on Pacific herring, and because they have a tremendous impact on the coastal ecosystem during their summer residence (i.e., they comprise the single largest component of fish biomass in the summer fish community of southern British Columbia), they have the potential to significantly reduce Pacific herring abundance. Stocker et al. (1985) used an age-structured model to estimate recruitment of Pacific herring, and found that natural mortality was inversely related to biomass, (i.e., depensatory). They suggested that the principal mechanism for depensation was increased natural mortality due to predation associated with small school sizes at low biomass. Therefore, fish predation remains an important risk factor for the Cherry Point Pacific herring population, given the population's reduced abundance (EVS 1999).

Small larval size—In 1991, mean weight of herring larvae from two sites at Cherry Point were 91 µg and 75 µg, compared to a control larval weight of 120 µg (Kocan 1998). Likewise, Hershberger et al. (2005) showed that mean dry weights at hatch of larvae derived from naturally spawned Pacific herring eggs at Cherry Point in 1999 (82 µg), 2000 (95.6 µg), 2001 (133 µg), and 2002 (112 µg) were significantly smaller than similar larvae from other Puget Sound stocks in each of these years (104 µg in 1999, 112–141 µg in 2000, 151–191 µg in 2001, and 150–175 µg in 2002). Hershberger et al. (2005) also found that mean total length of newly hatched Pacific herring larvae at Cherry Point in 2002 (6.0 mm) were significantly smaller than larvae from other Puget Sound locations (6.4–8.8 mm). Hershberger et al. (2000) detected a significantly greater percentage of Pacific herring larvae at Cherry Point hatched without yolk (86%), compared to larvae from other Puget Sound locations (up to 28%) in 2000. In addition, Hershberger et al. (2005) reported that yolk deficiencies in Pacific herring eggs at Cherry Point in 1999 (97%) and 2000 (87%) were significantly greater than in other sampled Puget Sound stocks (35% in 1999 at Holmes Harbor and ranging from 1–33% in 2000 for a number of localities).

Hershberger et al. (2000, 2005) proposed several scenarios to explain the observed low larval weight and high incidence of larvae hatching without yolk at Cherry Point, but stated that the ultimate causes remain undetermined. Gilardi and Gaydos (2003, p. 1) reported that Hershberger, Naish, and Kocan had "found that Cherry Point Pacific herring larvae had similar weights and a similar incidence of developmental abnormalities regardless of whether they developed in the waters at Cherry Point or were incubated in clean laboratory water or were transplanted and developed in other areas of the Puget Sound which are considered uncontaminated." Hershberger et al. (2005, p. 333) also reported that "in situ egg exposures indicated that these [developmental] abnormalities were not related to conditions at the [Cherry Point] spawning location."

Because low larval weight at hatch implies that Pacific herring egg sizes were also low at Cherry Point (see Jones 1972), it may be pertinent to examine the studies of Tanasichuk and Ware (1987) and Tanasichuk et al. (1993). Tanasichuk and Ware (1987, p. 1490) examined the relationship of fecundity and egg size in British Columbia Pacific herring and showed that "there is a significant trade-off between fecundity and egg size" and "that there may be an optimal egg size which maximizes survival during the early life history." Tanasichuk et al. (1993) compared life history characteristics of SOG and Beaufort Sea Pacific herring. Both studies suggested that Pacific herring populations whose larvae experience higher sea temperatures would be expected to have smaller weight-specific egg (and larval) size to compensate for an "anticipated increase in predation pressure during the larval phase" (Tanasichuk et al. 1993, p. 971). This phenomenon is also seen among Atlantic herring, where early (winter-spring) spawning stocks produce larger eggs and late (summer-autumn) spawning stocks produce smaller eggs (Hempel and Blaxter 1967). Cherry Point Pacific herring larvae would be expected to encounter higher sea-surface temperatures as larvae and perhaps greater predation pressure than other local Pacific herring populations that spawn 2–3 months earlier. Unfortunately, Cherry Point Pacific herring fecundity and egg weight measurements are not available. In addition, since egg size also increases with adult female body size (Hay 1985) and larger, older Pacific herring spawn earlier than smaller, younger Pacific herring, it is important when comparing Pacific herring egg and larval size from different locations to use gametes from similar-sized adult female fish.

Larval skeletal abnormalities—Kocan (1998) examined the percent of abnormal or deformed larvae at hatch and after seven days of growth along the Cherry Point Reach, and detected few significant differences from laboratory controls. Hershberger et al. (2005) detected a significantly larger percentage of larvae at Cherry Point in 2000 (55%) and 2001 (38%) that had skeletal deformities compared to Pacific herring from other Puget Sound spawning locations (0–14% in 2000 and 10–20% in 2001). However, the percent of larvae with skeletal abnormalities at Cherry Point in 2002 (7%) were within the range of abnormalities seen in other sample locations in Puget Sound (1–35%). Purcell et al. (1990) detected high percentages of abnormalities in yolk-sac (up to 25%) and post-yolk-sac (up to 68%) larvae in a relatively pristine spawning location on Vancouver Island, British Columbia that may have resulted from exposure to unusually sunny, warm weather coinciding with daytime low tides during the egg incubation period. As mentioned above, Gilardi and Gaydos (2003, p. 1) reported that Hershberger, Naish, and Kocan had "found that Cherry Point Pacific herring larvae had … a similar incidence of developmental abnormalities regardless of whether they developed in the waters at Cherry Point or were incubated in clean laboratory water or were transplanted and developed in other areas of the Puget Sound which are considered uncontaminated." Likewise, Hershberger et al. (2005, p. 326) reported that "larval abnormalities originated primarily from factors independent of conditions at the spawning location because they were not reproduced by incubation of foreign zygotes along the Cherry Point shoreline but were reproduced after the development of indigenous [Cherry Point] zygotes in controlled laboratory conditions." Thus it is unlikely that the high percentages of abnormal larvae detected at Cherry Point were due to warm, sunny weather conditions.

Reduction in size and age at maturity—In the case of Cherry Point Pacific herring, the apparent reduction over time of both size-at-age (Figures 38 and 39) and age at first maturity from age 3 to age 2 (Figure 32) may have had a negative effect on population growth. Smaller body sizes likely lead to reduced fecundity, since fecundity increases exponentially with female weight, and smaller egg sizes and early maturity may lead to reduced longevity. Temporal and geographical trends in Pacific herring body size-at-age, age at maturity, and fecundity and their impact on stock productivity in Cherry Point Pacific herring were extensively reviewed in the previous status review (Stout et al. 2001a) in the sections entitled "Growth rate, body size-at-age, and age structure" and "Trends in Productivity" and are not repeated herein.

Anthropogenic stressors

Fishery harvest—It is likely that the Cherry Point stock was overharvested in the mid-1970s. The initial decline in stock biomass in the late 1970s and early 1980s may have been due to the initial high harvests. EVS (1999) indicates that total harvest of the Cherry Point prespawning stock biomass ranged from 4,450 short tons in 1974 to 126 short tons in 1988. No harvests were taken in 1981, from 1983 to 1986, or from 1997 to 1998. However, it could be argued that the stock was harvested during portions of the 1970s at rates that are equal to or more than those considered sustainable by the current scientific consensus. EVS (1999) notes that this pattern of initial overexploitation followed by reduced population size and greater regulatory control is common among new fisheries, as the Pacific herring sac roe fishery was in the early to mid-1970s. However, EVS (1999) noted that it was unlikely that these harvests played a major role in abundance declines during the 1990s, because the time elapsed since the harvest rate was reduced to sustainable levels is greater than the oldest recorded age class in the population (9 years). In other words, the population that was overharvested in the 1970s has since been replaced at least twice.

Habitat—Eelgrass beds, an important spawning habitat in Washington State, have been adversely impacted, particularly in areas of intense industrial development. Anthropogenic stressors on eelgrass include activities directly disturbing eelgrass beds, such as dredging and boat anchoring, and indirect activities that reduce light availability such as over-water structures, runoff that increases turbidity, and nutrient addition, which facilitates algal blooms (Sewell et al. 2002). The adoption of a "no net loss" policy by the State of Washington has led to the creation of the Submerged Vegetation Monitoring Program (Berry et al. 2003). Sewell et al. (2004) estimated that there are approximately 200 km^2 of eelgrass in Puget Sound, with more eelgrass in flats stratum (60%), but more miles of coastline with fringe eelgrass habitat.

Cherry Point proper is located south of the BP Cherry Point refinery pier (Figure 2), and at this point distribution of kelp beds shifts from distinctly subtidal and begins to straddle the boundary between the intertidal and subtidal zones. To the south of Cherry Point, kelp beds appear to narrow and eelgrass abundance to decline sharply with only small, scattered patches present down to the entrance to the Sandy Point Marina (Figure 2). According to EVS (1999), no eelgrass beds occur in the vicinity of the southernmost ConocoPhillips Ferndale refinery pier.

On nearby San Juan Island, Wyllie-Echeverria et al. (2003) documented a dramatic decline in eelgrass beds. Of particular concern is the loss of an entire eelgrass bed, as happened in Westcott Bay in the San Juan Islands between 2001 and 2003 (PSAT 2005). WADNR detected an overall 4% decline in eelgrass among the 76 monitored beds in Puget Sound between 2002 and 2003. This decline was mainly confined to Hood Canal and north Puget Sound, while the majority of the 76 monitored eelgrass beds have been stable since 2000 (PSAT 2005).

The decline of habitat, particularly eelgrass, at Cherry Point has been hypothesized as one of the factors for the decline of the Cherry Point Pacific herring stock. However, Kyte (1999, 2000, 2001, 2002, 2003, 2004) surveyed the Cherry Point shoreline and stated that the distribution and quantity of submerged aquatic vegetation, which is important as Pacific herring spawning substrate, varied yearly due to storms, natural littoral processes, and growth or recession of eelgrass and macroalgal beds. He concluded that, in general, habitat conditions for Pacific herring spawning have been good to excellent, as evidenced by increasing heavy use of the vegetated areas for spawning. In any event, the potential loss of eelgrass habitat remains a risk factor for Cherry Point Pacific herring.

Structures—Marine structures (e.g., the BP Cherry Point refinery pier, the Alcoa Intalco pier, and the ConocoPhillips Ferndale refinery pier) may potentially affect littoral transport of sediments along the Cherry Point Reach. According to EVS (1999), no site-specific studies have been conducted at any of the existing marine facilities along Cherry Point to investigate the potential impacts of those structures on wave sheltering and their effects on sedimentation. However, potential impacts of the existing marine facilities can be assessed in a general way by considering the reduction of wave energy on the sheltered side of structures and docked vessels, then considering how this change in wave energy might influence sediment transport behavior. The risk is that a significant reduction in wave energy could lead to the deposition of material in the "sheltered areas," which could adversely affect Pacific herring spawning substrate.

In their risk assessment of piers along the Cherry Point Reach, EVS (1999) concluded that the existing structures and docked vessels were not likely to cause substantial wave sheltering or increases in sedimentation. Furthermore, EVS (1999) stated that when compared to the total shoreline available along the Cherry Point Reach (approximately 14.5 km), the combined influence of these three piers impacts only a fraction of the available habitat. Thus any potential effects due to wave sheltering and sedimentation would be expected to be minimal when compared to the total available habitat. Wave sheltering and sedimentation have not historically been related to potential impacts on the Cherry Point Pacific herring stock. Nonetheless, the potential loss of spawning habitat from a variety of possible anthropogenic causes will remain a risk factor for Cherry Point Pacific herring.

Shading from over-water structures inhibits the growth of marine vegetation and may change the spatial distribution of algae under structures. The degree of impact depends on the vegetation type and the design of the over-water structure. In 1992, Whatcom County estimated the vegetated area shaded by the three piers along the Cherry Point Reach (EVS 1999). They determined the depth of the vegetated zone, the linear feet of trestle that would extend over this zone, and the width of each trestle, and calculated the vegetated area that would be shaded. The BP Cherry Point refinery pier was estimated to shade 1,433 m^2, the Alcoa Intalco pier 1,219 m^2, and the ConocoPhillips Ferndale refinery pier 1,065 m^2. Their estimates of vegetation depth have not been confirmed and should be considered minimum estimates since they assume light to be direct, overhead, and unchanging. Preliminary analysis suggests that the piers do form boundaries to the distribution both of the vegetation and the substrate. Based on aerial photographs, all three piers are located in vegetation gaps (EVS 1999). The effect of structures and shading and the attendant reduction in vegetation remains a risk factor for Cherry Point Pacific herring.

Vessel traffic—EVS (1999) provided a summary of marine vessel traffic likely to be encountered at Cherry Point. The largest tankers allowed to operate in Puget Sound displace 125,000 dead-weight tons (dwt). They may be as long as 290 m. Cargo ships that visit the Alcoa Intalco pier displace approximately 40,000 dwt with a draft of 9 m. Tug boats that assist marine shipping also range in size and may be propelled by conventional screw propellers ("conventional tug") or by V-S propellers, which consist of assemblies of vanes mounted vertically beneath the tug hull ("tractor tug"). The most powerful class of tractor tugs is about 47 m long and operates at 8,000 horsepower. The bottom hull of these tugs is approximately 4 m below the water surface, and the propulsion assembly extends over 2 m below the hull. Conventionally propelled tugs have twin screws mounted nearer the water surface than to the bottom of the hull and range from 4,000 to 7,200 horsepower. Other marine traffic in the Cherry Point area includes pleasure craft, fishing vessels, and other types of commercial shipping vessels.

Washington Department of Ecology estimates that approximately 95% of all tanker traffic into the Cherry Point area approaches through the Strait of Juan de Fuca and then northward through Rosario Strait. The passage through Georgia Strait, which represents the northern access to Cherry Point, is narrow and more restrictive to tanker traffic (EVS 1999).

At Cherry Point, spawning Pacific herring hold in an area offshore prior to moving inshore to the spawning habitat. The holding area serves as a dynamic migration corridor, in the sense that some Pacific herring leave the holding area as others enter it. According to EVS (1999), the shipping lanes for tanker traffic passage to the BP Cherry Point refinery pier likely cross the eastern portion of this holding area, although because the approach to the BP Cherry Point refinery pier is always into the current, and because tidal currents reverse over a tidal cycle, different approaches are used.

Assuming that the largest inbound tankers to the BP Cherry Point refinery pier draw no more than 14.6 m (i.e., the lowest point of the tanker's hull is 14.6 m below the water line), they are not likely to have a direct effect on Pacific herring. According to EVS (1999), recent monitoring of Pacific herring offshore of the spawning habitat shows that the Pacific herring hold near the bottom in depths from 21 to 37 m below the surface, which is over 8 m beneath the largest vessel's hull. Although propeller jets may extend deep enough to create a slight disturbance in water flow to affect the Pacific herring, it is unlikely that these effects are greater than those induced by tidal fluctuations (EVS 1999). It is also possible that the passage of a shadow caused by a moving ship would induce a type of avoidance behavior. Disruption of Pacific herring migration pathways by ship traffic cannot be ruled out as a potential risk factor for Cherry Point Pacific herring.

Noise—It remains uncertain whether noise from vessels in the vicinity of Pacific herring spawning grounds would cause adverse effects (Schwarz and Greer 1984), although reaction to simulated marine mammal echolocation sounds (Wilson and Dill 2002) and apparent production of endogenous sounds (Wilson et al. 2003) suggest that Pacific herring respond to many auditory inputs. Fish in general show an avoidance response to vessels within 100–200 m, when the noise threshold is exceeded by 30 decibels (dB) (Mitson 1995). Larger ships may affect Pacific herring from a greater distance compared to smaller vessels (Schwarz and Greer 1984). Assuming that Pacific herring have a noise threshold of 75 dB and vessels generally emit noise levels of 145 dB in the same frequency range, Pacific herring would be able to detect the vessels (EVS 1999). However, it is uncertain whether they would be sufficiently disturbed to react to vessel sounds, given the uncertain effects of various parameters and their interactions, for example, whether fish are feeding or migrating, water temperature, light levels, and physiological condition. The Cherry Point stock has continuously spawned near the BP Cherry Point refinery pier, despite the elevated vessel traffic and associated noise (EVS 1999). Nonetheless, under some conditions, vessel noise could pose a potential risk factor to Cherry Point Pacific herring.

Oil spills—According to PSAT (2005), there were a total of 223 reported "serious" oil spills (classified as between 25 and 10,000 gallons) between 1993 and 2003 that resulted in the release of over 114,000 gallons of oil into Puget Sound. Two recent oil spills in Puget Sound, at Point Wells in December 2003 (4,800 gallons) and in Dalco Passage in October 2004 (1,000 gallons) "illustrate the potential destruction a major spill could cause in Puget Sound" (PSAT 2005, p. 12).

EVS (1999) reported that marine shipping operations at Cherry Point associated with operation of the BP Cherry Point refinery involve the approach, docking, dockside activities, undocking, and departure of crude oil tankers, refined petroleum product carriers, and tug/barge units. Similar operations occur at the ConocoPhillips Ferndale refinery pier. The Alcoa Intalco pier receives cargo ships delivering alumina or liquified propane. Dockside activities at the refineries include unloading crude oil, loading or unloading product, and discharging or taking on ballast water. Bunkering, or the loading of fuel for ship engine use, is done at Port Angeles and at the ConocoPhillips Ferndale refinery.

There have been at least 47 oil spills of 10,000 gallons or more in Washington since 1964. The Washington State Department of Ecology operates a Spills Program that monitors vessel entries and transits and issues spill prevention bulletins. Clearly the effect of a major oil spill poses a major risk to Cherry Point Pacific herring and the Georgia Basin Pacific herring DPS as a whole. The acute and chronic toxicological affects that release of crude oil have on Pacific herring and on Pacific herring populations are addressed in the following contaminants section.

Ship ballast—The primary risk of ship ballast is the introduction of nonindigenous species that could be harmful to Pacific herring. However, another ballast-related risk factor concerns uptake of ballast water by ships while docked at Cherry Point. Taking on ballast has the potential to affect larval stages of Pacific herring by passively including Pacific herring larvae taken on with ballast and inadvertently transporting them when the vessel leaves the area.

However, EVS (1999) could find no data to quantify the risk of mortality to larval Pacific herring from uptake in ballast water.

EVS (1999) provided a summary of scenarios of ballast uptake at Cherry Point. While at the BP Cherry Point refinery pier, crude oil tankers only take on ballast through sea chests on the bottom of the hull measuring 1.8 m by 2.7 m. The largest tankers take on from 235,000 to 340,000 barrels of water, or approximately 10,000,000 gallons per tanker. It is worth noting that large tankers discharge no ballast, so contaminants or alien marine species are not released to local waters. Likewise, alumina carriers at the Alcoa Intalco pier take on ballast, but do not discharge ballast at the pier. Since water displacement of the alumina carriers is small compared to that of the large tankers, the amount of ballast taken on by these vessels is proportionally smaller. By comparison, product ships (generally 70,000 dwt or less) may discharge ballast from specially designed ballast tanks. Because the tanks only come in contact with ballast water, they are presumed to be free of toxic contaminants. Crude tankers do not discharge ballast at the pier because they are full of crude oil upon arrival. Therefore, it is the product ships that may introduce exotic species into the Cherry Point region when discharging ballast water. This remains a risk factor for Cherry Point Pacific herring.

General contaminants—The previous status review (Stout et al. 2001a) extensively reviewed the topic of environmental contaminants and their impacts on Pacific herring, relying heavily on information from West (1997). Contaminants considered of most concern in Puget Sound by Stout et al. (2001a) included 1) synthetic chlorinated organic chemicals, such as hexachlorobenzene, DDTs, and the polychlorinated biphenyls (PCBs); 2) polycyclic aromatic hydrocarbons (PAHs) from petroleum and creosoted pilings; 3) dioxins and a host of other organic compounds; 4) metals such as mercury, arsenic, and lead; and 5) organic matter and nutrients, such as nitrogen. To this list can be added endocrine-disrupting compounds and new toxics like PBDEs (flame retardants). The following section emphasizes studies on the issue of contaminants that have appeared since Stout et al. (2001a) or are of particular relevance to Cherry Point Pacific herring.

Oil—Petroleum release to the aquatic environment from catastrophic spills and chronic release from point and nonpoint sources creates risks regarding toxicity of oil to individual Pacific herring and to Pacific herring populations. Prior to the 1989 Exxon Valdez oil spill (EVOS) in Prince William Sound, Alaska, conventional acute toxicity bioassay tests, which assess toxicity as the concentration that kills half of the exposed organisms after 96 hours (LC_{50}), had indicated that aromatic hydrocarbons in unweathered crude oil were toxic to juvenile fishes (the most sensitive life history stage) at approximately 1 ppm. Most of this toxicity was assumed to be due to induced narcosis brought about by the 1- and 2-ringed aromatic hydrocarbons in crude oil—primarily benzene, toluene, ethylbenzene, and xylene (BTEX). Since these components of crude oil evaporate to the atmosphere within a few days of air contact, due to their relatively high vapor pressures, the toxic effects of oil on fish were thought to be limited to the first two weeks following an oil release. However, these types of toxicity tests failed to examine delayed mortality beyond the 96-hour exposure period and did not account for variable field conditions that may exacerbate risks to juvenile fish as a result of oil exposure (Rice et al. 2000, Short et al. 2003). In addition, these short-term (4-day) assays failed to account for effects due to chronic exposure to partially weathered oil containing 3-, 4-, and 5-ringed hydrocarbons (Peterson et al. 2003). These polycyclic aromatic hydrocarbons (PAH) are more persistent in the environment than mono-and di-aromatic compounds and are the second most abundant toxic component of crude oil, after BTEX (Rice et al. 2000, Carls et al. 2001).

After the EVOS contaminated shoreline spawning habitat of Pacific herring, as well as intertidal spawning habitat of pink salmon (*O. gorbuscha*), a number of laboratory and field studies were undertaken to examine the longer term effects of crude oil on Pacific herring development (Brown et al. 1996, Hose et al. 1996, Kocan et al. 1996a, Norcross et al. 1996, Marty et al. 1997, McGurk and Brown 1996, Middaugh et al. 1998, Carls et al. 1999, 2000). Carls et al. (2002) has synthesized these and other studies of the toxicological impacts of the EVOS on Pacific herring.

Laboratory exposure of Pacific herring eggs to solutions of PAH in seawater as low as 0.4 ppb (0.4 $\mu g\ L^{-1}$) for 4–16 days resulted in adverse effects including increased mortality, reduction in swimming ability, smaller length at hatch, and morphological abnormalities such as edema, skeletal defects, fanfold defects, and chromosomal aberrations (Carls et al. 1999). In close agreement with the Pacific herring studies are studies on pink salmon embryos (Marty et al. 1997, Heintz et al. 1999, 2000), as well as on other teleost species (Couillard 2002, Middaugh et al. 1996, 2002, Incardona et al. 2004), which document similar developmental defects after PAH exposure. In addition, Barron et al. (2003) demonstrated that exposure to sunlight increased toxicity in PAH-exposed Pacific herring larvae 1.5- to 48-fold (depending on PAH levels in larval tissue) over controls. Early life stages of Pacific herring are particularly vulnerable to photo-enhanced toxicity of PAH, since they occur in nearshore tidal and subtidal habitats as eggs and embryos, and within the photic zone as larvae (Barron et al. 2003).

Adult Pacific herring exposed to oil during the EVOS exhibited elevated tissue PAH concentrations and increased levels of hepatic necrosis (Marty et al. 1999). In addition, Carls et al. (1998) found that adult Pacific herring caught in the wild and experimentally exposed to weathered crude oil exhibited increased mortality and histopathologic lesions in concert with activation of viral hemorrhagic septicemia virus, presumably due to depressed immune function, in contrast to control fish. Kocan et al. (1996b) and Johnson et al. (1997) examined reproductive success in Pacific herring from oiled sites 3 years and 6 years after the EVOS, respectively. Kocan et al. (1996b) compared Pacific herring from only two sites, one oiled and one un-oiled, and detected a lower percent hatch and more morphologically abnormal larvae at the oiled site. However, Johnson et al. (1997) compared Pacific herring from four sites in Prince William Sound with three sites from Southeast Alaska and were unable to detect any evidence of reproductive impairment of Prince William Sound Pacific herring due to the EVOS in 1995, 6 years after the spill.

Low-level PAH exposure has also been shown to result in decreased growth and marine survival in pink salmon (Heintz et al. 2000). Pink salmon exposed as embryos to 1–20 ppb PAH, and control fish, were tagged as juveniles and released to the environment. Following 16 months at sea, salmon initially exposed to ≈5 ppb total PAH experienced a 15% decrease in marine survival (Heintz et al. 2000), while exposure “of about 20 ppb eventually killed half the fish before they could reproduce” (Carls et al. 2001, p. 401). The implication of the Heintz et al. (2000) study is that repeated low-level hydrocarbon exposure can negatively affect fitness and productivity of pink salmon and presumably Pacific herring populations. Several recent reviews of the scientific literature (Carls et al. 2001, 2002, Short et al. 2003) have suggested that the toxicity threshold for aqueous PAHs should be lowered to 1 ppb (1 μg × L^{-1}) to adequately protect juvenile fish rearing habitats.

PSAT (2005, p. 5) reporting on long-term monitoring of contaminated sediments in Puget Sound, stated that "although levels of PAHs are lower than their peak during the coal-burning era of the early twentieth century, levels increased from 1989 to 2000 at four out of 10 sampling sites: Strait of Georgia, Bellingham Bay, East Anderson Island, and Inner Budd Inlet."

Creosote—Vines et al. (2000) examined the effects of diffusible compounds (including PAHs, cresols, and phenols) in weathered creosote-treated pilings on Pacific herring development. Vines et al. (2000, p. 226) stated that

> water-diffusible compounds from creosote-treated pilings disrupted normal development in the Pacific herring in a concentration-dependent manner. Effects included cessation of early development, abnormal cardiovascular function, alterations in the movement of developing embryos/larvae, decreased hatching success, and abnormal larval morphology.

Vines et al. (2000, p. 225) reported that suboptimal salinities enhanced the negative impacts of creosote on larval morphology and hatching success, and that "similar effects were observed in embryos collected from creosoted pilings in San Francisco Bay."

PAH contamination studies at Cherry Point—West and co-authors (West et al. 2004, West[41]) examined total PAHs in spawned Pacific herring eggs from Cherry Point, Fidalgo Bay, Quilcene Bay, Port Orchard, and Quartermaster Harbor. PAH levels exceeded the larval effects threshold of 22 ppb in spawned Pacific herring eggs, as determined by Carls et al. (1999), at other spawning locations in Puget Sound (e.g., Port Orchard), but not at Cherry Point (West et al. 2004, West[42]).

Because PAHs do not accumulate in fish, exposure of adult Pacific herring to PAH in Puget Sound was estimated by West et al. (2001), West,[43] and O'Neill and West (2002) as fluorescing aromatic compounds (FACs), a measure of PAH-metabolites, in Pacific herring bile. Analysis of Pacific herring from six locations—Cherry Point, Semiahmoo Bay, Fidalgo Bay, Port Orchard, Quartermaster Harbor, and Squaxin Pass (West et al. 2001, West,[44] O'Neill and West 2002)—indicated that "Pacific herring from Central and Southern Puget Sound had higher FACs than those from the Northern Sound and Southern Georgia Basin" (West et al. 2001, p. 45). Examination of total PAHs in Dungeness crab hepatopancreas samples from four Puget Sound locations and in English sole (*Pleuronectes vetulus*) (as biliary FACs) from 24 Puget Sound locations (both studies included Cherry Point) showed similar trends, with lower PAH or biliary FAC concentrations in the northern areas such as Cherry Point and higher concentrations in the more urbanized South Sound.[45]

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[41] See Footnote 3.
[42] See Footnote 3.
[43] See Footnote 3.
[44] See Footnote 3.
[45] See Footnote 3.

Marine mussels (*Mytilus* spp.) have little ability to metabolize hydrocarbons (see references in Carls et al. 2002), and because they are filter feeders their body burden of total PAH contamination serves as an indication of the extent of biologically available oil contamination. Applied Biomonitoring (1999), Applied Biomonitoring and Boettner (2002), and Salazar and Salazar (2002, 2004) reported on studies that used bioaccumulation of PAHs over a 60-day exposure period in tissues of caged mussels as a proxy for the potential total PAH available to Pacific herring embryos and larvae along the Cherry Point Reach in 1998–2000, and at three other sites in Puget Sound in 2000. Between 1998 and 2000, the concentration of PAH in mussels indicated levels that "approached those associated with adverse effects on herring embryo-larval development" (Salazar and Salazar 2004, p. 1). However, exposure of early Pacific herring life stages and adult mussels likely differ in duration, magnitude, and timing, as well as in exposure pathways (Salazar and Salazar 2004). Applied Biomonitoring and Boettner (2002, p. 4) reported that "PAH concentrations measured in mussel tissues were lowest at Cherry Point Reach" and were progressively greater at Fidalgo Bay, Port Gamble, and Brownsville (Port Orchard-Port Madison stock) (Salazar and Salazar 2002).

Organochlorines—Polychlorinated biphenyls (PCBs) and organochlorine pesticides (DDTs and hexachlorobenzene (HCB)) were measured as composites from whole fish collected at Lambert Channel (Denby Island/Hornby Island) in the northern SOG (Figure 3) and at Cherry Point, Semiahmoo Bay, Port Orchard, Squaxin Pass (O'Neill and West 2002) and Quartermaster Harbor[46] (Figure 10) in Puget Sound, beginning in 1999. These chemical analyses were limited to adult males of age 2–4 to minimize variation between sites due to potential variation in age and reproductive condition (O'Neill and West 2002). Although lipid levels varied among the stocks, when lipid content variation was accounted for, total PCBs in Pacific herring from Squaxin Pass, Quartermaster Harbor and Port Orchard were significantly higher than in fish from the three northern sites: Cherry Point, Semiahmoo Bay and Denman/Hornby (O'Neill and West 2002, West[47]). Higher concentrations of PCBs were also observed in south Puget Sound locations compared to more northern locations (West et al. 2001, West[48]). Significantly lower concentrations of HCB were detected in whole bodies of Pacific herring from Cherry Point compared to all other collection locations (O'Neill and West 2002, West[49]).

West[50] compared PCB levels in Pacific herring embryos sampled between 3 and 10 days of age at Cherry Point, Fidalgo Bay, Quilcene Bay, Port Orchard, and Quartermaster Harbor in Puget Sound and detected significantly higher concentrations only at Quartermaster Harbor. PCB concentrations from the other sites were not significantly different from one another.

Trace metals—Applied Biomonitoring and Boettner (2002) examined bioaccumulation of arsenic, mercury, cadmium, copper, lead, zinc, and selenium in mussels deployed for 60 days along the Cherry Point Reach, and at Fidalgo Bay, Port Gamble, and Brownsville (within the Port Orchard-Port Madison Pacific herring spawning grounds). Although all mussels accumulated metals, the concentrations were "lower than those known to elicit effects" (Applied Biomonitoring and Boettner 2002, p. 112) in either mussels or Pacific herring. However, as

[46] See footnote 3.
[47] See footnote 3.
[48] See footnote 3.
[49] See footnote 3.
[50] See footnote 3.

Applied Biomonitoring and Boettner (2002, p. 112) stated, these effect levels "are based primarily on acute effects by measuring mortality endpoints that could underestimate potential chronic effects from long-term exposures to low metal concentrations in the field."

Application of IUCN Categories

IUCN (2004, p. 18) recommends using biomass as an "index of abundance appropriate to the taxon" when evaluating marine fish population declines, since assessing declines in the number of mature individuals may underestimate the severity of the decline in situations where reduction in the mean age and size of individuals is also occurring. Therefore we have used biomass as an index of abundance for Pacific herring IUCN risk assessments.

The IUCN population reduction criteria call for measuring decline "over the longer of 10 years or 3 generations" (IUCN 2004, p. 10). A simple definition of generation time is the average age of the total number of parents (spawners) in the population. If generation time "varies under threat … [then] pre-disturbance generation length should be used" (IUCN 2004, p. 18). Calculating the average age of the number of spawning adults over time in the Cherry Point population indicates that generation time stood at about 5 years in the mid-1970s and has been below 3 years for most of the past 15 years (Figure 48). This indicates that a pre-decline generation length of 5 years and a three-generation time of 15 years are the most appropriate scales over which to assess the decline of the Cherry Point population in light of the IUCN decline criteria. Similar temporal analysis of SOG Pacific herring (Figure 49) indicates that generation time is closer to 4 years for this portion of the DPS. Although the time series of data is less complete for other components of the Washington State portion of the DPS, generation time for several WDFW stocks appears to be somewhat less than either Cherry Point or SOG Pacific herring, ranging from 2.5 to 4 years. We chose a three-generation time of 15 years over which to analyze declining populations as being the most precautionary.

Over the three-generation time of 15 years, the overall biomass of the Georgia Basin Pacific herring DPS has increased approximately 107%, while the Cherry Point Pacific herring population has undergone a 54% decline (Table 14). Under the IUCN decline criteria, a reduction in population size of this magnitude "where the reduction or its causes may not have ceased or may not be understood or may not be reversible" (IUCN 2004, p. 29), would place Cherry Point Pacific herring in the IUCN "Endangered" category.

Results of Modified Risk Matrix for the Georgia Basin Pacific Herring DPS

Members of the BRT were asked to rate the overall risk to the Georgia Basin Pacific herring DPS using the risk matrix described in the above "Risk Assessment Methods" section, with 1 representing very low risk and 5 representing high risk of extinction in the near future, for the four viability criteria: abundance, growth rate/productivity, spatial structure, and diversity.

Table 14. Results of application of the IUCN decline criteria to possible subpopulations within the Georgia Basin Pacific herring DPS. All abundances are given as metric tons of spawner biomass. Estimated values (in italics) were derived from extrapolation of linear equations of existing abundance data for missing years. (Methods described in IUCN 2004). Category designations: LC, least concern; NT, near threatened; E, endangered; CE, critically endangered.

Subpopulation	**Past biomass**	**Present biomass (closest to 2004)**	**Current subpopulation estimate**	**Subpopulation 3 generations ago (5-year mean generation time)**	**Estimated 3-generation reduction (=15 years)**	**IUCN category**
Bute Inlet	400 (1973)	350	350	*465*	25%	NT
North SOG	11,516 (1973)	97,557	97,557	37,971	157% increase	LC
Eastern SOG Inlets	232 (1973)	817 (2001)	*16*	*600*	large increase	LC
South SOG + North Puget Sound	5,214 (1973)	8,659	8,659	7,890	10% increase	LC
Strait of Juan de Fuca	675 (1976)	249	249	1,332	81%	CE
Cherry Point	11,767 (1973)	1,573	1,573	3,398	54%	E
South/Central Puget Sound	1,058 (1975)	7,062	7,062	5,507	28% increase	LC
Squaxin Pass	270 (1975)	751	751	*260*	189% increase	LC
Georgia Basin DPS	57,124 (1975)	116,201	116,201	56,098	107% increase	LC

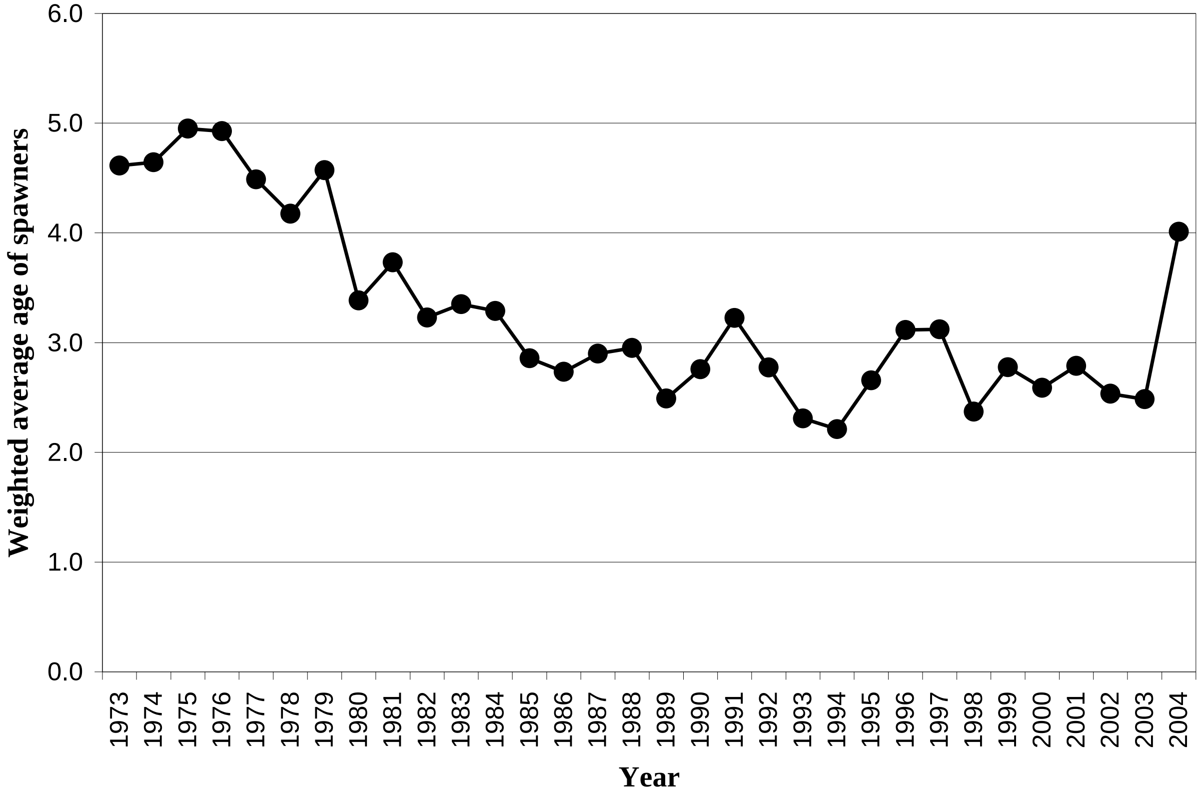

Figure 48. Weighted average age of spawning Pacific herring in the Cherry Point Pacific herring population from 1973 to 2004. Data from WDFW.[51]

Abundance

BRT scores for abundance ranged from 1 to 2, with a modal score of 1. A score of 1 represents "very low risk" and a score of 2 represents "low risk." In this context, very low risk means that it is unlikely that current trends and levels of abundance contribute significantly to risk of extinction for the DPS, either by itself or in combination with other factors. Low risk means that it is unlikely that current trends and levels of abundance contribute significantly to risk of extinction by itself, but some concern that they may, in combination with other factors.

Comments on the abundance criterion included consideration that the overall DPS is at historically high levels of abundance since monitoring began in the 1930s, both in estimated tonnage (recent abundance is well over 100,000 metric tons) and numbers of Pacific herring (estimated at more than half a billion mature Pacific herring); however, the decline of Cherry Point Pacific herring from 24 million fish in 2003 to 14 million in 2004 is troubling.

Growth Rate/Productivity

BRT scores for growth rate and productivity of the DPS ranged from 1 to 2, with a modal score of 2. Again, a score of 1 represents "very low risk" and a score of 2 represents "low risk."

[51] See footnote 5.

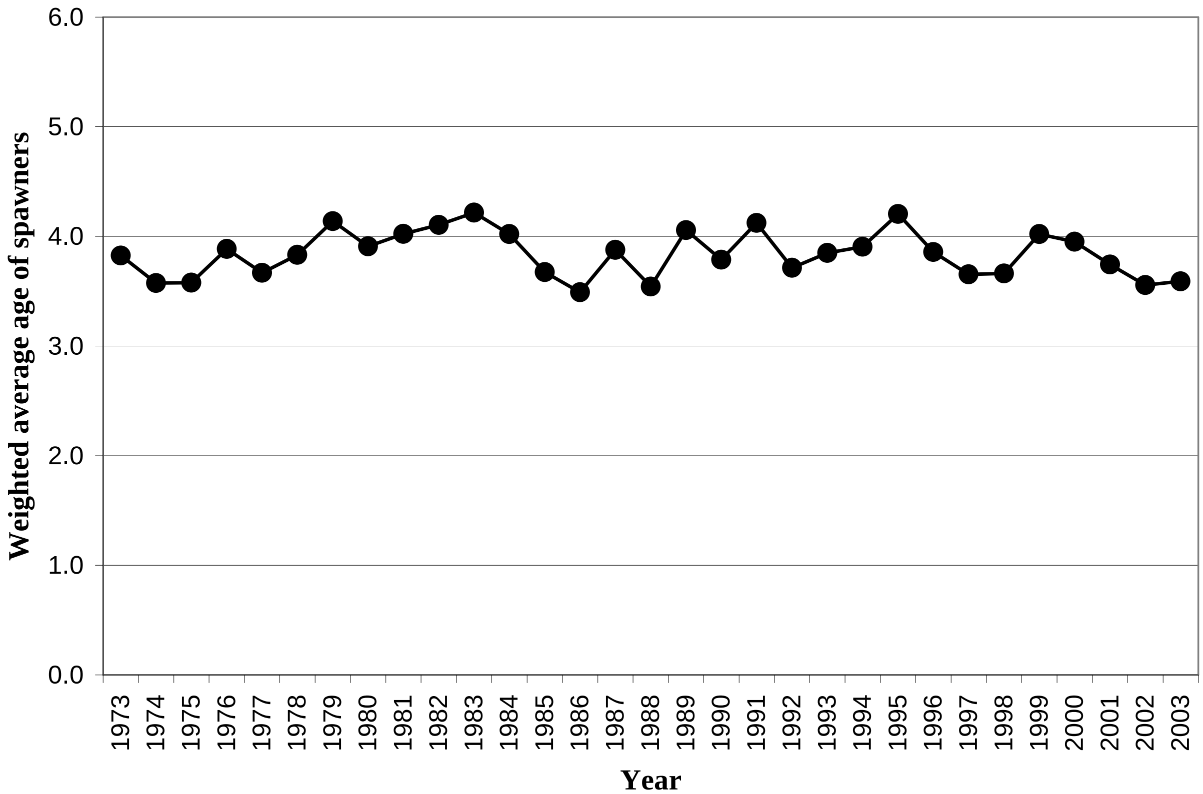

Figure 49. Weighted average age of spawning Pacific herring in the Strait of Georgia region from 1973 to 2004. Data from Schweigert (2004, Appendix 1.4).

In this context, very low risk means that it is unlikely that population productivity (growth rate) contributes significantly to risk of extinction for the DPS, either by itself or in combination with other factors. Low risk means that it is unlikely that population productivity (growth rate) contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors. Comments on the growth rate/productivity criterion included consideration that overall the DPS is highly productive with the overall population trend and lambda (λ) very positive. This was contrasted with some periods in the past (early to mid-1960s) when the overall DPS was in steep decline. In addition, it was noted that despite these past declines, some subpopulations have shown very high productivity levels, indicating the resiliency and ability to rebound inherent in these subpopulations. It was also noted that the recent short-term trend is very positive for the whole DPS and that recruitment is staying high, even though there is an apparent increase in adult mortality possibly correlated with increased harbor seal predation and disease factors (other risk factors are also likely at work here).

Spatial Structure and Connectivity

BRT scores for spatial structure and connectivity ranged from 1 to 4, with a modal score of 2. A large majority of the BRT scored this category as 1 (very low risk) or 2 (low risk). Small minorities of the BRT scored this category as either 3 (moderate risk) or 4 (increasing risk). In this context, very low risk means that it is unlikely that population spatial structure and connectivity contribute significantly to risk of extinction for the DPS, either by themselves or in combination with other factors. Low risk means that it is unlikely that population spatial structure and connectivity contribute significantly to risk of extinction by themselves, but some concern that they may, in combination with other factors. Moderate risk means that population spatial structure and connectivity contribute significantly to long-term risk of extinction, but do not by themselves constitute a danger of extinction in the near future. Increasing risk means that population spatial structure and connectivity contribute significantly to long-term risk of extinction and are likely to contribute to short-term risk of extinction in the foreseeable future. Comments on spatial structure and connectivity criteria included observations that there are no gaps in the geographic range of spawning within the DPS, that all or most historically occupied areas continue to experience spawn events, and that there has been little loss of connectivity between any populations, except those with low abundance. It was also noted that although increasing population trends are not uniform across the DPS (central and northeastern parts of the DPS show declines), the tagging data indicates that there is likely high connectivity throughout the DPS, so these declining trends would not be a major concern in the context of a metapopulation. It was noted that an estimated 22% of SOG Pacific herring emigrate to other regions of British Columbia while 16% immigrate into the SOG from other regions of British Columbia (Hay et al. 2001a, their table 5). Other comments indicated concerns that the bulk of the spawning distribution and most of the abundance and productivity in the DPS has become spatially compacted, especially in the northern half of the DPS. However, this concern was tempered by the feeling that this spatial compaction may be a natural phenomenon.

Diversity

BRT scores for diversity ranged from 1 to 3, with a modal score of 2. A small minority of the BRT scored this category as 1 (very low risk), while a larger minority scored this criterion as 3 (moderate risk). In this context, very low risk means that it is unlikely that diversity contributes significantly to risk of extinction for the DPS, either by itself or in combination with other factors. Low risk means that it is unlikely that diversity contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors. Moderate risk means that diversity contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future. Comments on the diversity criterion included observations that diversity in spawn timing is still normally distributed around a bell-shaped curve, that there has been little change in the natural range of long-term spawn timing within and between populations, that diverse migration still exists in the DPS in the form of nonmigratory and migratory Pacific herring, and that that there has been no apparent genetic loss comparable to other marine species, although long-term data on this topic are limited. Other comments included concerns that the DPS's life history diversity has apparently declined over time with a compressed age structure (few old fish), precipitous decline in late-spawning Pacific herring populations, and an apparent decline in nonmigratory inlet populations on the mainland or eastern side of the SOG. In addition, it appears that there has been a northward shift in the spawning core area of the DPS, but this may be a natural phenomenon and the DPS is still very productive. It was noted that although life history diversity may be declining, since fewer nonmigratory Pacific herring are observed in the SOG, it is difficult to differentiate between "migratory" and "nonmigratory" life history types. It is unclear whether these life history characters are specific to certain populations or present to some degree in all or most Pacific herring spawning aggregates in the SOG and Puget Sound.

Recent Events

The BRT did not identify any specific "recent events" that might have predictable consequences for DPS status in the future but have occurred too recently to be reflected in the population data. Past events that were recognized as already having had a positive effect on the DPS were the closing of certain fisheries, a possible Pacific Decadal Oscillation (PDO) shift to colder climate conditions, a decrease in predation on Pacific herring by Pacific hake due to declining hake size-at-age and loss of larger, older hake in Puget Sound and the SOG, and a decrease in certain pollutants in Puget Sound and the SOG. Past events that were recognized as already having had a negative effect on the DPS were long-term temperature increase, declines in local eelgrass beds (Wyllie-Echeverria et al. 2003), an apparent increase in harbor seal predation in inshore waters (Olesiuk 1993, Baraff and Loughlin 2000) and hake predation in offshore waters (Ware and McFarlane 1995), loss of shoreline spawning habitat in Puget Sound and the SOG (WADNR 2004, PSAT 2005), and an apparent increase in prevalence of certain parasites like *Ichthyophonus hoferi* (Hershberger et al. 2002).

Risk Determination

Although not adopted in this review, application of the IUCN decline criteria to the Georgia Basin Pacific herring DPS would have resulted in this DPS being placed in the Least Concern (LC) category. However, as indicated above, the Pacific herring BRT adopted risk procedures utilized in recent salmonid status assessments. The outcome of this process resulted in the BRT classifying risk to the Georgia Basin Pacific herring DPS as 1) very low to low for abundance concerns, 2) very low to low for growth rate and productivity concerns, 3) very low to increasing risk for spatial structure and connectivity concerns, and 4) very low to moderate risk for diversity concerns. The BRT did not identify any specific "recent events" that might have predictable consequences for DPS status in the future but have occurred too recently to be reflected in the population data. The BRT's overall risk assessment conclusions are further elucidated in the "Conclusions: Risk Assessment" section near the end of this document.

Significant Portion of the Range of the Georgia Basin DPS Question

Previous Findings on the “Significant Portion of its Range” Question

The significant portion of the Georgia Basin Pacific herring range issue was discussed at length by the previous Pacific herring BRT from the perspectives of biomass and distribution of spawning habitat. The previous Pacific herring status review (Stout et al. 2001a, p. 145) related that:

> …some stocks within the Georgia Basin, such as Cherry Point and Discovery Bay, have declined to such an extent that they may meet the IUCN criteria to be considered “vulnerable.” Although the BRT recognized that herring populations in north Puget Sound and Puget Sound proper may be vulnerable to extinction, these populations [i.e., Cherry Point] represent a relatively small portion of the overall DPS of herring in the Georgia Basin.

Although the BRT recognized that Cherry Point Pacific herring is an important component of the diversity within the Georgia Basin DPS, the consensus opinion of the previous BRT as described in Stout et al. (2001a) was that Cherry Point Pacific herring did not represent a significant portion of the range of the overall Georgia Basin Pacific herring DPS.

Approaches to the “Significant Portion of its Range” Question

Pacific herring in this area of the Northwest Pacific appear to roughly fit the classical concept of a metapopulation over reasonable spatial and temporal scales (Ware et al. 2000, Ware and Schweigert 2001, 2002, Ware and Tovey 2004) (see Herring and the Metapopulation Concept on page 9). Therefore, it is challenging and difficult to apply the significant portion of the range test to the Georgia Basin DPS, which for the most part functions as a metapopulation, where some populations are always going to be in decline while others are on the rise. Nevertheless, there is also some evidence that some populations in the DPS are more distinctive than others. The vast majority of Pacific herring in the Canadian SOG migrate to offshore feeding areas each spring immediately after spawning and then return in the late fall and early winter of each year prior to spawning (Stevenson 1955, Taylor 1964, DFO 2004). In contrast, a number of small resident populations are believed to spend their entire lives in coastal inlets and bays or in the Canadian SOG itself and to forgo extensive seasonal offshore migrations (Stevenson 1955, Taylor 1964, Hay 1985). Penttila (1986) also postulated that some proportion of adult Pacific herring remain in Puget Sound throughout the summer while others migrate to offshore feeding grounds. However, it is unclear whether Pacific herring nonmigratory life history diversity is structured on a geographic framework or is spread amongst all spawning locations. Spawn timing separation could also promote isolation and thus development of subpopulation structure, as is the case with Cherry Point Pacific herring.

The BRT approached the "significant portion of its range" question for the Georgia Basin Pacific herring DPS in a two-step process. First, we asked the question: "Are there subpopulations or components of the Georgia Basin Pacific herring DPS that can be identified as relatively independent from one another on the basis of ecological, life history, or genetic diversity criteria?" The types of data that are relevant to providing an answer to this first question are essentially the same as those examined on page 13 in the Evidence Supporting Discreteness and Significance Decisions section. Second, we asked: "Is the DPS at risk in a significant portion of its range, such that loss of the at-risk components or subpopulations would pose a substantial risk to long-term viability of the DPS?" In order to differentiate between a species that is threatened or endangered throughout its entire range and one that is threatened or endangered only in a significant portion of its range, the BRT recognized that the answer to the second question rests largely on the time frame for which the question is asked. In other words, some portions of the DPS may be needed for viability of the DPS in a time frame that is beyond the foreseeable future—long-term climate or ecosystem changes may cause certain diversity elements of the DPS to become more important to the DPS's viability over very long time frames (i.e., centuries).

In attempting to identify components of the Georgia Basin DPS that may represent independent subpopulations we have adapted concepts and methods for identification of "demographically independent populations" developed by McElhany et al. (2000) and various Technical Recovery Teams (TRTs) that are developing recovery plans for Pacific salmon ESUs that have been listed as threatened or endangered under the ESA (see Northwest Salmon Recovery Planning website: http://www.nwfsc.noaa.gov/trt/index.html). The various TRTs have identified current and historical salmon populations using a variety of data sources including: 1) documented historical presence, 2) drainage size and structure, 3) geographic isolation by distance or elevation, 4) genetic attributes, 5) phenotypic characteristics, 6) environmental characteristics, and 7) population dynamics and size. Each of the TRTs have fine-tuned the process and methods for identifying demographically independent populations in ESUs under their purview, and the reader is directed to documents published by the TRTs for details (Ruckelshaus et al. in press, Interior Columbia Basin TRT 2003, Myers et al. 2006, Lawson et al. 2004, Lindley et al. 2004). Identifying these population groups may be useful to the TRTs for several reasons. The first is that such groups represent life history genetic diversity within the ESU, and maintenance of this diversity is important for long-term ESU persistence (McElhany et al. 2000). In addition, the problem of ESU risk would be simplified by identifying independent populations whose viability could then be assessed as individual units.

Evidence for Demographically Independent Subpopulations

When the BRT considered the DPS question, Cherry Point Pacific herring was deemed a discrete population; however, it was not considered to be significant to the species of Pacific herring as a whole. Evidence presented above in the DPS analysis can reasonably be taken to propose that Cherry Point Pacific herring represent a "demographically independent subpopulation" within the DPS. Therefore, evidence cited below will focus on the question of whether we can identify any additional parts of the Georgia Basin DPS, other than Cherry Point, that may represent demographically independent subpopulations.

Although Pacific herring spend, at most, 5% of their lifetime on or near a particular spawning ground, Pacific herring populations are traditionally defined by the boundaries of their spawning grounds. In Washington, Pacific herring occupying each of these spawning grounds are presumed to represent discrete stocks by WDFW (Lemberg et al. 1997, O'Toole et al. 2000). This assumption is based on "stock specific characteristics such as strong site specificity, unique growth characteristics, distinctive spawning time and prespawner holding area behavior" and "early meristic studies which concluded that heterogeneity exists among herring samples taken from various spawning areas throughout Puget Sound (Chapman et al. 1941)" (Lemberg et al. 1997, p. 4).

Although Pacific herring have been documented as spawning at over 1,300 locations in British Columbia (Hay and Kronlund 1987, Hay and McCarter 1999, 2004a), DFO currently recognizes only five Pacific herring management regions in British Columbia: 1) Queen Charlotte Islands, 2) North Coast (Prince Rupert District), 3) Central Coast, 4) Strait of Georgia, and 5) West Coast Vancouver Island (Figure 4). Johnstone Strait is not considered a management region at this time, although it was in the past. Each of these regions is further divided into Statistical Areas, which are further divided into sections (= subareas), each of which is named and numbered (Hay and McCarter 2004a). Schweigert (unpubl. data, p. 3) stated that a location within a section is an "artificial construct, usually a local geographic name used to identify a section of shoreline" and that within a section, "locations are often contiguous and often differ markedly in size."

Spawn Timing

The small South Hood Canal Pacific herring stock spawns at the extreme southern end of Hood Canal (Lemberg et al. 1997) and spawning "is relatively early, beginning in January and finished by early March" (O'Toole et al. 2000, p. 5). The data illustrated in Table 1 indicates that peak spawn timing at Quartermaster Harbor is also earlier than most other Puget Sound locations. Spawning at Holmes Harbor begins "relatively late in the year, occurring in early to mid-April" (O'Toole et al. 2000, p. 6) (Table 1). Comparison of the range of peak spawning as the day of the year (corrected for leap years) in Puget Sound and the SOG indicates that spawn timing is generally earlier in the South Sound than in more northern locations within the DPS (Figure 50).

Spawn Location and Spawning Behavior

The Squaxin Pass Pacific herring stock occupies the southernmost spawning locale in Puget Sound (Figure 10) and exhibits unusual spawning behavior, commonly depositing spawn subtidally on rocks, gravel, and marine algae due to the lack of eelgrass in the area (Lemberg et al. 1997, O'Toole et al. 2000). The Port Susan Pacific herring stock, in Central Puget Sound (Figure 10), also occasionally deposits spawn on rocks and gravel due to a lack of marine algae on the west shoreline of Port Susan (Lemberg et al. 1997, O'Toole et al. 2000).

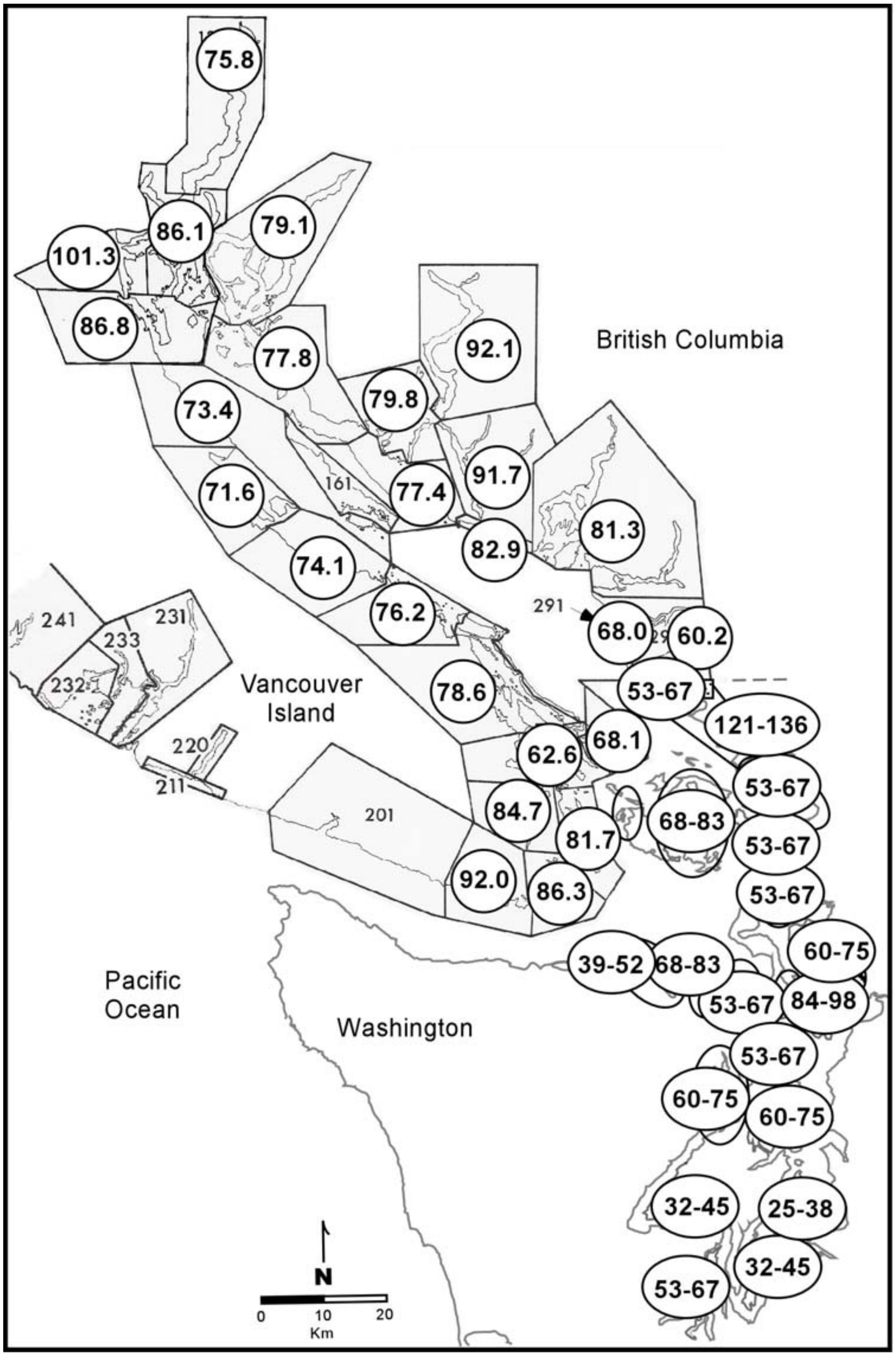

Figure 50. Spawn timing of Pacific herring in British Columbia herring sections (represented as mean day of the year [DOY] for all spawn observations) and in WDFW herring stock units (represented as range of DOY during peak spawning). Data from DFO (2004) and WDFW.[52]

[52] See footnote 5.

Pacific herring spawning in Squaxin Pass and South Hood Canal in Puget Sound, and Bute Inlet (Herring Section 134), Jervis Inlet (Herring Section 164), and Sechelt Inlet (Herring Section 165) in the northern part of the SOG are geographically distant from other spawning locations and are spawning at the heads of inlets (Figure 10). These latter characteristics have been associated with development of local resident Pacific herring populations (Stevenson 1955, Taylor 1964).

Annulus Patterns

Trumble (1980, 1983) described differences in the character and quality of Pacific herring scales that indicated that Pacific herring from Case Inlet (Squaxin Pass) grew rapidly initially but showed very little growth after age 3. Other stocks of Pacific herring in Puget Sound, including Cherry Point, showed scale growth to continue after age 3.

Growth Rate and Body Size-at-age

Ware (1985) attempted to use Pacific herring growth patterns to separate stocks at the regional level in British Columbia. Ware (1985, p. 134) postulated that “variations in size at age presumably reflect differences in the spatial distribution of the stocks during the late spring and summer feeding period.” Ware (1985, p. 135) found that Pacific herring growth patterns contain “some circumstantial information on distributions and degree of mixing that can be used in association with other characteristics for stock identification.” However, “when growth conditions are favorable, particularly when the population is declining, the average weight at age can increase by as much as 50%, and the age at first maturity can decrease by 1 or 2 yr” (Ware 1985, p. 137). Thus any evaluation of growth pattern differences in Pacific herring should include a determination of the temporal stability of the observed patterns (Begg et al. 1999). Problems may also arise in comparing differences in length and weight data collected by different investigators for different stocks that may vary in their degree of maturation (Hay 1985).

Schweigert (1991) applied multivariate statistical analyses to 3 years of mean length, mean weight, and age structure data at ages 3–6 for 26 spawning populations of Pacific herring in British Columbia. Schweigert (1991, p. 2375) stated that these analyzes “indicated stock separation on a smaller spatial scale” than is currently recognized. In reference to the SOG, Schweigert (1991) found evidence that Pacific herring spawning in Johnstone Strait and Strait of Georgia proper are distinct from one another and that Jervis Inlet (Sections 163 and 164) is a distinct stock from the rest of the Strait of Georgia. Other than Jervis Inlet, Schweigert (1991) was unable to detect strong differentiation of individual spawning areas between Lambert Channel (Sections 141–143), Powell River (Section 152), Nanoose Bay (Section 172), and Deepwater Bay (Section 132) (Figure 10). There was “an indication that stocks from Deepwater Bay and Powell River may differ from the other more southerly [SOG] areas, but the evidence is not conclusive” (Schweigert 1991, p. 2370).

As stated previously, Trumble (1979, 1980) described statistically significant differences in mean growth rate and length-at-age data for three populations of Pacific herring sampled in the mid-1970s in Puget Sound: 1) Case Inlet (Squaxin Pass stock), 2) Hale Passage (Kitsap County)-Carr Inlet (unknown stock), and 3) southern Strait of Georgia purse seine catch (Cherry

Point stock). Trumble (1979, 1980) fit length-at-age data for these three areas to the von Bertalanffy growth equation and used a least-squares technique for statistical comparison. Trumble (1980, p. 105) stated that:

> Strait of Georgia [Cherry Point] herring [were] consistently larger (L_∞ = 263 mm) and continually growing (K = 0.36). In contrast, fish from Case Inlet [likely Squaxin Pass stock] grow rapidly to age 3 (K = 0.59), then grow very slowly to a small size (L_∞ = 197 mm). Fish from Hale Passage-Carr Inlet [unknown stock] show intermediate size (L_∞ = 230 mm) and growth rate (K = 0.48). Two of the three von Bertalanffy growth parameters, L_∞ and K, showed significant differences between the three areas at the 1 percent level when compared using least squares analysis.

Gonyea and Trumble (1983) expanded on Trumble's (1979, 1980) growth studies and added North Hood Canal (Quilcene Bay stock) and Protection Island (most likely Discovery Bay stock) Pacific herring to the analysis. They found no significant differences in von Bertalanffy growth parameters between North Hood Canal and Protection Island samples, which were also similar to the growth parameters for the Hale Passage (Kitsap County)-Carr Inlet sample. In addition, Buchanan (1985) reported on the identification of a minor group of Pacific herring spawning in the Fidalgo Bay-Padilla Bay region that were differentiated from other stocks on the basis of their small size at age, scale pattern, and advanced maturity stage.

The smaller length- and weight-at-age of adult Squaxin Pass and Fidalgo Bay Pacific herring compared to a large number of other Pacific herring samples from two sites on WCVI and to other available locations in Puget Sound and the SOG from 1990 to 2002 is illustrated in Figures 20, 21, 28, and 29. As mentioned above, data for these comparisons were derived from midwater trawl samples[53] or seine gear samples (Hamer and Schweigert 1990, 1992, 1993, 1995, 1996, Hamer and Midgley 1997, 1999, Midgley and Hamer 1999, Midgley and Schweigert 2000, 2002a, 2002b, 2002c) obtained during the spawn season for each stock or herring section. All British Columbia data were from collections with a majority of the fish expressing a maturity index of 4 or higher. Length in all cases was recorded as standard length (Gonyea 1985, Hamer 1989).

Over the period 1990–2002, mean length of Squaxin Pass Pacific herring at age 3 was significantly ($P \leq 0.05$) smaller than mean length of Cherry Point, Semiahmoo Bay, Port Susan, Port Gamble, Kilisut Harbor, Quartermaster Harbor, and all the Canadian sections except Powell River (Figure 20 and Table 3). At age 6, mean length of Squaxin Pass Pacific herring was significantly ($P \leq 0.05$) smaller than mean length of Cherry Point, Semiahmoo Bay, Port Gamble, and all Canadian sections except Powell River (Figure 21 and Table 5). At both age 3 and age 6, mean length of Squaxin Pass Pacific herring was not significantly ($P \leq 0.05$) different from Samish/Portage bays, Fidalgo Bay, Port Orchard-Port Madison, and Powell River (Tables 3 and 5).

Over the period 1990–2002, mean weight of Squaxin Pass Pacific herring at age 3 was significantly ($P \leq 0.05$) smaller than mean weight of Cherry Point, Port Susan, Port Gamble, Kilisut Harbor, and all the Canadian sections except Powell River (Figure 28 and Table 4). At

[53] See footnote 5.

age 6, mean weight of Squaxin Pass Pacific herring was significantly ($P \leq 0.05$) smaller than mean weight of only Cherry Point, Semiahmoo Bay, and three of the seven British Columbia herring sections (Figure 29 and Table 6).

Similarly, Fidalgo Bay Pacific herring over the period 1990–2002, had statistically ($P \leq 0.05$) smaller mean lengths and weights than all the Canadian Pacific herring sections except for Powell River, at both age 3 and age 6 (Figures 20, 21, 28, and 29, and Tables 3–6). However, at age 3, Fidalgo Bay Pacific herring were not statistically smaller than Interior San Juan Islands, Samish/Portage bays, Skagit Bay, Port Orchard-Port Madison, Quartermaster Harbor, and Squaxin Pass for length, nor smaller than this list of stocks and Semiahmoo Bay for weight (Tables 3 and 4). At age 6, Fidalgo Bay Pacific herring mean length and weight were statistically ($P \leq 0.05$) different from all samples except Samish/Portage bays, Squaxin Pass, and Powell River (Figures 21 and 29 and Tables 5 and 6).

At age 3, Baynes Sound Pacific herring (Section 142) over the period 1990–2002 were statistically ($P \leq 0.05$) larger in mean length from all but Nootka Sound, West Barkley Sound, Nanoose Bay, and Swanson Channel (Table 3) and had a statistically ($P \leq 0.05$) greater mean weight than all but Cherry Point and West Barkley Sound (Table 4). However, by age 6, these differences for Baynes Sound Pacific herring are for the most part not apparent (Figures 21 and 29 and Tables 5 and 6). Unlike Cherry Point Pacific herring, Baynes Sound Pacific herring during the period 1976–1980 did not appear to have mean length (Figure 30) or weight (Figure 31) values that set them apart from other samples in the analysis.

Morphological Differentiation

Numerous researchers have attempted to separate races or stocks of Pacific herring on the basis of differences in body proportions or meristic characters. These differences may be due either to environmental or hereditary factors, and it is not possible to determine the underlying causes of these differences with the data available to the BRT. In addition, morphometric and meristic differences between groups of fish are not normally apparent in individual fish but only in the mean value of a large number of individuals.

Taylor (1964) noted that besides analysis of tag returns, the second main method of identifying Pacific herring populations in British Columbia was based on variations in the number of vertebrae, which varies within the range of 48 to 55 vertebrae. McHugh (1954, p. 149) reviewed meristic and morphometric studies on Pacific herring and stated that “the number of vertebrae is capable of modification by temperature during early development, so that in any one locality the mean vertebral number may vary from year to year.” Tester (1937), and later McHugh (1954), confirmed that the mean vertebral count in Pacific herring populations increases with latitude. Nevertheless, Tester (1937) examined meristic and morphometric variation (vertebrae count, head length, length to dorsal fin insertion) in Pacific herring from 19 localities in British Columbia, and, as in earlier studies, found differences in mean vertebral counts to be most informative for stock discrimination. Tester (1937) concluded that meristic characters could be used to separate SOG Pacific herring into three fairly discrete populations: 1) Point Grey (near Vancouver, British Columbia), 2) Granite Bay (North Quadra Island), and 3) Saltspring Island-Departure Bay-Nanoose Bay (Figure 3). In a later paper, Tester (1938) stated that “variation in the number of vertebrae and certain other meristic characters in fishes is caused in part at least by variation in environmental conditions, notably water temperature" (Tester 1938, p. 71). This statement was based in part on evidence that the mean count of vertebrae in successive year classes of Pacific herring from Barkley Sound on the west coast of Vancouver Island varies inversely with water temperature at the time of spawning and early development (Tester 1938). In a later paper, Tester (1949) found this relationship to hold in general for Pacific herring from the entire west coast of Vancouver Island. McHugh (1942) also found significant differences in vertebral counts of juvenile Pacific herring from the same year class sampled at a number of localities within the Strait of Georgia.

In Washington State, Chapman et al. (1941) and Katz (1942) compared mean vertebral counts between Pacific herring collected at 11 locations in the years 1936 and 1937: 1) Wollochet Bay (in south Puget Sound), 2) Poulsbo (Port Orchard-Port Madison stock), 3) Holmes Harbor, 4) Hale Passage (Samish Bay-Portage Bay stock), 5) Seal Rock (Quilcene Bay stock), 6) Birch Bay (Cherry Point stock), 7) Point Migley (Lummi Island), 8) Willapa Bay, 9) East Sound (Interior San Juan Islands stock), 10) Gig Harbor, and 11) Steamboat Island (Squaxin Pass stock). Comparison of Pacific herring samples from Willapa Bay, Wollochet Bay, and Birch Bay revealed "good separation of the mean vertebral counts in the two- and three-year age classes, but in the four-, five-, and six-year-olds, the differences of the mean vertebral counts were so slight as to cast doubt upon the significance of their difference" (Katz 1942, p. 14). Katz (1942, p. 14–15) stated that:

> the older age classes of the herring of Washington fail to show a significant difference in their mean vertebral counts and cannot, therefore, be designated as races if vertebral differences are to be used as a racial criterion. Whether this lack of racial distinctiveness in the older age classes is due to intermingling or to other causes cannot be determined with the scanty data on hand.

Katz (1942) also observed that annual variation in mean vertebral counts of Pacific herring was greater for the Wollochet Bay aggregation in southern Puget Sound than in the Birch Bay aggregation, whose spawning location was closer to the open ocean. Katz (1942, p. 22) postulated that the greater variation in the Wollochet Bay vertebral counts "might be due to a greater temperature fluctuation of the southern waters of the Sound."

Otolith Chemistry

As stated previously, Gao et al. (2001) analyzed oxygen and carbon isotope ratios in otoliths from spawning Pacific herring collected at Cherry Point in north Puget Sound and at Port Orchard and Squaxin Pass in south Puget Sound. Isotope ratios from nuclei of otoliths from the two southern Puget Sound samples were not significantly different from one another; however, Cherry Point otoliths were significantly different from the two southern Puget Sound samples. The Port Orchard and Squaxin Pass isotope ratios suggested that Pacific herring from this location experience higher salinities as larvae and juveniles than Pacific herring from Cherry Point. However, Gao et al. (2001, p. 2117) noted that "there are some crossing samples in the database." Their figure 2 shows that isotope ratios from 3 of the 32 Cherry Point fish fell well within the range of values shown for the other two sites. This overlap may indicate some degree of mixing of Pacific herring between the two areas or that water conditions characteristic of south Puget Sound may also occur in the areas frequented by Cherry Point Pacific herring during early life stages. Gao et al. (2001) also studied isotope ratios of second summer (1999) otolith rings in these three Pacific herring stocks. The results indicated that most south Puget Sound Pacific herring were rearing in high salinity conditions and were therefore "moving to the ocean" (migratory stock) and that most Cherry Point Pacific herring with otolith isotope ratios indicative of lower salinities "might still remain in the spawning ground" (Gao et al. 2001, p. 2115) (nonmigratory stock). This result is surprising because nonmigratory Pacific herring would be expected to be slow growing and previous studies (based on limited tagging data and the relatively high growth rate of Cherry Point Pacific herring) had speculated that Cherry Point Pacific herring migrate to feed in offshore waters. Gao et al. (2001) did not consider the possibility that migratory fish may have been merely feeding deeper in the water column where salinity is higher than nonmigratory fish.

Tagging

Results of Pacific herring tagging operations in Washington State and British Columbia were reviewed in the previous status review (Stout et al. 2001a). The following discussion and Figures 51–54 provide more detail on results of previous Washington State tagging efforts and review documents related to tagging that have been released since the previous status review. Tagging information specific to Cherry Point Pacific herring was discussed on page 61 in the subsection entitled "Artificial Tagging."

Heyamoto and Pasquale (1961) presented results of Washington State Pacific herring tagging studies from 1953 to 1958. Until 1957, when Washington State Pacific herring reduction fisheries began, recovery of tags was almost entirely dependent on the Canadian reduction fisheries. Besides 1953, when about 45% of the fish were tagged with external Petersen tags, all fish were tagged with internal metal tags. Buchanan (1986) and O'Toole et al. (2000) also reviewed the results of Washington State Pacific herring tagging at 1) Quilcene Bay, Holmes Harbor, and Brownsville-Miller Bay (Port Orchard-Port Madison stock) of spawning fish in the 1950s; 2) Bellingham Bay in February 1958; and 3) Point Roberts in March 1958 (Semiahmoo Bay stock). Two populations in the first tagging group had some fish return to their tag release sites in subsequent spawning seasons; two Holmes Harbor tags were recovered at Holmes Harbor five years after tagging (Figure 51) and Port Orchard-Port Madison had one fish returned after 3 years (Figure 52) (Heyamoto and Pasquale 1961). All three of the populations in the first tagging group had tag returns from either the fall of the year of tagging, or in subsequent years, in the Canadian reduction fishery in the southeast Vancouver Island region (Figures 51–53) (Heyamoto and Pasquale 1961, Hourston 1981b, his table 2.36). Other Canadian recoveries included one Holmes Harbor (Figure 51) and four Quilcene Bay (Figure 53) Pacific herring, tagged in summer fisheries, recovered at Swiftsure Bank off the southwestern tip of Vancouver Island (Taylor 1973). At least three Quilcene Bay fish tagged in April 1956 were recovered in the subsequent winter fishery (December 1956) in Deepwater Bay at the extreme southern end of Johnstone Strait (Figure 53).

Over 6,000 Pacific herring were tagged during February 1958 in Bellingham Bay. Most of the recoveries from this tagging study occurred in the same year of tagging in Bellingham Bay, although four fish were recovered in the Southeast Vancouver Island region and two were recovered during winter fisheries on the west coast of Vancouver Island (Heyamoto and Pasquale 1961, Taylor 1973, his table 5). Over 4,000 Pacific herring were tagged in March 1958

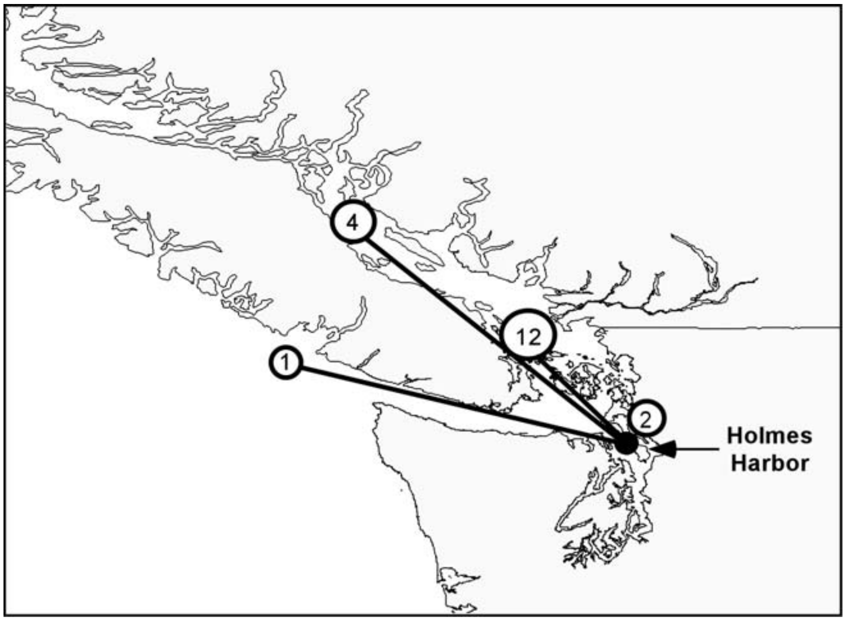

Figure 51. Tagging and recovery locations of over 21,000 Pacific herring tagged on the spawning grounds at Holmes Harbor during March of 1953 and April of 1955–1957. Black dot indicates site of tagging and circled numbers indicate number of tag recoveries at the approximate recovery location. Data from Taylor et al. 1956, Heyamoto and Pasquale 1961, Taylor 1973, Hourston 1981, and Buchanan 1986.

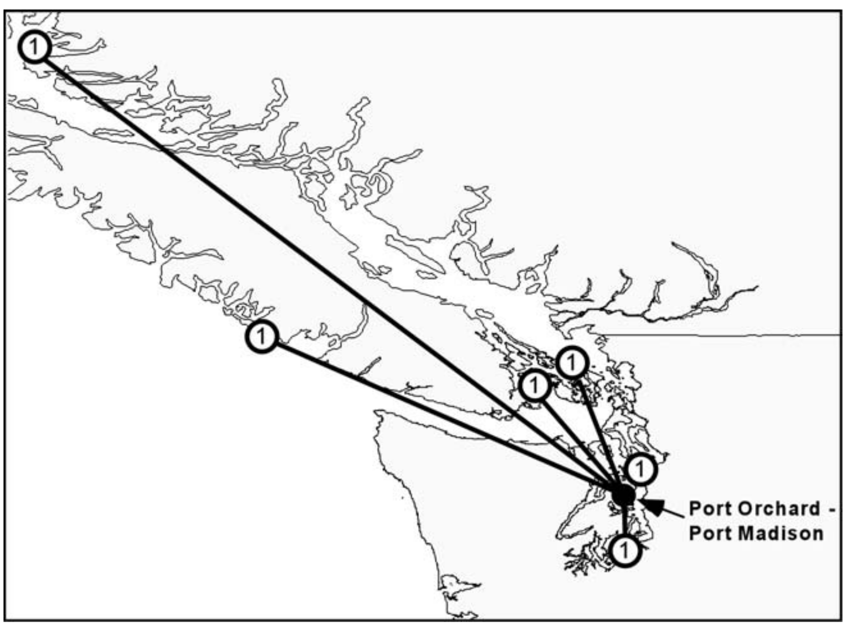

Figure 52. Tagging and recovery locations of over 7,300 Pacific herring tagged on the spawning grounds at Port Orchard-Port Madison (Miller Bay and Brownsville) during March of 1953–1955. Black dot indicates site of tagging and circled numbers indicate number of tag recoveries at the approximate recovery location. Data from Taylor et al. 1956, Heyamoto and Pasquale 1961, Hourston 1981, and Buchanan 1986.

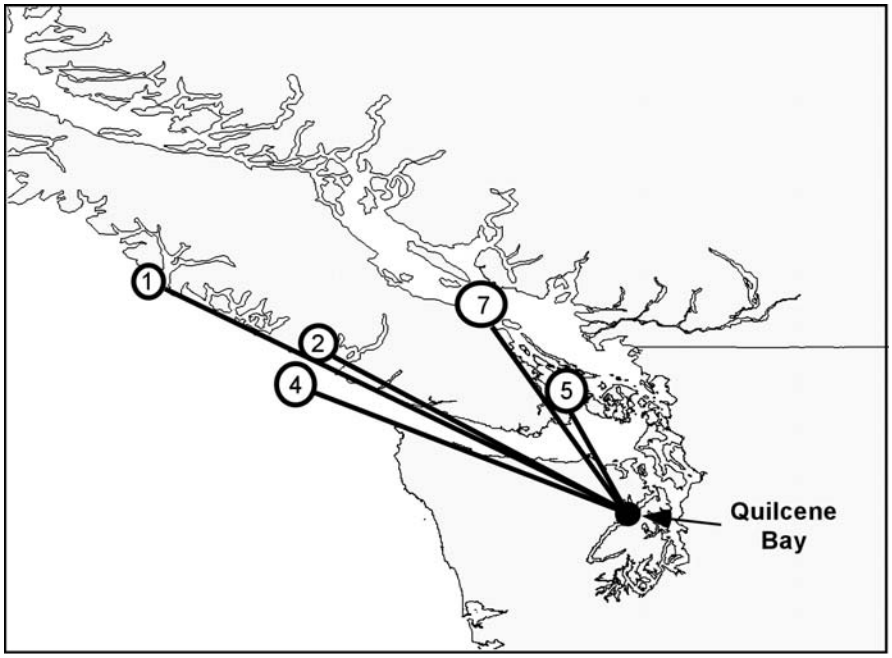

Figure 53. Tagging and recovery locations of 6,000 Pacific herring tagged on the spawning grounds at Quilcene Bay (Hood Canal) during April 1953 and 1956. Black dot indicates site of tagging and circled numbers indicate number of tag recoveries at the approximate recovery location. Data from Taylor and Outram 1955, Heyamoto and Pasquale 1961, Taylor 1973, Hourston 1981, and Buchanan 1986.

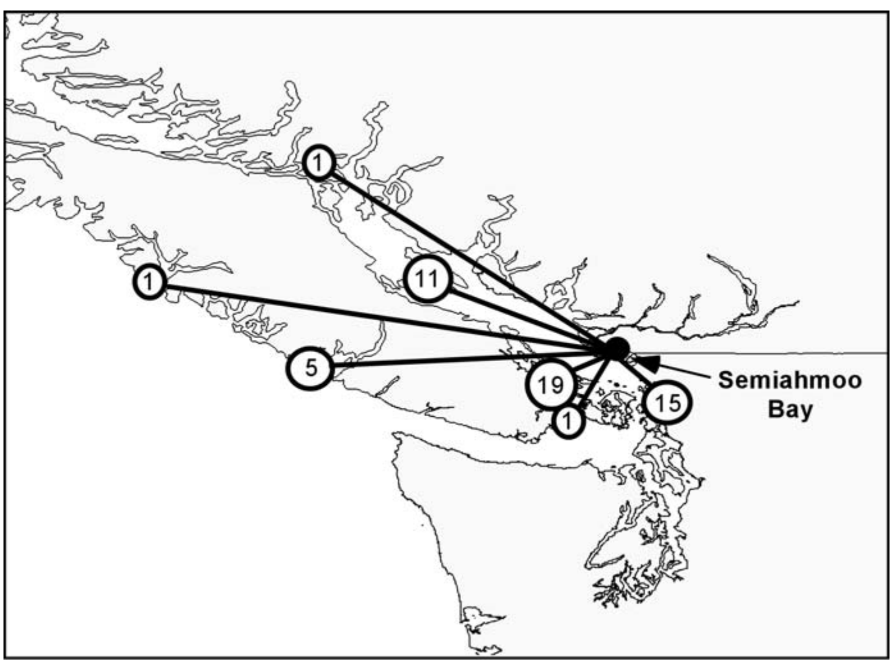

Figure 54. Tagging and recovery locations of over 4,000 Pacific herring tagged on the spawning grounds at Semiahmoo Bay (Boundary Bay) during March of 1958. Black dot indicates site of tagging and circled numbers indicate number of tag recoveries at the approximate recovery location. Data from Heyamoto and Pasquale 1961, Taylor 1973, Hourston 1981, and Buchanan 1986.

at Boundary Bay (Semiahmoo Bay stock). Five of these Semiahmoo Bay Pacific herring were recovered off the west coast of Vancouver Island during winter fisheries of 1958–59 (Figure 54) (Heyamoto and Pasquale 1961, Taylor 1973, his table 5), and a number of fish were recovered during summer and fall in the Canadian southeast Vancouver Island region (Figure 54) (Heyamoto and Pasquale 1961, Hourston 1981b, Buchanan 1986). Buchanan (1985, p. 9–10) reported that 33 of the Semiahmoo Bay Pacific herring "were returned from the Bellingham fishery" in 1958–59, although (Heyamoto and Pasquale 1961) record only 15 tag returns to Bellingham Bay (Figure 54). Taylor (1973, p. 9) stated that:

> These recoveries suggest that movement of herring from the Puget Sound, the San Juan Islands, and the Boundary Bay-Bellingham Bay regions into British Columbia is mostly from the adjacent areas and is probably no greater than between adjacent stocks of similar size in B.C. The recoveries on Swiftsure Bank and on the west coast of Vancouver Island suggest that the American stocks tagged perhaps move to offshore summer feeding grounds in the same way as the Canadian Strait of Georgia stocks.

Buchanan (1986, p. 158) reported that from 12,000 Pacific herring tagged in the summer of 1965 on Swiftsure Bank, off the west coast of Vancouver Island, 2 were recovered in "the western San Juan Islands, 3 from Pt. Roberts, 1 from Bellingham Bay, and 2 from one of these areas."

Migratory and Nonmigratory Pacific Herring

The vast majority of Pacific herring in the SOG migrate to offshore feeding areas each spring immediately after spawning and then return in the late fall and early winter of each year prior to spawning (Stevenson 1955, Taylor 1964, DFO 2004). In contrast, a number of small resident populations are believed to spend their entire lives in coastal inlets and bays or in the SOG itself and to forgo extensive seasonal offshore migrations (Stevenson 1955, Taylor 1964, Hay 1985). Penttila (1986) also postulated that some proportion of adult Pacific herring remain in Puget Sound throughout the summer while others migrate to offshore feeding grounds.

In a summary of Pacific herring tagging studies from 1936 to 1951, Stevenson (1955) reported that he was able to distinguish migratory and nonmigratory (resident) Pacific herring in British Columbia, based on 1) population abundance, 2) seasonal migration (tagging), 3) growth and age composition, 4) location of spawning grounds, and 5) homogeneity of individual spawning runs. In particular, Stevenson (1955, p. 34) recognized migratory populations in the SOG on the "middle east coast of Vancouver Island" and on the "lower east coast of Vancouver Island." Small resident Pacific herring populations were identified by Stevenson (1955, p. 34) "in the long inlets of the north central, south central and upper east coast regions," areas that are outside of the SOG. However, Stevenson (1955, p. 34) also noted that "the presence within … [the middle east coast of Vancouver Island] sub-district of resident or partially resident stocks, as well as a migratory stock, resulted in a relatively complicated situation." These resident populations were "relatively slow-growing, suggesting that their summer feeding areas are less productive than the offshore feeding areas of the migratory stocks" (Stevenson 1955, p. 34). Stevenson (1955, p. 34) contrasted the Pacific herring population from the middle east coast of Vancouver Island that "showed the greatest emigration" and thus "was the least independent stock" with "the runs within the population of the lower east coast of Vancouver Island [that] appeared to be freely mixing and homogeneous showing no differential emigration outside the sub-district."

Taylor (1964) also recognized two types of Pacific herring in British Columbia, based on their migration patterns: large migratory populations that migrate to the open ocean to feed and minor local populations that are found towards the heads of inlets or as resident populations that remain in inshore regions throughout the year. According to Taylor (1964), separation of these two types of Pacific herring is based on 1) population abundance (migratory populations greatly exceed the local populations in abundance), 2) seasonal migration (minor local stocks stay inshore throughout the year, while the large migratory stocks feed offshore during the summer and return to inshore waters in the fall and winter), 3) growth and age composition (minor local populations have a slower growth rate), 4) location of spawning grounds (small local stocks tend to spawn at the heads of inlets and large migratory stocks spawn in more exposed regions such as near the mouths of inlets), and 5) homogeneity of individual stocks (minor stocks are complex assemblages of small individual runs, whereas various runs of the large migratory stocks are similar to one another). Taylor (1964, p. 57) identified a different type of small resident Pacific herring that:

> occur in the middle and lower east coast subdistricts where they provide the basis of small summer fisheries: probably the three best known are the Active Pass, Porlier Pass and Point Grey stocks [in Herring Sections 173, 182, and 291 respectively]. … They appear to be not so much separate stocks as residual stocks, fish that were a part of the major migratory population but failed to go offshore after spawning. This is indicated by their similar rates of growth and age composition.

Likewise, Schweigert (1991, p. 2374) stated that, "significant numbers of adult nonmigratory herring are found each year in the various tidally active passes throughout the Gulf Islands lending further support to the existence of … a discrete stock." Ware (1985) postulated that some of the resident stocks grow more slowly than migratory stocks due to the poorer production of food in the nearshore environment. Hay et al. (1999, p. 16) stated that, "the issue of the status of non-migratory herring may be the most significant problem for current herring management." Furthermore, Hay et al. (1999, 2001a) noted that although recent spawn deposition estimates are high for most areas of the SOG, spawning has declined in some local areas (Hay and McCarter 1999) and there has been an apparent decline in the number of Pacific herring that reside in the SOG in summer. Hay et al. (1999, p. 16) suggested that:

> One potential explanation for this is that non-migratory herring represent distinct biological stocks, perhaps genetically differentiated, and that their numbers have declined. ... An alternative explanation is that these non-migratory herring are simply part of the major herring stocks that choose not to migrate. The option to migrate or remain resident may be trophically determined and affected by climatic conditions.

Hay et al. (1999, p. 16) pointed out that in British Columbia some individual tagged Pacific herring were recaptured in the same sections and even locations that they were tagged in, and that "this apparent fidelity may reflect the life history of a non-migratory or sedentary fish that never really leaves an area."

In regards to potential small resident inlet populations of Pacific herring in the SOG, the DFO Integrated Fisheries Management Plan for Roe Herring (DFO 2000, p. 13–14) refers to:

> spawning populations using the heads of mainland channels or fjords, including … all of the inlets in … Georgia Strait. These areas have records of spawning that often are inconsistent in time, indicating varying degrees of utilization of these areas. At this time, however, we cannot rule out the possibility that one or more of these areas may support a genetically unique herring stock. … The confinement of the fishery to the large central populations ensures that the small marginal populations, mainly in inlets and fjords, are protected or conserved. This is especially important because these small populations of herring, like other fish species, may have special significance in the maintenance of genetic diversity.

DFO (2002, p. 2) had this to say about nonmigratory Pacific herring in the SOG:

> All herring spawning within the Strait [of Georgia] are assumed to belong to a single stock that migrates into the SG in the late fall and leaves, after spawning, in March. Many areas in the Strait retain some resident or non-migratory herring throughout the summer, but the distribution and abundance of non-migratory fish changes among years.

Penttila (1986, p. 73) postulated that:

> although it has been presumed that Puget Sound adult herring are migratory, there is now indication that this is not totally the case. It may in fact be a variable phenomenon for some proportion of these fish.

Trumble (1983) stated that many juvenile Pacific herring in Puget Sound overwinter in southern and central Puget Sound and migrate to Pacific Ocean feeding grounds in March to July, not returning until their first year of maturity. Adult Pacific herring were thought to migrate, on an annual, basis between summer feeding grounds (mostly off the Washington and British Columbia coasts) and Puget Sound spawning grounds (Trumble 1983). Lassuy (1989, p. 6) suggested that growth and size-at-age differences between Squaxin Pass and Cherry Point Pacific herring "may result because the Strait of Georgia stocks [Cherry Point] are migratory while the Case Inlet [Squaxin Pass] stocks are resident."

Genetic Variation

Overall, the genetic analysis of Beacham et al. (2001, 2002) supported the metapopulation view of Pacific herring populations in British Columbia, at least among the large migratory stocks. Besides the single sample from a single year at Cherry Point, a few other samples from remotely sited "resident" Pacific herring in British Columbia mainland inlets were identified as being somewhat more distinct (Beacham et al. 2001, 2002) relative to the larger assessment stocks. Several Beacham et al. (2001, 2002) samples were obtained from locations within the boundaries of the Georgia Basin Pacific herring DPS and deserve some comment. A single sample from Bute Inlet (Section 134) was not significantly different from other putative populations in Johnstone Strait. However, "differentiation was observed between the Johnstone Strait stock and herring in more northern and southern regions in British Columbia" (Beacham et al. 2002, p. 9). Beacham et al. (2001, 2002) also reported that no population differentiation was detected among samples from three putative populations along the east coast of Vancouver Island. When data from these three putative western SOG populations were pooled and compared to single samples from Bargain Harbour and Secret Cove (both in Section 163, Malaspina Strait) on the mainland (east) coast of the SOG, no significant differences were detected between Bargain Harbour and the Vancouver Island population, although significant differentiation was observed between the Secret Cove sample and the Vancouver Island population at 5 of 13 loci. Beacham et al. (2001, 2002) also observed significant differentiation between a single sample from Victoria Harbour (Portage Inlet/Esquimault Harbour) and all other samples, including Cherry Point and more northern samples in the SOG. In all cases, these differences need to be evaluated by further sampling to ensure they are stable over time (Beacham et al. 2001, 2002).

Results of the microsatellite DNA study of Small et al. (2004) suggest that a number of genetically discrete population aggregations may exist in Puget Sound. There was a small degree of genetic differentiation among sampling sites and in some cases between years within a site within Puget Sound. Besides Cherry Point Pacific herring, samples from Squaxin Pass were also somewhat differentiated from other collection sites and "formed a branch with 77% bootstrap support" (Small et al. 2004, p. 3). The BRT hypothesized that the Puget Sound Pacific herring populations, particularly in the South Sound, may be characterized by a degree of isolation similar to other inlet locations in British Columbia. In some cases it was possible for the BRT to hypothesize a mechanism for some level of demographic isolation. For example, temporal differences in spawning time (Cherry Point) or geographic isolation (Squaxin Pass) could result in the observed levels of genetic distinctiveness.

Possible Subpopulations in the Georgia Basin DPS

The Pacific herring BRT examined subpopulation structure of the Georgia Basin Pacific herring DPS using the above demographically independent approach, which is essentially a metapopulation approach. It was evident that some local subpopulations have distinguishing characteristics such as discrete and persistent spawning location, discrete spawn timing, phenotypic distinctiveness (mean length-at-age, weight-at-age, or growth rate), contaminant profiles, otolith chemistry, parasite incidence, migration behavior, and genetic distinctiveness (variation in microsatellite DNA allele frequency). Temporal variation (comparison between 1970s and 1990s) in some growth parameters were noted within subpopulations; however, differences between subpopulations were generally stable and maintained over time (see Begg et al. 1999). These data indicate that some subpopulations in the DPS may be more reproductively isolated than others. This observation is most consistent with the mixed structure metapopulation model as articulated by Harrison and Taylor (1997), which accounts for more isolated subpopulations operating within a metapopulation where most of the subpopulations are connected by higher rates of exchange. Based on the above information, the BRT concluded the DPS could provisionally be divided into the following eight demographically identifiable subpopulations:

1. Cherry Point—Microsatellite DNA allele frequency variation, spawn timing, geographical location (exposed spawning location), growth rate, and contaminant profiles indicate that the Cherry Point Pacific herring population is discrete compared to most other Pacific herring in the DPS.

2. Squaxin Pass—Microsatellite DNA allele frequency variation, geographical location (inlet population), growth rate, and spawning behavior indicate relative discreteness.
3. South/Central Puget Sound (Skagit Bay, Port Susan, Kilisut Harbor, Holmes Harbor, Port Gamble, Quilcene Bay, South Hood Canal, Port Orchard/Port Madison, Quartermaster Harbor, and Wollochet Bay)—It is difficult to subdivide this WDFW management unit, with the exception of Squaxin Pass. The geographical location (inlet population) of the South Hood Canal stock may indicate distinctiveness, although life history data are nonexistent.
4. Strait of Juan de Fuca (Discovery Bay, Dungeness Bay, Sooke Harbour, Victoria Harbour)—This unit may be distinctive based on its geographical location (early entry into relatively open ocean conditions of Strait of Juan de Fuca). Relationship to North Puget Sound plus Southern SOG is uncertain.
5. Bute Inlet (BC Herring Section 134)—This unit may be distinctive on basis of geographical location (inlet population) and supposed migration behavior.
6. Eastern SOG Inlets (BC Herring Sections 162, 163, 164, 165, plus sections 292 and 280, which have had intermittent spawn)—This unit may be distinctive on basis of geographical location (inlet populations) and supposed migration behavior. Schweigert (1991) showed Jervis Inlet as distinct based on multivariate analyses of size-at-age and age composition.
7. Northern SOG (BC Herring Sections 135, 136, 151, 152, 141, 142, 143, 172)—It is difficult to subdivide this unit. Relationship to North Puget Sound plus Southern SOG is uncertain. This is the large, clearly migratory, component of the DPS.
8. North Puget Sound plus Southern SOG (BC Herring Sections 173, 181, 182, 191, 192, plus Semiahmoo Bay, Samish/Portage Bays, NW San Juan Islands, Interior San Juan Islands, and Fidalgo Bay)—Lack of data makes it difficult to subdivide this unit. Relationship to large Northern SOG migratory subpopulation is uncertain. There are past indications of intermingling of spawning locations for nonmigratory and migratory Pacific herring.

The distinctiveness of nonmigratory SOG Pacific herring (historically identified in Jervis/Sechelt Inlets [Eastern SOG], Bute Inlet, and in the Gulf Islands) and nonmigratory Puget Sound Pacific herring is largely uncertain, as is the biological distinctiveness among inlet populations.

The number and boundaries of these proposed subpopulations within the DPS are inexact and subject to revision when additional data are acquired. Their main usefulness at this time is to provide some degree of spatial structure to the BRT's analysis of the significant portion of the DPS's range question (see Figure 55).

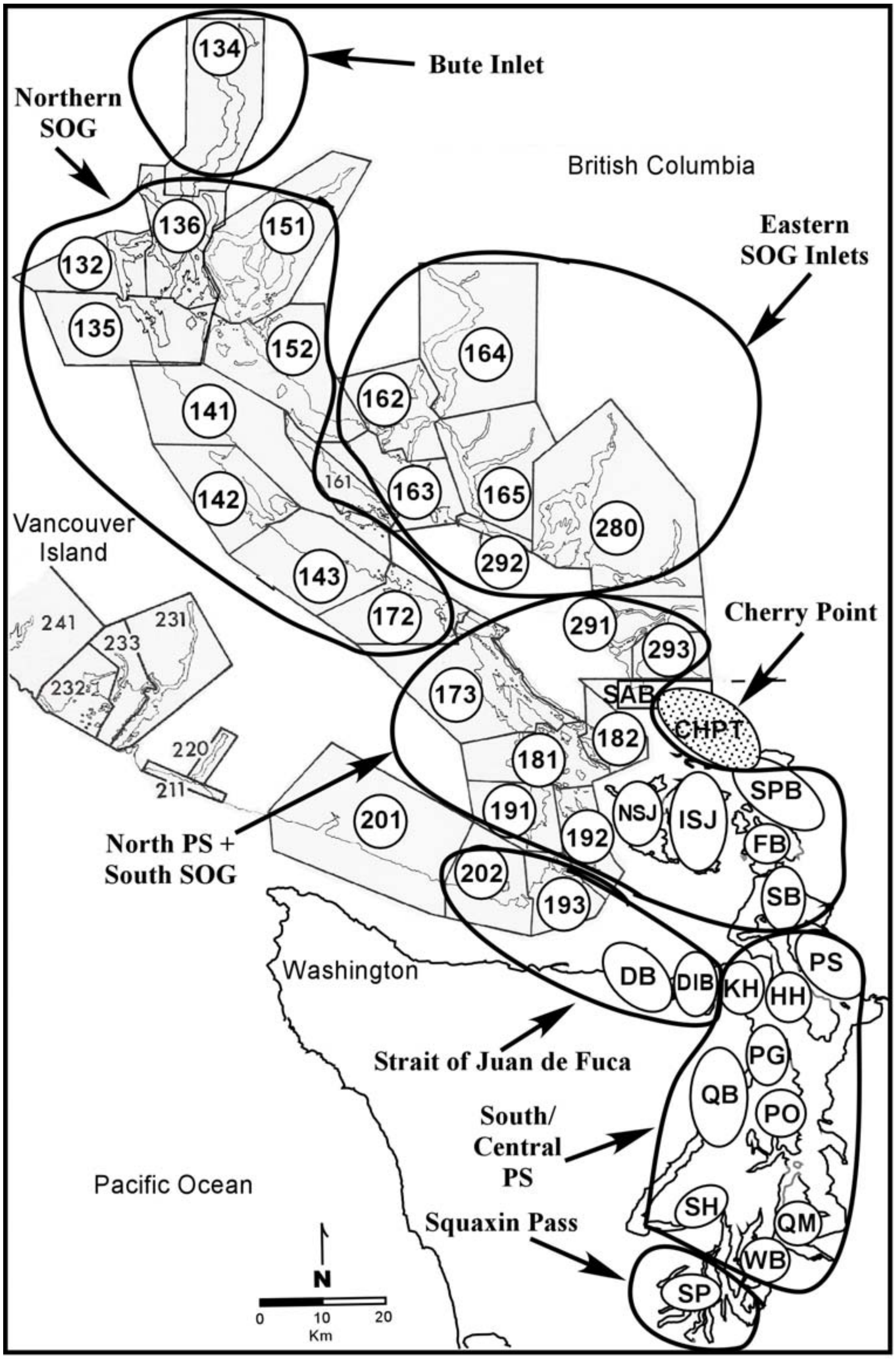

Figure 55. Geographic distribution of eight proposed subpopulations of Pacific herring in the Georgia Basin DPS. Washington stock abbreviations are shown in Table 1 and British Columbia herring section designations are shown in Figure 10.

Extinction Risk of Possible Subpopulations in the Georgia Basin DPS

Abundance and Productivity

The time series of estimated spawner biomass in metric tonnage for each of the eight proposed Georgia Basin Pacific herring subpopulations is provided in Table 15 and graphically presented in Figures 56–63. The abundance data series begins in 1973, when Washington State data are first available. Short-term (1990–2004) and long-term (1973–2004) trends in biomass for these subpopulations are compared graphically in Figures 64 and 65. The North SOG subpopulation is significantly larger than any other subpopulation in the DPS and is likely the healthiest in the DPS. Four of the subpopulations (Cherry Point, Strait of Juan de Fuca, Eastern SOG Inlets, and Bute Inlet) have long-term trends less than one (Figure 64), and three (Cherry Point, Strait of Juan de Fuca, and Bute Inlet) have short-term trends less than one (Figure 65), indicating these subpopulations are in decline over these time periods. However, there is a great deal of uncertainty about the trend of the Eastern SOG Inlets subpopulation, as indicated by the large confidence intervals, that is likely due to the high variability, and absence of data in some years (Figure 59).

Summary statistics on population trends are presented in Table 16. The methods for estimating trends and population growth rate (λ) are described in the previous risk assessment methods section. For the North SOG time series data (Figure 66), data support is very high that $\lambda > 1$ (population increasing). This means that the data are much more likely to have come from an intrinsically increasing population rather than an intrinsically decreasing population. Note that by chance, increasing time series can be observed from populations whose dynamics are intrinsically decreasing. However, for this time series, the observed rate of increase is high and the year-to-year variability is low. Such combinations are much more likely to be observed in intrinsically increasing populations. The data from the North Puget Sound plus South SOG (Figure 67), South/Central Puget Sound (Figure 68), Strait of Juan de Fuca (Figure 69), and Squaxin Pass (Figure 70) subpopulations are more equivocal. The posterior probability surface is split between $\lambda > 1$ and $\lambda < 1$ indicating that the data are equivocal on whether the subpopulations are intrinsically decreasing or increasing. The point estimates should be viewed with caution for these subpopulations. For example, although λ for the South/Central Puget Sound subpopulation is high, these could have been produced by an intrinsically decreasing population; the data support for $\lambda > 1$ is only approximately four times higher than for $\lambda < 1$. Finally, for the Cherry Point population (Figure 46), the data support is very high that this is from an intrinsically declining population. The data observed are much more likely to have been produced by an intrinsically declining population rather than an intrinsically increasing one.

Schweigert (1986, p. 150) suggested that the unrestricted reduction fishery that ended in 1967 likely eliminated many "of the smaller and less productive resident stock[s]" in British Columbia. Likewise, Wallace (2002, p. 25) referring to the British Columbia portion of the Strait of Georgia, stated that, "during the period of over-exploitation [prior to 1967], numerous resident meta-populations [of Pacific herring] were depleted and have failed to return." Wallace (2002, p. 26) also suggested that "the loss of numerous small resident stocks has likely had

Table 15. Pacific herring spawner biomass (metric tons) estimates for proposed subpopulations within the Georgia Basin DPS from 1973 to 2004. Data from WDFW[a] and DFO.[b] See Figure 55 for “subpopulation” boundaries.

Year	Bute Inlet	North SOG	Eastern SOG Inlets	North PS + South SOG	Strait of Juan de Fuca	Cherry Point	South/ Central Puget Sound	Squaxin Pass	DPS total
1973	400	11,516	232	5,214		11,767			29,129
1974	465	27,928	452	12,327		8,630			49,802
1975	741	36,875	1,738	10,552		5,890	1,058	270	57,124
1976	379	32,520	792	11,919	675	8,699	4,369	1,940	61,293
1977	388	48,485	275	7,073	1,435	7,984	5,737	18	71,395
1978	163	41,359	33	8,786	1,193	8,018	3,730	53	63,334
1979	242	25,313	0	12,007	800	7,296	4,523	124	50,305
1980	496	35,525	418	8,472	3,264	7,023	6,695	620	62,513
1981	422	37,317	326	10,257	2,785	5,642	4,305	700	61,755
1982	384	40,010	155	3,525	2,137	4,449	5,535		56,195
1983	284	20,117	0	5,155	2,517	7,315	5,774		41,162
1984		14,436	0	5,035	2,880	5,353	6,277		33,981
1985		18,536	0	7,938	1,329	5,225	6,082		39,110
1986	255	32,538	0	8,032	1,633	5,145	5,526		53,127
1987	136	26,345	136	5,766	1,445	2,702	7,570		44,100
1988		43,076		9,756	774	3,903	5,221		62,730
1989		37,971		7,890	1,332	3,398	5,507		56,098
1990	575	44,848		13,838	776	4,266	5,879	513	70,695
1991	856	43,530		7,660	1,136	3,957	4,518	855	62,511
1992	575	50,215	23	12,162	679	3,465	3,527	699	71,345
1993	648	68,058		10,311	776	4,165	4,655	541	89,154
1994	102	50,717		9,901	380	5,429	4,853	204	71,588
1995	226	45,421		6,875	500	3,422	7,342	142	63,928
1996	105	53,849	109	2,906	841	2,685	5,260	339	66,095
1997	146	51,431	265	10,071	324	1,428	5,833	135	69,633
1998		63,535		3,716	103	1,199	6,104	62	74,718
1999	134	57,013	214	8,412	598	1,148	9,375	430	77,324
2000	159	59,461	30	5,449	269	733	8,605	337	75,043
2001	199	63,326	817	8,618	209	1,126	10,125	1,449	85,868
2002	93	91,074		10,626	253	1,207	9,344	2,858	115,453
2003	285	95,029		18,149	228	1,461	8,086	1,997	125,234
2004	350	97,557		8,659	249	1,573	7,062	751	116,201

[a] K. Stick, Washington Dept. Fish and Wildlife, La Conner, WA. Pers. commun., October 2004.
[b] D. Hay and J. Schweigert, Dept. Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Canada. Pers. commun., December 2004.

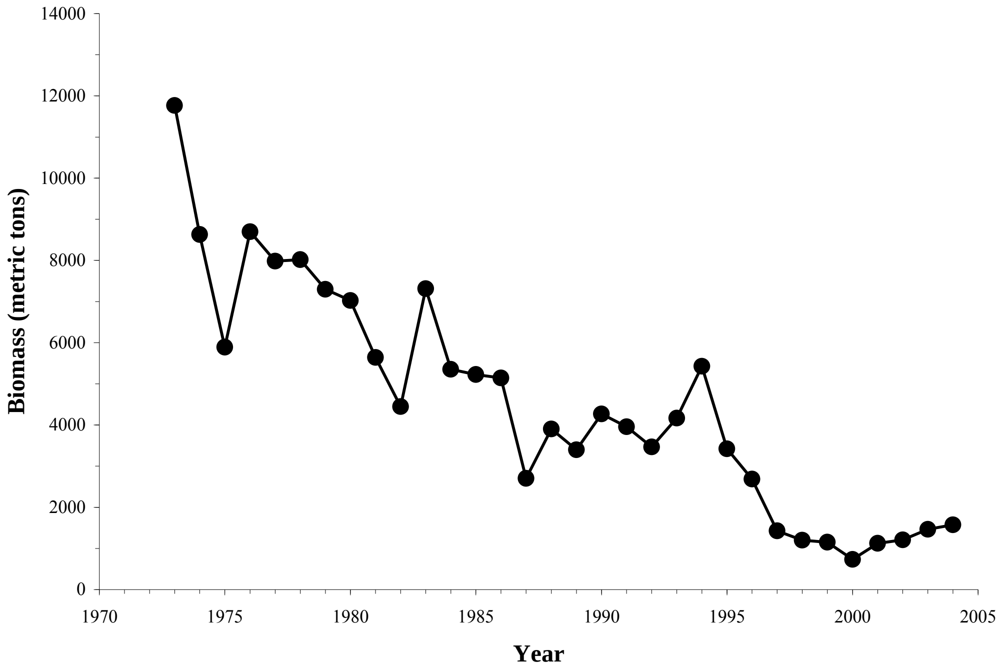

Figure 56. Cherry Point Pacific herring spawner biomass (metric tons) from 1973 to 2004. Data from WDFW[54] and DFO.[55]

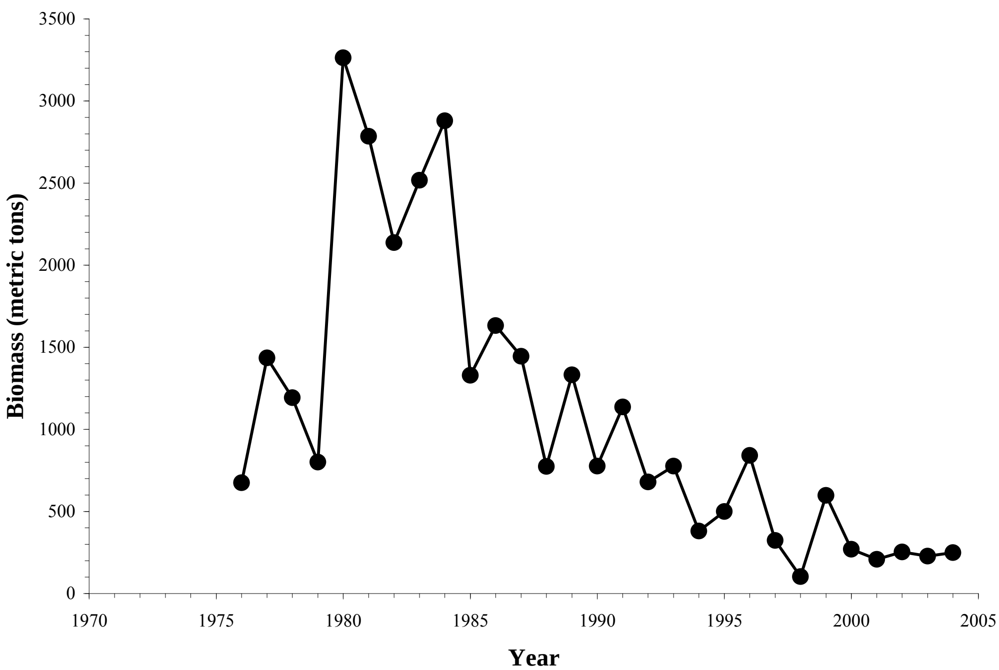

Figure 57. Strait of Juan de Fuca Pacific herring spawner biomass (metric tons) from 1973 to 2004. Data from WDFW[56] and DFO.[57]

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[54] See footnote 5.
[55] See footnote 36.
[56] See footnote 5.
[57] See footnote 36.

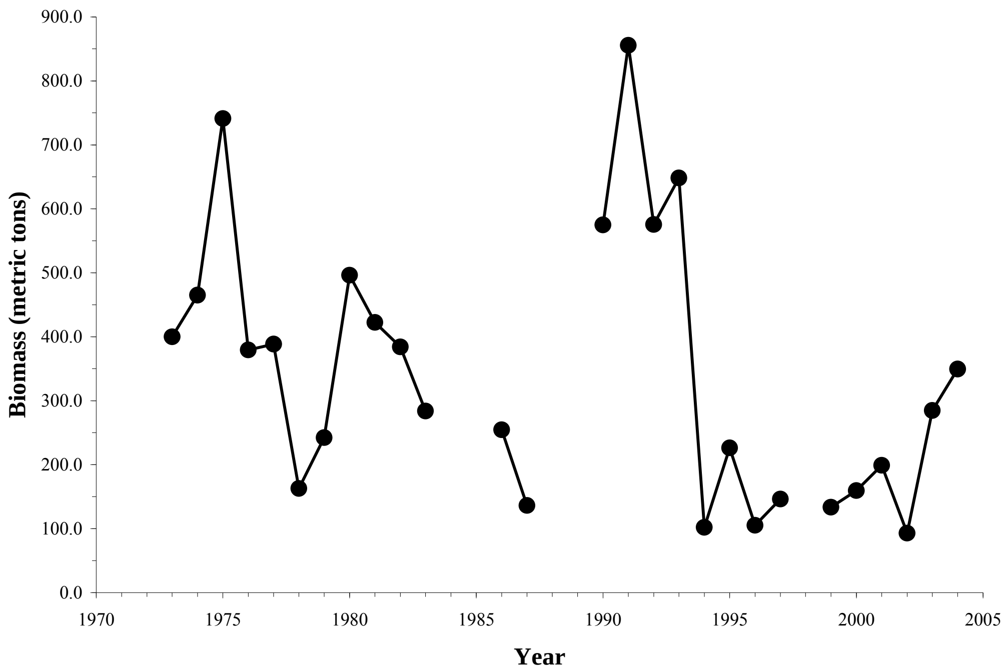

Figure 58. Bute Inlet Pacific herring spawner biomass (metric tons) from 1973 to 2004. Data from WDFW[58] and DFO.[59]

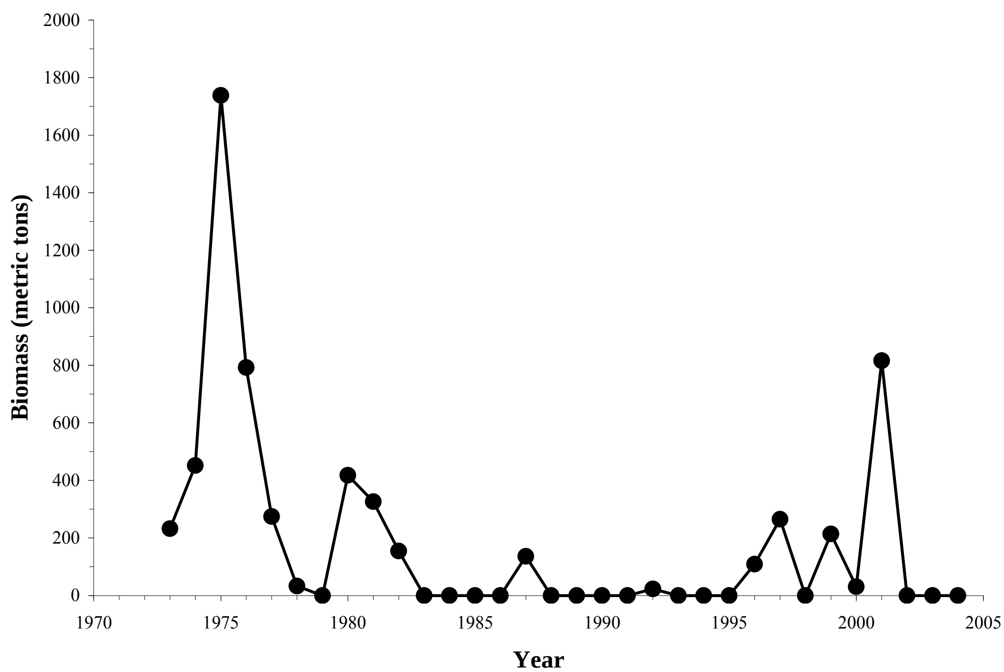

Figure 59. Eastern Strait of Georgia Inlets Pacific herring spawner biomass (metric tons) from 1973 to 2004. Data from WDFW[60] and DFO.[61]

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[58] See footnote 5.
[59] See footnote 36.
[60] See footnote 5.
[61] See footnote 36.

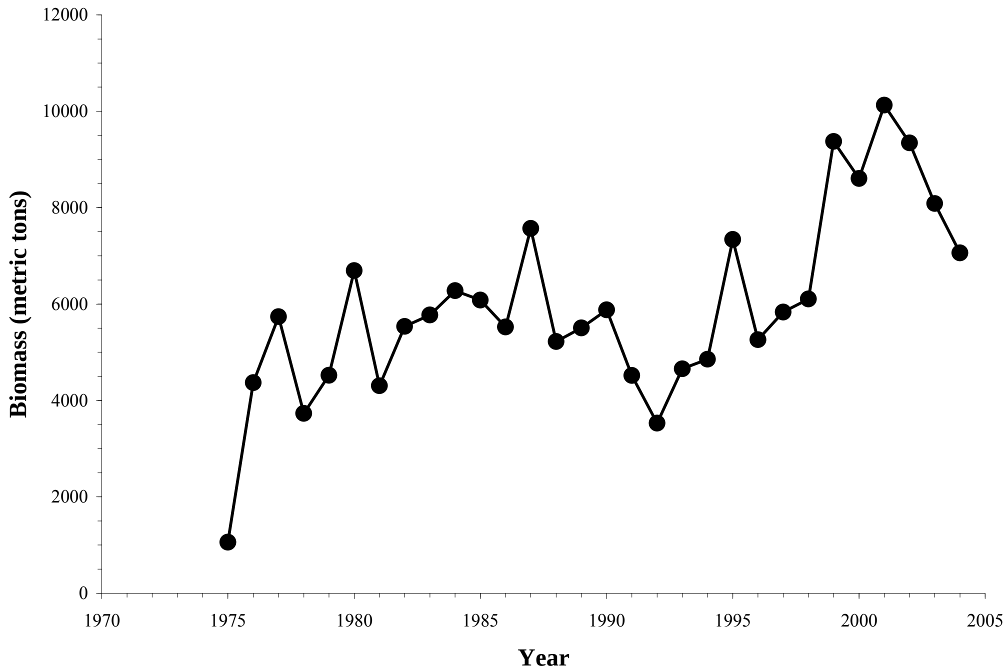

Figure 60. South/Central Puget Sound Pacific herring spawner biomass (metric tons) from 1973 to 2004. Data from WDFW[62] and DFO.[63]

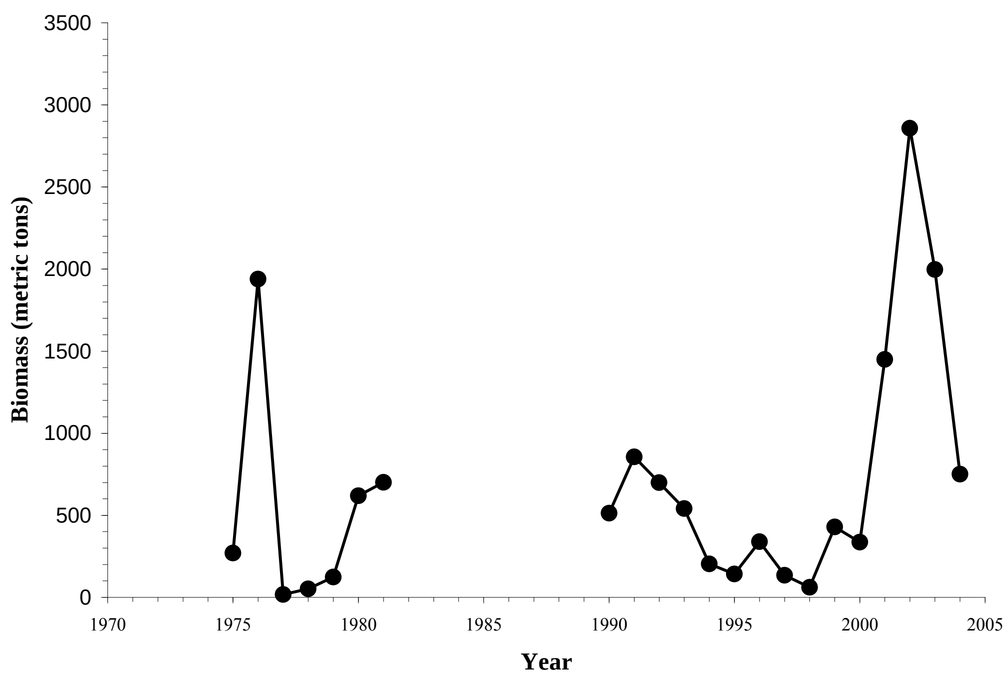

Figure 61. Squaxin Pass Pacific herring spawner biomass (metric tons) from 1973 to 2004. Data from WDFW[64] and DFO.[65]

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[62] See footnote 5.
[63] See footnote 36.
[64] See footnote 5.
[65] See footnote 36.

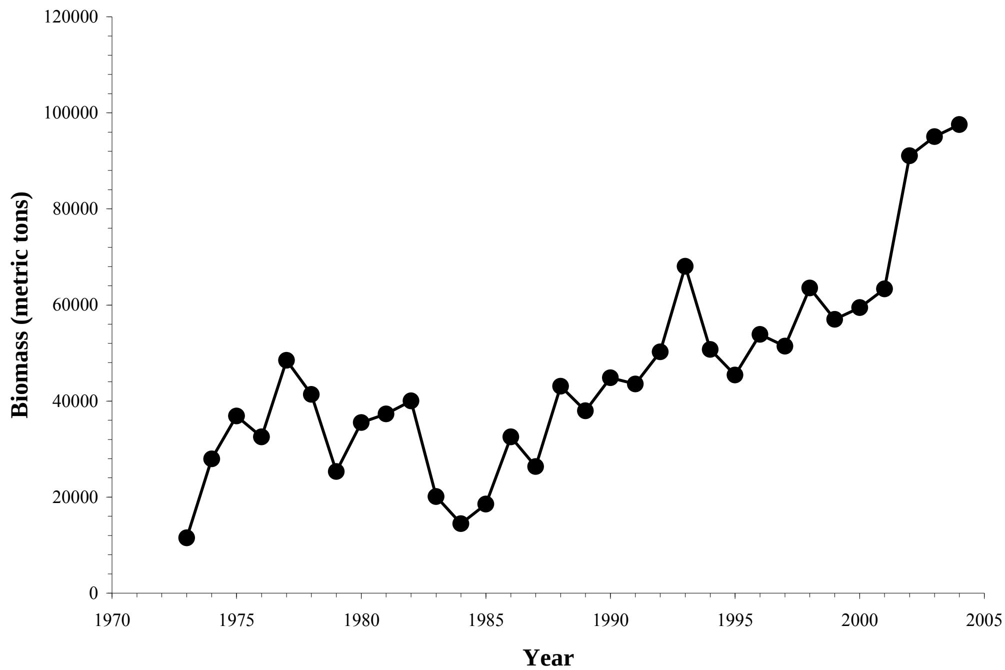

Figure 62. North Strait of Georgia Pacific herring spawner biomass (metric tons) from 1973 to 2004. Data from WDFW[66] and DFO.[67]

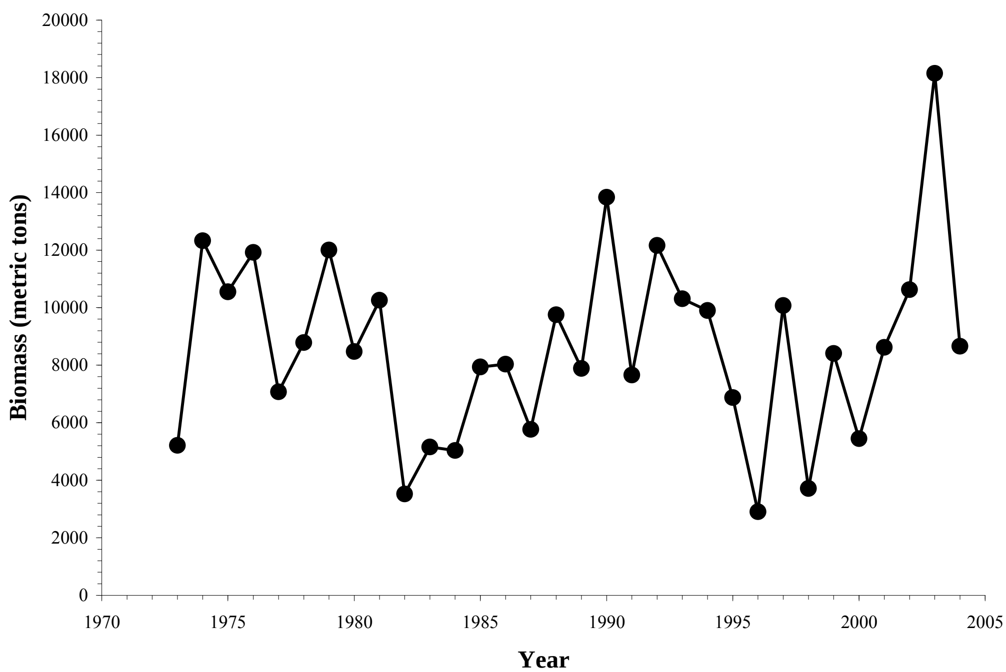

Figure 63. North Puget Sound and South Strait of Georgia Pacific herring spawner biomass (metric tons) from 1973 to 2004. Data from WDFW[68] and DFO.[69]

[66] See footnote 5.
[67] See footnote 36.
[68] See footnote 5.
[69] See footnote 36.

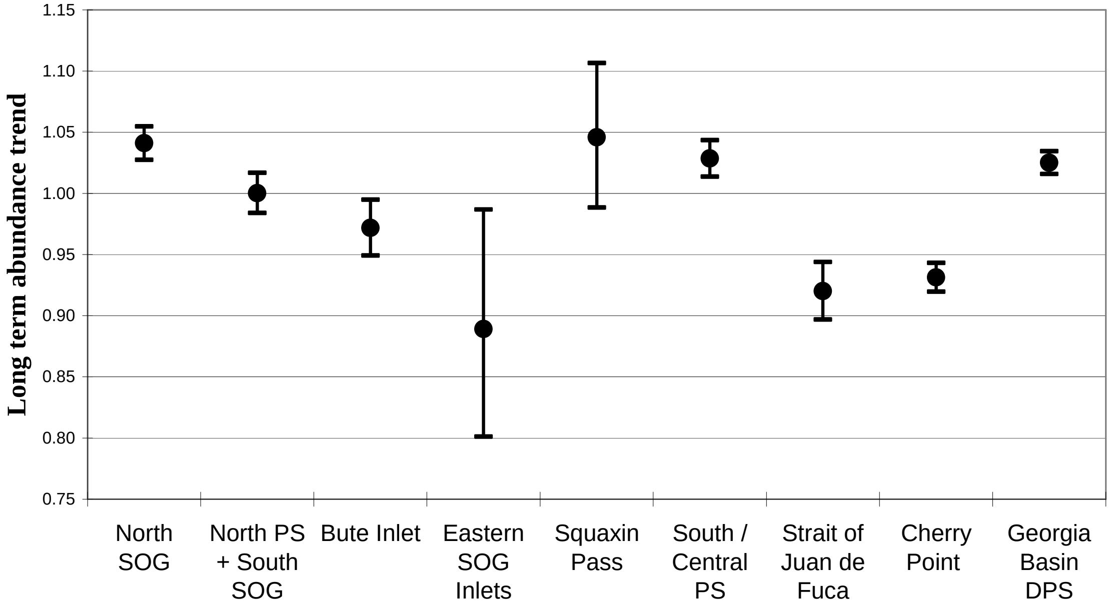

Figure 64. Pacific herring long-term abundance trends (1973–2004) and associated 95% confidence limits for the Georgia Basin DPS and proposed subpopulations in the Georgia Basin DPS.

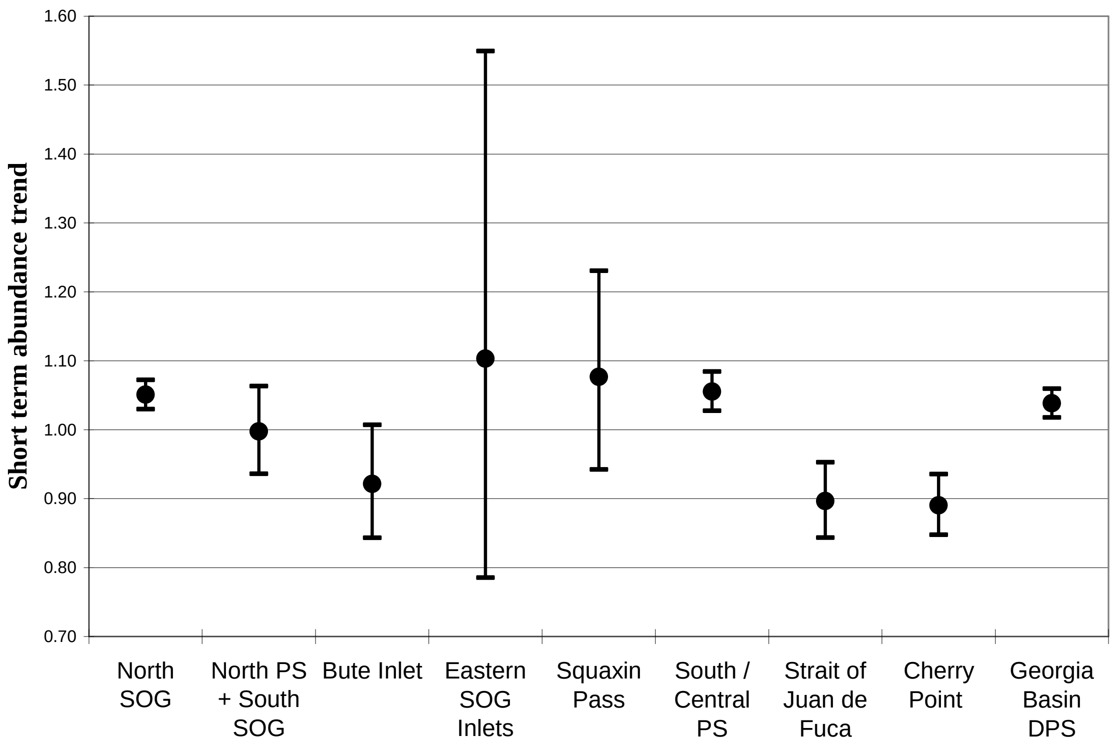

Figure 65. Pacific herring short-term abundance trends (1990–2004) and associated 95% confidence limits for the Georgia Basin DPS and proposed subpopulations in the Georgia Basin DPS.

Table 16. Estimates of long- and short-term trends and their 95% confidence intervals for proposed subpopulations of Pacific herring in the Georgia Basin Pacific herring DPS.

DPS subpopulations	Data years	LT Trend (CI)	ST Trend (CI) (1990-2004)
Bute Inlet	1973–2004	0.97 (0.95–0.99)	0.92 (0.84–1.01)
North SOG	1973–2004	1.04 (1.03–1.05)	1.05 (1.03–1.07)
Eastern SOG Inlets	1973–2004	0.89 (0.80–0.99)	1.10 (0.79–1.55)
North PS + South SOG	1973–2004*	1.00 (0.98–1.02)	1.00 (0.94–1.06)
Cherry Point	1973–2004	0.93 (0.92–0.94)	0.89 (0.85–0.94)
South / Central Puget Sound	1975–2004*	1.03 (1.10–1.04)	1.06 (1.03–1.08)
Squaxin Pass	1975–2004	1.05 (0.99–1.11)	1.08 (0.94–1.23)
Strait of Juan de Fuca	1976–2004*	0.92 (0.90–0.94)	0.90 (0.84–0.95)

* Missing several years of biomass estimates for some subunits.

far-reaching ecological consequences" in the Strait of Georgia. Hay and McCarter (1999, 2004b) have documented the recent geographic concentration of spawning in the northern SOG and contraction of spawn timing in the SOG in general. In particular, there are fewer early spawnings in the SOG than in previous decades (Hay and McCarter 1999, 2004b). Despite the suspected reduction in nonmigratory Pacific herring stocks and the reduction in spawning distribution in the SOG, the overall level of abundance in the SOG has reached near record levels in recent years (Hay and McCarter 1999, Wallace 2002).

The length of coastline receiving spawn deposition (spawn length) since 1940 for subpopulations of the DPS in British Columbia, and since 1972 for all of the DPS, is illustrated in Figure 71. It is recognized that comparison of annual spawn length records over wide geographic areas can be misleading, since spawning at different locations can vary in width and intensity (Hay and Kronlund 1987). In particular, spawn width and intensity can vary geographically due to topographical differences in spawn habitat (i.e., wide mudflats versus steep-sided inlets), changes in survey methods, shifts in spawn location, and real changes in spawner abundance (Hay and Kronlund 1987). However, this metric is one of the few indices that is available for all portions of the DPS and may therefore be a crude estimator of widespread trends. With the above caveats in mind, Figure 71 shows that the overall spawn length within the DPS has been relatively steady or increasing over time. With the exceptions of the Eastern SOG Inlets and Cherry Point subpopulations, spawn length in the individual subpopulations has also been relatively steady or increasing over time.

IUCN Categories

Results of application of the IUCN decline criteria to possible subpopulations within the Georgia Basin Pacific herring DPS are presented in Table 14. Over the past three generations (= 15 years), overall biomass of the Georgia Basin Pacific herring DPS has increased approximately 107% while the Cherry Point population and the proposed Strait of Juan de Fuca and Bute Inlet subpopulations have declined 54%, 81%, and 25%, respectively. Under the IUCN decline criteria, a reduction in population size of this magnitude "where the reduction or its causes may not have ceased or may not be understood or may not be reversible" (IUCN 2004, p. 10) would place Cherry Point in the "Endangered" category, Strait of Juan de Fuca in the "Critically Endangered" category, and Bute Inlet in the "Near Threatened" category. The other

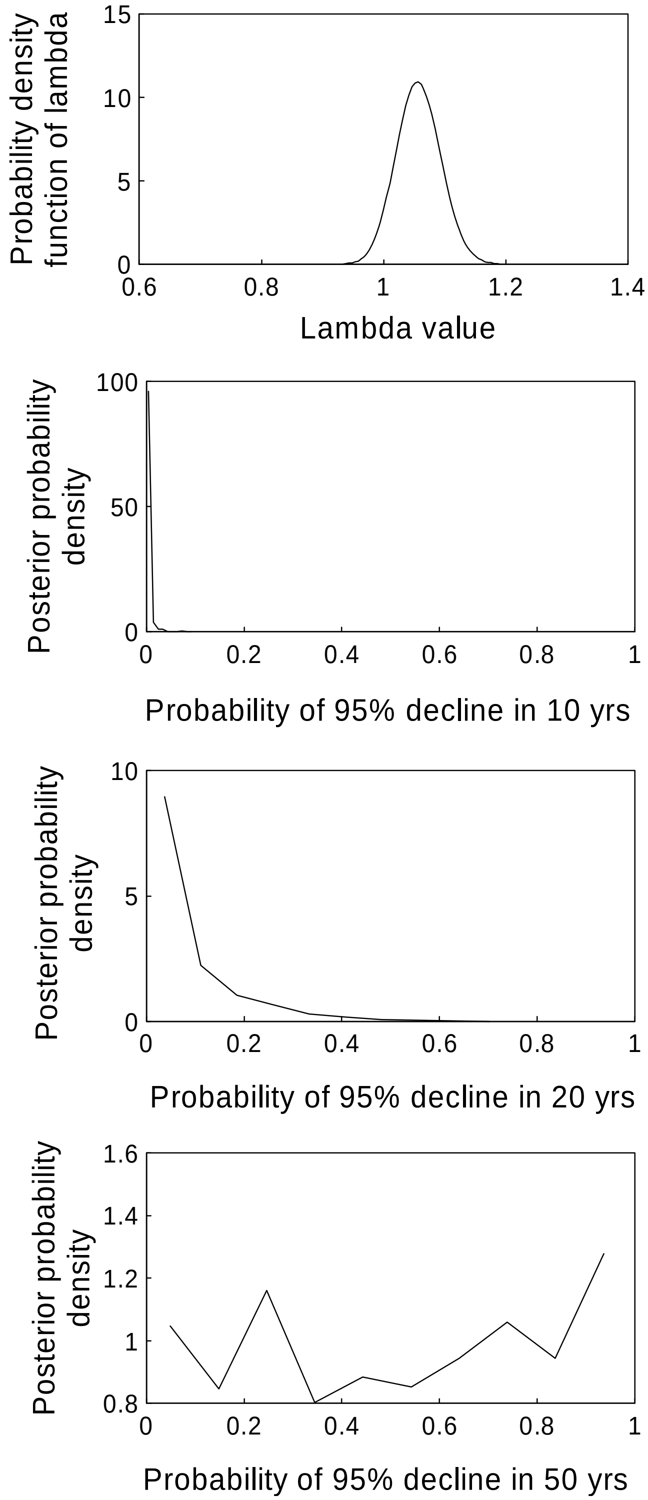

Figure 66. Lambda estimates for the North SOG Pacific herring subpopulation and the posterior probability that the subpopulation experiences a 95% decline in biomass within the next 10, 20, or 50 years.

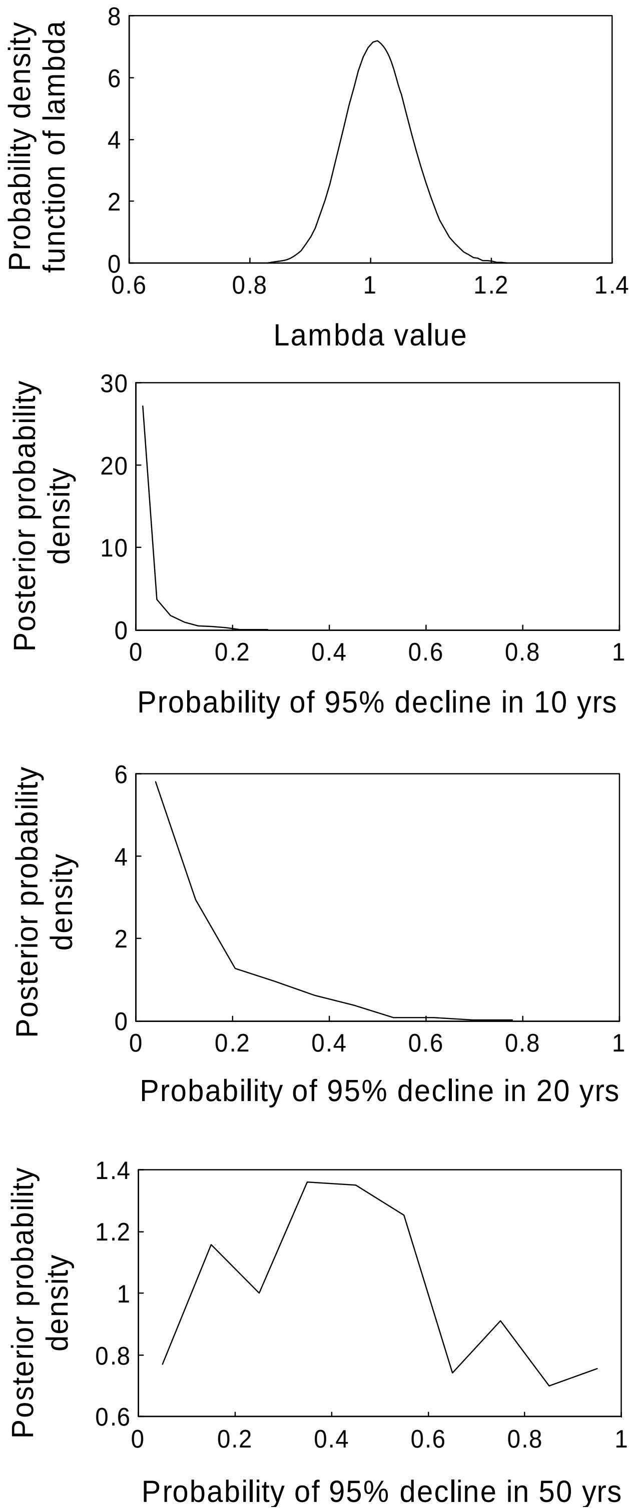

Figure 67. Lambda estimates for the North Puget Sound plus South SOG Pacific herring subpopulation and the posterior probability that the subpopulation experiences a 95% decline in biomass within the next 10, 20, or 50 years.

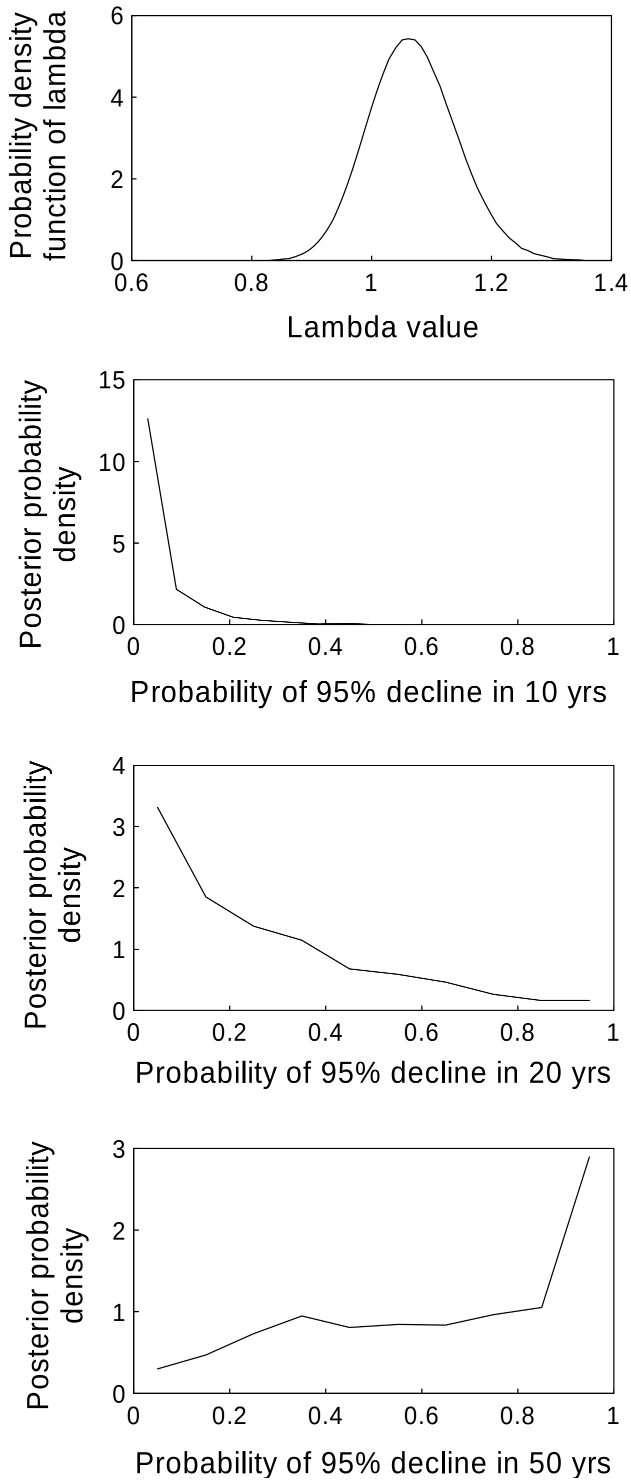

Figure 68. Lambda estimates for the South/Central Puget Sound Pacific herring subpopulation and the posterior probability that the subpopulation experiences a 95% decline in biomass within the next 10, 20, or 50 years.

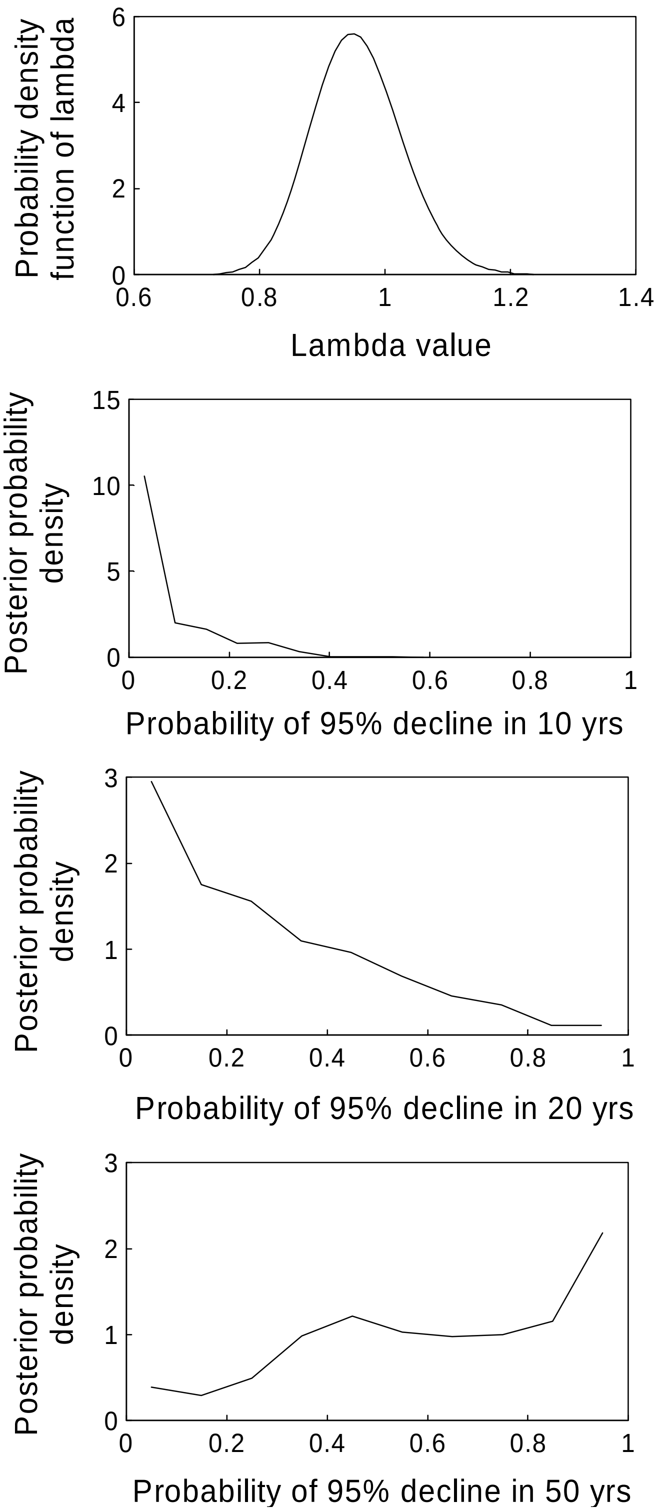

Figure 69. Lambda estimates for the Strait of Juan de Fuca Pacific herring subpopulation and the posterior probability that the subpopulation experiences a 95% decline in biomass within the next 10, 20, or 50 years.

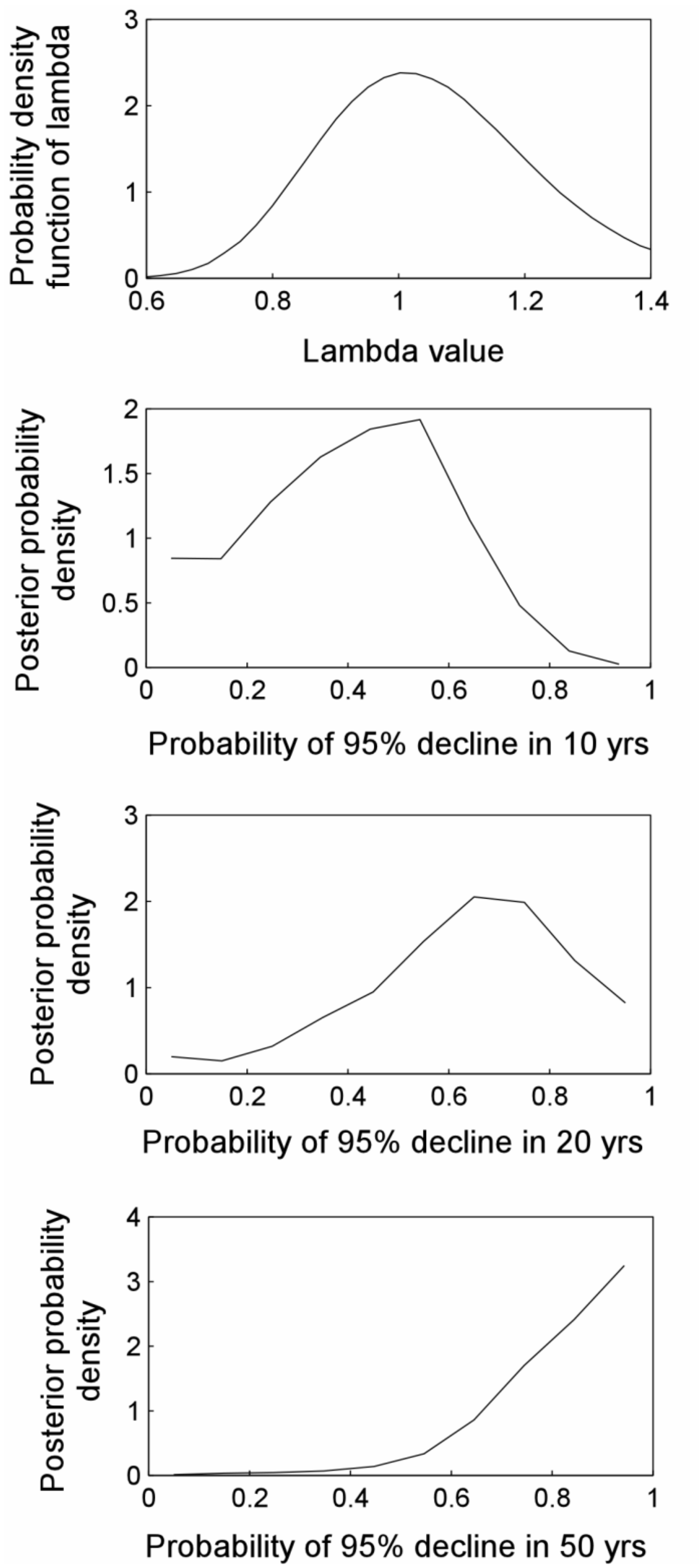

Figure 70. Lambda estimates for the Squaxin Pass Pacific herring subpopulation and the posterior probability that the subpopulation experiences a 95% decline in biomass within the next 10, 20, or 50 years.

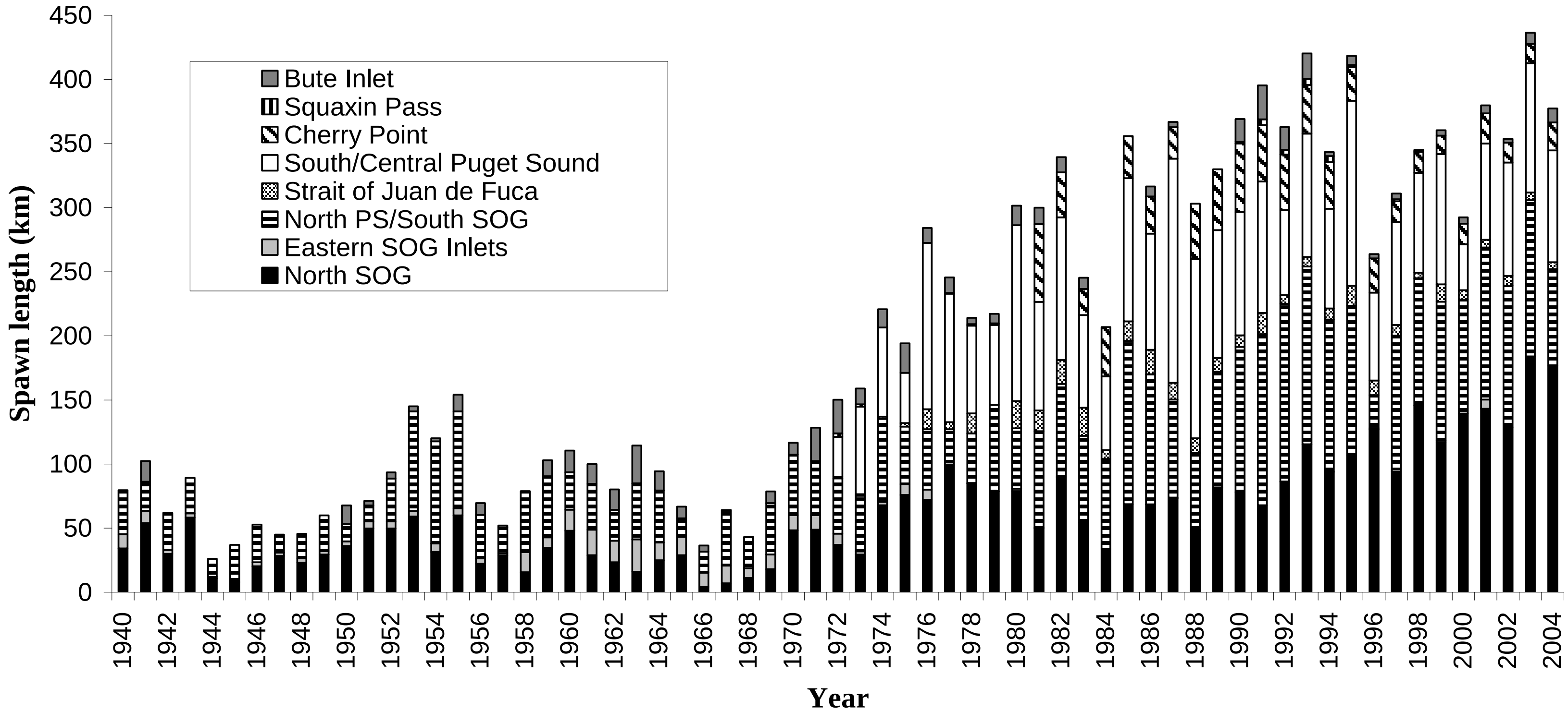

Figure 71. Kilometers of shoreline receiving Pacific herring spawn deposition in proposed subpopulations of the Georgia Basin Pacific herring DPS (1940–2004). Washington State data series begins in 1972. Data from WDFW[70] and DFO.[71]

[70] See footnote 5.
[71] See footnote 36.

five proposed subpopulations, comprising the vast bulk of the DPS, have increased in abundance over the past three generations (Table 14) and would be classified in the IUCN "Least Concern" category.

Conclusions: Risk Assessment

The BRT has concluded that the Georgia Basin Pacific herring DPS is not at risk of extinction in all or a significant portion of its range, nor likely to become so in the foreseeable future. Details about how the BRT reached this conclusion are summarized below.

Available information (genetics, life history, tagging studies, etc.) suggests that population structure of Pacific herring roughly conforms to the classical concept of a metapopulation, in which local subpopulations are linked demographically by at least episodic migration, and extinction and recolonization of local subpopulations are common over ecological time frames. In this type of system, at any given point in time some local subpopulations are expected to be increasing and some declining, and some suitable habitat patches are expected to be uninhabited.

Available information suggests that the Georgia Basin DPS of Pacific herring does not differ substantially in general features of biology from Pacific herring in other areas. Therefore, the BRT concluded that, as a reasonable approximation, the classical metapopulation model provides a framework for assessing extinction risk of the DPS. Under this framework, the fact that some local subpopulations are declining is not by itself cause for concern about the long-term viability of the DPS. Rather, the key question becomes, “Have recent factors, either natural or human-mediated, disrupted the functioning of the metapopulation to such an extent that its long-term viability is compromised?” This question could also be rephrased as: “Is the DPS at risk in a significant portion of its range, such that loss of the at-risk components would pose a substantial risk to long-term viability of the DPS?”

To make this question more operational, the BRT considered the related question, “Are subpopulation declines more pervasive and more pronounced than we would expect to find in a healthy metapopulation?” To evaluate this last question, the BRT considered trends in eight different areas of the DPS, roughly defined on the basis of geography, life history, and genetics (Cherry Point, Squaxin Pass, South/Central Puget Sound, Strait of Juan de Fuca, Bute Inlet, Eastern SOG inlets, Northern SOG, and North Puget Sound plus Southern SOG). Overall abundance is declining within some of these areas and increasing in others (see Tables 14 and 15, Figures 56–65). Ideally, one would like to be able to compare the current data with what might be obtained from taking a random series of historical “snapshots” from a healthy DPS, as this would provide a baseline against which to evaluate current patterns. Unfortunately, this is not feasible, at least at the present time. However, it is possible to compare patterns within the Georgia Basin DPS with data for Pacific herring in other areas. This comparison suggests that patterns of abundance and distribution within the Georgia Basin Pacific herring DPS appear to be fairly typical of what is seen in other Pacific herring populations throughout northwestern North America, including many relatively pristine areas in southeastern Alaska and British Columbia (Hay et al. 2001b). Furthermore, overall abundance of the DPS is at historically high levels, and the number of kilometers of coastline used by Pacific herring for spawning has also been increasing (Hay and McCarter 1999) (see Figure 71). Therefore, the BRT concluded that available evidence does not suggest unusual levels of risk to the DPS as a whole, nor to a significant part of the DPS.

However, the BRT also identified reasons for concern about some local subpopulations within the DPS and some potential future developments that would increase risks to the DPS. First, metapopulation theory indicates that in source-sink systems (that is, when some areas [sources] regularly produce excess migrants that colonize habitat patches with negative net productivity [sinks]), the existence of sinks can buffer extinction risk of the entire metapopulation, compared to a scenario in which the sink areas cease to function at all. Furthermore, habitat patches that are sinks during one environmental regime can become sources if conditions change (and vice versa). Hilborn et al. (2003) recently provided a good empirical example of the importance of temporal changes in relative productivity of different populations of Bristol Bay sockeye salmon (*O. nerka*) in stabilizing long-term, overall abundance. Therefore, a scenario in which currently unproductive habitat is allowed to cease functioning altogether, or to permanently degrade to the point at which it cannot revert to good habitat during favorable environmental regimes, can impair the functioning of the entire metapopulation. Available evidence does not suggest that this factor has contributed significantly to the current patterns of subpopulation declines within the DPS. For example, some of the most depressed (perhaps even extirpated) subpopulations occur in eastern SOG inlets, areas that have relatively pristine habitat. In addition, at Cherry Point, where recent declines are a concern, the most intense Pacific herring spawn activity is concentrated in some of the most disturbed habitat—not the pattern that would be expected if habitat factors were impairing metapopulation function. Nevertheless, this issue warrants close monitoring in the future, as human population pressures are expected to increase in many areas used by the DPS.

Second, the BRT recognized that the classical metapopulation concept does not perfectly fit the Georgia Basin Pacific herring DPS. The pattern of subpopulation structure in the DPS is more similar to the mixed structure metapopulation model of Harrison and Taylor (1997) than to Levins' (1969, 1970) classical metapopulation. Although the DPS is characterized by high levels of homogeneity, the Cherry Point population and some subpopulations such as Squaxin Pass are relatively more distinctive, based on spawn timing, growth rate, contaminant profiles, and genetic differences. And as noted above, the BRT concluded that Cherry Point Pacific herring meets the DPS criteria to be considered a "discrete" population. These differences are not of a magnitude that suggests long-term evolutionary divergence, but it is possible that demographic linkages between these and other subpopulations in the DPS are weak enough that they are largely demographically independent on ecological time scales. If this is the case, and if these subpopulations were lost, recolonization might take longer than it would for areas that are part of a classical metapopulation. Still, the BRT did not feel that current risks to these areas represent risks to a significant portion of the range of the DPS as a whole. Cherry Point Pacific herring are characterized by late mean spawn timing, but this timing is not temporally discontinuous and falls within the tail of the distribution for the DPS as a whole, and subpopulations with similar spawn timing occur in other geographic areas, beyond the boundaries of the DPS. The Cherry Point Pacific herring population represents only one of about 40 recognized assessment regions or stocks within the DPS, although historically it may have been one of the largest populations in the central part of the DPS. At its peak several decades ago, Cherry Point Pacific herring represented perhaps about 11% of the biomass of the DPS as a whole, but this proportion is speculative and not necessarily indicative of historical conditions, because at that time many of the larger subpopulations in the DPS were severely depressed due to overharvesting and poor recruitment conditions.

If Cherry Point and Squaxin Pass are largely independent demographically, they would correspond to independent populations under the criteria established in the viable salmonid populations framework (McElhany et al. 2000). Therefore it is useful to briefly review the ESA listing status of Pacific salmon DPSs comparable in size and complexity to the Georgia Basin Pacific herring DPS. Most Pacific salmon DPSs cover roughly comparable geographic areas (e.g., Pacific salmon DPSs have been identified at the level of Puget Sound, Georgia Basin, Snake River Basin, and California Central Valley) and include a substantial number (typically 20–40) of demographically independent populations/stocks. Thus the Georgia Basin Pacific herring DPS, with perhaps a few demographically independent populations interacting with a larger metapopulation, shows less demographic/genetic structure than most Pacific salmon DPSs. Many Pacific salmon DPSs include populations with considerable life history/ecological/genetic diversity, on a scale as large or (in most cases) larger than found within the Georgia Basin Pacific herring DPS. Conservation of this diversity has been given important consideration in both ESA listing determinations and in ongoing recovery planning efforts (Ruckelshaus et al. in press, Interior Columbia Basin TRT 2003, Myers et al. 2006, Lawson et al. 2004, Lindley et al. 2004), and about half of the more than 50 Pacific salmon and steelhead DPSs recognized in the lower 48 states are now listed under the ESA. The status of these listed DPSs has recently been reviewed and updated (Good et al. 2005), and several relevant points emerge from a comparison of these results with data for the Pacific herring DPS:

1. In no listed Pacific salmon DPS is abundance of natural fish anywhere near historic levels.
2. No Pacific salmon DPS is listed based on declines in only a small fraction of the component populations.
3. Although life history diversity is considered very important, risks to one or two distinctive populations do not necessarily result in a conclusion of risk to the entire DPS. For example, the Klamath Mountains Province steelhead and upper Klamath River Chinook salmon DPSs are not listed, in spite of concerns for the status of certain life history types (summer steelhead and spring Chinook salmon, respectively).
4. Although risk factors for Pacific salmon are many and complex, in all listed DPSs loss or degradation of habitat was identified as a factor contributing to population declines. In many cases, it has been possible to roughly quantify the changes in Pacific salmon habitat compared to historic conditions, which provides a basis for determining how far from the historic (presumably viable) template current situations are. In contrast, no specific risk factor has been identified as the primary cause of decline in the portions of the Georgia Basin Pacific herring DPS that are of most concern. This makes it difficult to determine whether the current population trajectories are out of the range of historic patterns.

Therefore, the BRT conclusion that the Georgia Basin Pacific herring DPS is not at risk in all or a significant portion of its range appears to be consistent with how previous BRTs have considered risk for complex DPSs of Pacific salmon.

Finally, the BRT noted that Pacific herring play important roles in the Georgia Basin ecosystem. If the fundamental biological processes necessary for Pacific herring were to be disrupted in the future, such that the metapopulation ceased to function effectively, the consequences for other species could be substantial. Although these consequences are difficult to predict, it is worth noting that Pacific herring are important forage fish for both Pacific salmon and killer whales, so collapse of the Pacific herring DPS could have serious negative effects on these other protected species.

Glossary

Allele. An alternative form of a gene that can occur at the same location (locus) on homologous (paired) chromosomes. A population can have many alleles for a particular locus, but an individual can carry no more than two alleles at a diploid locus.

Allozymes. Alternative forms of an enzyme that have the same function, are produced by different alleles, and are often detected by protein electrophoresis.

Anthropogenic. Caused or produced by human action.

BTEX. Acronym for benzene, toluene, ethylbenzene, and xylene. Volatile organic compounds found in crude oil and other petroleum hydrocarbons.

BRT (Biological Review Team). The team of scientists who evaluate scientific information considered in the National Marine Fisheries Service status reviews.

CWT (coded-wire tag). A small piece of wire, marked with a binary code, which is normally inserted into the nasal cartilage of juvenile fish. Because the tag is not externally visible, the adipose fin of coded wire-tagged fish is removed to indicate the presence of the tag. Groups of thousands to hundreds of thousands of fish are marked with the same code number to indicate stock, place of origin, or other distinguishing traits for production releases and experimental groups.

Comanagers. Federal, state, and tribal agencies that cooperatively manage groundfish in the Pacific Northwest.

dB (decibel). The decibel is a measure of sound level and is a subunit of a larger unit called the bel. As originally used, the bel represented the power ratio of 10 to 1 between the strength or intensity of two sounds, and was named after Alexander Graham Bell.

DDT (1,1,1-trichloro-2,2-bis-[p-chlorophenyl] ethane). Persistent contaminants of aquatic sediments and biota. Commercial formulations of DDTs are mixtures of individual chlorinated biphenyls. Prior to the 1975 congressional ban on DDT manufacture, DDTs were commonly used as pesticides.

Depensation. Depensation occurs when a decrease in abundance leads to reduced survival or production of offspring due either to increased predation per offspring, given constant predation pressure, or to the reduced likelihood of finding a mate (Allee effect).

DPS (distinct population segment). A population, or group of populations, of a vertebrate organism that is “discrete” from other populations and “significant” to the biological species as a whole.

DNA (deoxyribonucleic acid). DNA is a complex molecule that carries an organism's heritable information. DNA consists of a polysugar-phosphate backbone from which the bases (nucleotides) project. DNA forms a double helix that is held together by hydrogen bonds between specific base pairs (thymine to adenine, guanine to cytosine). Each strand in the double helix is complementary to its partner strand in terms of its base sequence. The two types of DNA commonly used to examine genetic variation are *mitochondrial DNA* (mtDNA), a circular molecule that is maternally inherited, and nuclear DNA, which is organized into a set of chromosomes (see also *allele*).

dwt (dead weight tons). The total lifting capacity of a ship expressed in tons of 2,240 lbs. It is the difference between the displacement light and the displacement loaded.

Endangered species. A species in danger of extinction throughout all or a significant portion of its range.

ESA. U.S. Endangered Species Act.

ESU (evolutionarily significant unit). An ESU represents a distinct population segment of Pacific salmon under the Endangered Species Act that 1) is substantially reproductively isolated from conspecific populations, and 2) represents an important component of the evolutionary legacy of the species.

Euryhaline. Refers to organisms that tolerate a wide range of salinities.

EVOS. Exxon Valdez oil spill. Refers to the largest oil spill in U.S. history, which occurred in Prince William Sound, Alaska, on 24 March 1989 when the oil tanker Exxon Valdez ran aground on Bligh Reef.

FACs (fluorescent aromatic compounds). Fish possess a significant capability, primarily in the liver, to readily metabolize PAHs and related aromatic compounds to more polar products (metabolites) that pass into the bile for excretion. These compounds are not detectable in customary PAH analytical procedures, but are determined by their fluorescence, most of which is retained during the metabolic transformations.

Genetic distance. A quantitative measure of genetic difference between a pair of samples.

Genetic drift. The occurrence of random changes in the gene frequencies of populations.

Georgia Basin. The semienclosed marine basin comprised of the Strait of Georgia, Puget Sound, and the Juan de Fuca Strait, together with the lands that drain into these marine waters.

Haplotype. The collective genotype of a number of closely linked loci; the constellation of alleles present at a particular region of genomic or mitochondrial DNA.

IUCN. International Union for the Conservation of Nature and Natural Resources. In 1990 the name was shortened to IUCN -The World Conservation Union.

Least squares means. Means that have been corrected for imbalances in other variables are called least squares means (also known as adjusted means).

LC_{50}. The “lethal concentration” of a chemical or substance that kills 50% of the test organisms in a given time period, normally 96 hours for aquatic organisms.

Locus (pl. loci). The site on a chromosome where a gene is found; often used more or less synonymously with gene (cf *allozymes*).

Meristic trait. A discretely varying and countable trait (e.g., number of fin rays or basibranchial teeth).

Metapopulation. A metapopulation is an assembly of closely related subpopulations (usually spatially fragmented) that were established by colonists, survive for a while, send out migrants, and eventually disappear. The persistence of a subpopulation depends on the rate of colonization successfully balancing the local extinction rate.

Microsatellite DNA. A class of repetitive DNA. Microsatellites are simple sequence repeats one to eight nucleotides in length. For example, the repeat unit can be simply “CA”, and might exist in a tandem array (CACACACACA) 50 or more repeat units in length. The number of repeats in an array can be highly polymorphic.

Mitochondrial DNA. The DNA genome contained within mitochondria and encoding a small subset of mitochondrial functions; mtDNA is typically circular and 15–20 kilobases in size, containing little noncoding information between genes.

MLLW (mean lower low water). A tidal measure. The average of the lower low water height of each tidal day observed.

Morphometric trait. A discretely varying trait related to the size and shape of landmarks from whole organs or organisms analyzed by appropriately invariant biometric methods in order to answer biological questions.

NWFSC. Northwest Fisheries Science Center.

Otolith. Crystalline calcium carbonate structures within the inner ear of fish. These structures have distinctive shapes, sizes, and internal and surface features that can be used for age determination and species identification.

ppb (parts per billion). A unit of chemical concentration.

ppm (parts per million). A unit of chemical concentration.

PDO (Pacific Decadal Oscillation). A pattern of Pacific climate variability persisting for 20–30 years, in contrast to typical El Niño climate events, which persist for 6–18 months. The climatic indicators of the PDO are most visible in the North Pacific region.

Phenotype. The appearance (or other measurable characteristic) of an organism that results from interaction of the genotype and environment.

PCB (polychlorinated biphenyl). Persistent contaminants of aquatic sediments and biota that are very widespread. Commercial formulations of PCBs are mixtures of individual chlorinated biphenyls (congeners) varying according to the numbers of chlorines and their ring positions on the biphenyl. Prior to the 1975 congressional ban on PCB manufacture, various mixtures of some 209 individual PCBs were used extensively in electrical transformers, capacitors, paints, waxes, inks, dust control agents, paper, and pesticides.

PAH (polycyclic aromatic hydrocarbon). The PAHs are widely distributed throughout the marine environment and commonly occur in sediments in urban coastal and estuarine areas. Sources include crude oil, petroleum products, and residues from combustion of fossil fuels. They are composed of fused benzene rings, with or without alkyl substituents (e.g., methyl groups).

Population. A group of individuals of a species living in a certain area that maintain some degree of reproductive isolation.

Puget Sound. A coastal fjord-like estuarine inlet of the Pacific Ocean located in northwest Washington State between the Cascade and Olympic mountains and covering an area of over 9,000 km^2 including 3,700 km of coastline.

Reduction fishery. Commercial fisheries where the harvested fish are processed (reduced) into low-value products, such as fish meal and oil.

Species. Biological: A small group of organisms formally recognized by the scientific community as distinct from other groups. Legal: Refers to joint policy of the USFWS and NMFS that considers a species as defined by the ESA to include biological species, subspecies, and DPSs.

Standard length. Length in millimeters from the tip of the snout to the end of the silvery portion of the body.

SOG (Strait of Georgia). The body of water separating the southern portion of Vancouver Island and the British Columbia mainland. The strait extends from Cortes Island and Desolation Sound in the north to the San Juan Islands in the south.

Strait of Juan de Fuca. The body of water separating the southern portion of Vancouver Island and the Olympic Peninsula in Washington. The strait extends from the Pacific Ocean east to the San Juan and Whidbey Islands.

Threatened species. A species not presently in danger of extinction but likely to become so in the foreseeable future.

TPAHs (Total PAHs). The summed total of all the individual PAHs detected in a sample.

Trophic. Pertaining to nutrition. A trophic migration would be a movement of fish to a feeding area.

VSP (**viable salmonid population**). An independent population of any Pacific salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a long time frame (McElhany et al. 2000).

WDFW (Washington Department of Fish and Wildlife). Department that comanages certain fisheries in Washington State with WWTIT and other fisheries groups. The agency was formed in the early 1990s by combining the Washington Department of Fisheries and Washington Department of Wildlife.

WWTIT (Western Washington Treaty Indian Tribes). An organization of Native American tribes with treaty fishing rights recognized by the United States. WWTIT comanages certain fisheries in western Washington in cooperation with WDFW and other fisheries groups.

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