Biological Synopsis of Pacific Herring in Support of Marine Emergency Response To Hydrocarbon Spill Events

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Schweigert, J.F., and Herborg, M. 2024. Biological Synopsis of Pacific Herring in Support of Marine Emergency Response to Hydrocarbon Spill Events. Can. Manuscr. Rep. Fish. Aquat. Sci. 3274: xii + 113 p.

Marine emergency response activities require information on the distribution and sensitivity of potentially impacted species from incursions of deleterious substances into the environment. This report summarizes available information and studies on the characteristics of hydrocarbons released in previous spills such as *Exxon Valdez*, their response to weathering and the resulting effects on Pacific Herring (*Clupea pallasii*). The report also summarizes the general life history of Pacific Herring in British Columbia, and what is known of its distribution, relative abundance, timing of reproduction, and vulnerability to, and outcomes from, exposure to components of petroleum during various stages of its life history. Herring eggs are adhesive when spawned so they are susceptible to exposure to petroleum or other spilled toxicants particularly alkylated polyaromatic hydrocarbons (PAH) that have been shown to produce developmental abnormalities and impact survival. After hatching, larval herring are pelagic and have limited mobility rendering them susceptible to interactions with surface slicks and potential impacts from petroleum or other spills. Following metamorphosis to the adult form, Pacific Herring juveniles form mobile schools leaving them less prone to environmental disturbances. Similarly, adult herring spend the greater portion of the year on offshore feeding grounds remote from most toxicant incursions. However, they are prone to petroleum impacts during the spring inshore migration and spawning period.

RÉSUMÉ

Schweigert, J.F., and Herborg, M. 2024. Biological Synopsis of Pacific Herring in Support of Marine Emergency Response to Hydrocarbon Spill Events. Can. Manuscr. Rep. Fish. Aquat. Sci. 3274: xii +113 p.

Dans le cadre des activités d'intervention en cas d'urgence maritimes, il faut disposer de renseignements sur la répartition et la sensibilité des espèces qui pourraient être touchées par la pénétration de substances nocives dans l'environnement. Le présent rapport résume les renseignements et les études disponibles sur les caractéristiques des hydrocarbures rejetés lors de déversements antérieurs, comme celui de l'*Exxon Valdez*, la réaction de ces hydrocarbures au processus d'altération et leurs effets sur le hareng du Pacifique (*Clupea pallasii*). Le rapport résume également le cycle vital général du hareng du Pacifique en Colombie-Britannique, ainsi que les aspects connus de sa répartition, de son abondance relative, du moment de sa reproduction, ainsi que de sa vulnérabilité à une exposition aux composantes du pétrole et des conséquences connexes à divers stades de son cycle vital. Les œufs de hareng sont adhésifs après la fraie, ce qui les rend vulnérables à une exposition au pétrole ou à d'autres substances toxiques déversées, en particulier les hydrocarbures aromatiques polycycliques (HAP) alkylés, qui produisent des anomalies du développement et ont une incidence sur la survie des individus, selon les études réalisées. Après l'éclosion, les larves de hareng sont pélagiques et peu mobiles, ce qui les rend vulnérables aux interactions avec les nappes de surface et aux impacts possibles des déversements de pétrole ou d'autres substances. Après l'atteinte de la forme adulte, les harengs du Pacifique juvéniles forment des bancs mobiles, ce qui les rend moins vulnérables aux perturbations environnementales. De même, le hareng adulte passe la plus grande partie de l'année dans des aires d'alimentation extracôtières, qui sont éloignées de la plupart des lieux où des substances toxiques pénètrent dans l'environnement. Cependant, ils sont vulnérables aux impacts du pétrole pendant la période de fraie et la migration côtière du printemps.

INTRODUCTION

Pacific Herring (*Clupea pallasii*) is one of the most common species to be found in the nearshore and coastal waters of British Columbia (BC). It is an important prey species at all stages of its life history and plays a critical role in the ecosystem. It is atypical of most marine fish species in the fact that reproduction occurs inshore with eggs being deposited on marine vegetation and bottom substrates within the intertidal and upper subtidal zones of much of the north temperate Pacific Ocean (Haegele and Schweigert 1985). Consequently, herring populations have been displaced and often eliminated from areas impacted by human activities such as foreshore development and associated activities that introduce harmful substances including hydrocarbons into the marine environment. The objective of this report is to summarize what is known about the characteristics of hydrocarbon releases and their fate in the marine environment, describe the life history and distribution of Pacific Herring throughout the year when they may be most susceptible to impacts from hydrocarbon releases, document the spawning habitat critical to the conservation and survival of herring populations in British Columbia, and summarize what is known about the individual and population level effects of hydrocarbons on Pacific Herring.

CHARACTERISTICS AND FATE OF HYDROCARBON RELEASES

The National Research Council (2003) estimates that 600,000 tonnes of the 1,300,000 tonnes of annual worldwide input of petroleum hydrocarbons (46%) into the oceans from all sources comes from natural seeps. Of the remainder, hydrocarbons have entered into the marine environment for decades from routine or accidental releases resulting from various human activities such as drilling, manufacturing, storing, transporting, and waste management (National Research Council 2003). When oil is released into the environment it undergoes various transformations that depend on many variables, including the chemical makeup, the physical properties, the location of the oil (deep water, shallow water, nearshore, shoreline) and weather conditions (temperature, wave height, winds). The oil will be adsorbed or attach to various surfaces; it will biodegrade as a result of micro-organism (bacteria, fungi, yeasts) consumption; it will disperse in the surface layers by wave action; some components of the oil will dissolve in the water; it will emulsify or become dispersed in the water in the form of small droplets; some of the lighter volatile compounds will evaporate; and sunlight can cause photo-oxidation to degrade some chemical components (Lee et al. 2015; MPunt 2020).

CHEMICAL PROPERTIES

The chemical composition of the oils is described by the hydrocarbon groups, volatile organic compounds, *n*-alkane distribution, and distribution of alkylated polyaromatic hydrocarbon (PAH) homologues (Wang et al. 2003). Each individual oil type has a unique "chemical fingerprint" described by a wide range of chemical compounds in various ratios. Environment and Climate Change Canada also maintains a chemical database of individual oil products and crude monitor. The four main classes of chemicals found in oils are: saturates, aromatics, resins and asphaltenes (SARAs) (Lee et al. 2015). In addition to the SARA fractions, petroleum may also contain small and variable concentrations of non-hydrocarbon components derived from biological or geological sources. These include metals, organometals, sulphur, naphthenic acids, mineral particles, water (Lee et al. 2015). The influence of the SARA fractions on oil behaviour has been summarized as follows (Federici and Mintz 2014; Dupuis and Ucan-Marin 2015; Lee et al. 2015):

Saturates are considered the least toxic of the SARA fractions and usually represent the major component of petroleum. Saturates are hydrocarbons that contain single carbon-carbon bonds with the maximum number of hydrogens around each carbon atom. Three subclasses are defined within the fraction: paraffins and isoparaffins with straight or branched chain structures; napthenes that contain one or more saturated ring structures; and fused-ring aliphatics that include hopanoids and steroids having complex structures that are combinations of the other two subclasses. Most saturate components are also readily biodegradable, except for steroids and hopanoid compounds (Lee et al. 2015). The higher the saturate concentration the lower the viscosity of an oil.

Aromatics are the most water-soluble of the hydrocarbons and most mobile by diffusion. They have at least one benzene ring and are typically associated with toxicity in aquatic organisms because of an ability to move across biological membranes (Lee et al. 2015). These include mono-aromatic hydrocarbons such as benzene, toluene, ethylbenzene and xylene (collectively referred to as BTEX) and also, PAHs (National Research Council 2003). PAHs can comprise up to 60% of the composition of oil. In general, the lower molecular weight aromatic hydrocarbons are found in greater amounts in oil relative to those of higher molecular weight and tend to be more toxic. One to three ring PAHs can account for up to 90% of the total aromatic hydrocarbons in oil while, four to six ring PAHs are found in lower concentrations (National Research Council 2003). The higher the aromatic concentration the lower the viscosity of an oil.

Resins are not hydrocarbons since they contain elements other than carbon and hydrogen, i.e., they include the heteroatoms sulphur, nitrogen and/or oxygen. The heteroatoms make resins more polar than hydrocarbons, and sometimes more toxic due to their solubility in water. Resins are chemically related to, but smaller, than asphaltenes and are largely responsible for the adhesive qualities of oil (Lee et al. 2015). They also are very resistant to biodegradation resulting in environmental persistence. Oils with high resin contents tend to form stable emulsions.

Asphaltenes are also not hydrocarbons because they contain sulphur, nitrogen and oxygen heteroatoms like resins. They are the most complex, most diverse and highest molecular weight components of petroleum and are the least susceptible to biodegradation. Light crude oils have a much lower percentage of asphaltenes than heavier oils and bitumens. The high percent of asphaltenes in heavy oils cause them to have high densities and viscosities and also cause them to form stable emulsions (Lee et al., 2015).

Another important chemical property of oil is the wax content, defined as the amount of organic compounds that are malleable near ambient temperature (Federici and Mintz 2014). Waxes are typically insoluble in water and the higher the wax content the higher the oil viscosity. They can represent a substantial proportion of certain crudes, may precipitate out of petroleum at low temperature and can also form coatings on surfaces, affecting the interfacial properties of the oil. They are non-toxic but resist biodegradation due to low solubility in water.

Inorganic sulfur present in elemental form or as gaseous hydrogen sulfide may be a minor component of oil by mass (often <1%), but hydrogen sulfide is toxic to humans even at parts per million levels (Lee et al. 2015). It is also of concern regarding corrosion to infrastructure (e.g., pipelines and surface handling facilities) and the potential for explosion in confined spaces, including rail cars. It may exist as a gas depending on the water content of the oil or may be dissolved in the water phase. Hydrogen sulfide may represent only a fraction of the total sulfur in sour crudes which contain mostly organic sulfur compounds. The organic sulfur has different chemical properties than hydrogen sulfide and is more problematic in refineries than in the environment. Oils with a significant proportion of total sulfur (usually ≥1%) are known as 'sour' crudes, as opposed to 'sweet' crudes with ≤0.5% sulfur (Lee et al. 2015). Sweet oils tend to be more valuable than sour, since sulfur removal is costly for the refinery and hydrogen sulfide must be reduced before transportation for safety reasons.

The general chemical composition of petroleum is complex and varies across crude oils and refined products formed through a variety of distillation, cracking and blending processes. In general, light and mid-range distillates (gasoline and diesel) and light crude oils contain a higher proportion of low molecular weight saturates and aromatics (BTEX and 2-ringed PAHs) than heavy crude oil. In contrast, heavy crude oil contains higher percentages of PAHs than light crude oil. Lighter petroleum products are characterized by their low proportion of waxes, resins and asphaltenes compared to the heavier crude oils and oil products. Trace metals can also be found in oil products and relative composition of metals differs between oil types. Total metal concentrations generally increase from light distillates and light crude oil to heavier oil products.

Low molecular weight aromatic hydrocarbons are highly toxic to aquatic organisms. These include mono-aromatics and 2-ringed PAHs that are generally highly soluble, and thus acutely toxic. The low molecular weight constituents are also highly volatile compounds and remain in the environment for hours to days following a spill. The higher molecular weight constituents (PAHs with 3 or more benzene rings) are less soluble but also less volatile remaining longer in the environment. Many studies have found that 3- to 5-ringed PAHs have chronic effects in fish, especially in early-life stages (eg. Carls et al. 1999; Adams et al. 2014). In a study of heavy fuel oil, it was demonstrated that 3- to 5-ring PAHs and alkyl-PAHs fractions were more toxic to rainbow trout (*Oncorhynchus mykiss*) embryos, while those containing waxes and long-chain alkanes showed lower toxicity (Bornstein et al. 2014).

PHYSICAL PROPERTIES

There are many different types of petroleum oils with variable chemistry and the relative proportions of its constituents determine the physical characteristics of oil and its behaviour and fate when spilled into the environment (Dupuis and Ucan-Marin 2015). Physical properties that have been identified as important factors in determining oil behaviour include American Petroleum Institute (API) gravity, density, viscosity, pour point, surface and interfacial tension, flash point, emulsion formation, sulphur and water content, adhesion, predicted evaporation, and simulated boiling point distribution (Wang et al. 2003; Lee et al. 2015).
Density is a measure of the mass of a substance and the density of oil relative to water is the specific gravity that determines if the oil will float or sink. Bitumen and some fuel oils may have

density greater than water at some temperature ranges causing them to submerge. Following a spill, the density of oil changes due to weathering processes, typically losing lighter volatile fractions leaving denser components. Although density is a key indicator of oil buoyancy, weathering, temperature, salinity and interactions with particles affect whether the oils float or sink (Dupuis and Ucan-Marin 2015; Lee et al. 2015).

Viscosity is the resistance of a fluid to shear, movement or flow, essentially its thickness. In general, the greater the fraction of saturates and aromatics in an oil and the lower the amount of asphaltenes and resins, the lower the viscosity. As oil weathers, the evaporation of the lighter components results in increased viscosity which is also inversely related to temperature. When oil is spilled on water, the higher the viscosity the less it will spread on water and the less it will penetrate into soils or shoreline materials (Lee et al. 2015). High viscosity oils or emulsions can also be difficult to pump or skim off water.

The pour point is the temperature at which no flow of the oil from a standard measuring vessel is visible over a period of five seconds. Oils with more volatile components and lower viscosities generally have lower pour points. The pour point represents a consistent temperature at which an oil will pour very slowly but is a poor indicator of the state of the oil. For example, waxy oils may have very low pour points but continue to spread slowly at that temperature and evaporate to a significant degree. The pour point of crude oils generally varies from -60°C to 30°C.

The interfacial tension is a measure of the stress at the boundary between two substances or how much they attract each other. In effect, the higher the interfacial tension, the less attractive the two surfaces are to each other. Therefore, the lower the interfacial tension of oil with water, the more likely it is to spread making for a thinner slick (MPunt 2020). In general, interfacial tensions are lower at higher temperature making it more likely for oil to spread on warm than on cold water. However, other factors affect spreading behaviour such as viscosity (Lee et al. 2015). The interfacial tension at the oil and water interface is often referred to as surface tension and measures the attraction or cohesion between the surface molecules of the oil rather than to molecules in air (adhesion) (Lee et al. 2015). Oils with a lower surface tension tend to spread more readily over the water surface or penetrate into the soil or shoreline material. Adhesion is a measure of the degree to which an oil will coat a surface (e.g., shoreline material, response equipment, coastal infrastructure). It is based on measuring the mass of oil adhering on a standard surface per unit area (Lee et al. 2015).

The volatility or flash point refers to the temperature at which the vapour over a liquid will ignite. In the case of oil spill response, the flash point is an important safety consideration. A liquid is considered to be flammable if its flash point is less than 60°C. Gasoline and other light fuels can ignite under most ambient conditions making them a serious hazard when spilled. Crude oils may have a low flash point when spilled but typically the lighter components evaporate or disperse quickly raising the flash point (MPunt 2020).

The emulsification of an oil is the extent to which it mixes with water and is typically grouped into four classes: stable, mesostable, unstable, and entrained water (Fingas and Fieldhouse 2004). In the case of spilled oil, an emulsion implies a stable water-in-oil mixture and as it becomes more stable the properties of the mixture will differ from the oil that was spilled. Most importantly, the viscosity of the mixture will be higher than the source oil. Therefore, when an oil slick on water becomes emulsified the volume of the slick is increased due to the added water. The increased viscosity and volume and, in the case of marine spills, the introduction of brine to the slick can greatly impact the effectiveness of spill response options (MPunt 2020). Emulsions can be more difficult to respond to because of the high water content that renders them inefficient for ignition, generating more waste and making mechanical recovery less effective.

Most petroleum hydrocarbons are virtually insoluble in water. In general, the saturates are highly water insoluble compared to similar sized aromatics. Monoaromatics are the most water soluble while PAHs are poorly soluble but remain toxic (Lee et al. 2015). Small aromatics and resins because they are polar may be more soluble than comparable hydrocarbons. However, the large resin compounds and asphaltenes despite being polar are water insoluble and have a tendency to partition at the oil water interface.

ENVIRONMENT AND WEATHERING

Immediately following a spill, petroleum oil and products begin to undergo weathering. Weathering processes include spreading, evaporation, biodegradation, emulsification, oxidation, dissolution into water and sedimentation. The rate of weathering depends on the product, the physical location and environmental conditions (e.g., temperature, light, and wind mixing energy) (Dupuis and Ucan-Marin 2015). Biodegradation is a natural process whereby living organisms or their enzymes break organic material into simpler compounds such as organic acids, alcohols, or gases. Temperature and oxygen levels and the number of benzene rings in PAH molecules may affect biodegradation rates (Wang et al. 1998). Immediately following a spill, evaporation is an important weathering process. In the first few days, the volume of light crude oils can be reduced by up to 75% and medium crude oils up to 40% while heavy oils lose about 5% of their volume (Dupuis and Ucan-Marin 2015).

During the weathering process, composition of petroleum oil changes significantly. Low molecular weight *n*-alkanes are depleted while the proportion of higher weight *n*-alkanes increases. The aromatics C3-benzenes and the BTEX group are depleted and eventually disappear. The 2-ringed naphthalene PAHs decrease substantially relative to the other alkylated PAHs (Wang and Fingas 2003). Consequently, the hydrocarbon composition of weathered oil shifts towards a higher concentration of larger aromatics. The remaining higher weight components: PAHs with greater than 3 rings, waxes, resins and asphaltenes are more resistant to weathering processes persisting in the environment longer (National Research Council 2003). The weathering process also produces an increase in viscosity and density of the remaining mixture that affects oil distribution in the water column.

Oil that does not evaporate may disperse into the water column through wave action that breaks it down into micron-sized oil droplets. Whole oil droplets may be dispersed into the water column while monocyclic compounds (e.g., benzene and alkyl-substituted benzenes) and selected lower molecular weight, 2–3 ring PAHs may undergo partial dissolution (Gong et al. 2014). The curling force of the waves entrains oil droplets pushing them down into the water column. Some droplets rise back to the water surface due to their buoyancy, but heavier and weathered oils, such as Bunker C, form dense droplets that will remain in the water column or potentially sink.

Oil in water can also partition into droplets or dissolved fractions. Viscosity determines the rate of spreading and resistance to dispersing into droplets while surface and interfacial tensions are determinants of droplet size (Environment Canada 2013). Wave action, as an example, provides mixing energy in a marine spill breaking surface films and distributing oil droplets into the water column. Solubility of the oil determines the tendency for constituents to dissolve in water and the ability of the dissolved fractions to diffuse across biological membranes (e.g., gills) making it perhaps the most important factor determining toxicity to aquatic species (Dupuis and Ucan-Marin 2015). Buoyancy of petroleum products in water is also affected by temperature. There are indications that some diluted bitumen could sink in brackish seawater and freshwater at temperatures below 15°C (Environment Canada 2013). However, environmental conditions in BC are unlikely to lead to sinking of bitumen in coastal marine waters (Johannessen et al. 2020).

When oil disperses as droplets into waters with a high load of suspended particles, they form oil-particle aggregates (OPAs) stabilizing dispersed oil in the water column. They are referred to as oil-mineral aggregates (OMAs) when they include minerals or inorganic material such as clay. These aggregates have greater densities than the source oil and water which may be advantageous as the dispersed OPA makes the oils available for biodegradation and reduces impacts on sea birds and the probability of oil reaching shoreline environments. In contrast, the high density OPAs can sink to the seabed as marine oil snow causing adverse effects to benthic organisms (Lee et al. 2015). As oil on water approaches shoreline areas, the amount of particulates increase due to water turbulence as it shallows, increasing the likelihood of contacting with sediment particles. Consequently, oil-particle aggregates (OPAs), tar balls, tar patties and tar mats are formed, which can also cause the oil to become negatively buoyant and sink. MPunt (2020) notes that a one cubic centimeter tar ball of Bunker C oil can become negatively buoyant with the incorporation of as few as ten sand grains.

Persistence of oil is another important consideration following a spill into the environment. Several characteristics of oil such as the evaporation, viscosity, and adhesiveness, can influence its persistence in the environment before degrading (Owens et al. 2008). Persistence of various oil constituents are categorized as: gasoline and light distillates such as diesel that persist for days; crude oils that persist for months; and heavy distillates such as heavy fuel oil that persist for years (National Research Council 2003). Several environmental factors including temperature determine the rate of natural physical removal or weathering of oil and some substrate conditions can also extend persistence. For example, oil residues stranded on coarse-sediment beaches can persist for decades where sediment-oil adherence and oil penetration depth reduces the influence of weathering (Owens et al. 2008). Persistence has also been defined based on distillation temperatures and the specific gravity of the product (Dupuis and Ucan-Marin 2015). Research also indicates that the lower the viscosity of the oil the lower the maximum thickness achievable on the various materials, with the shoreline having less ability to retain lower viscosity oils (MPunt 2020).

Salinity can also affect the solubility of oil components. For alkanes and aromatic hydrocarbons, solubility decreases with increasing salinity. The increased solubility of oil in freshwater relative to saltwater equates to increased bioavailability of potentially toxic components. Laboratory studies with euryhaline fish found that decreasing salinity from seawater to freshwater produced increased solubility and uptake of PAHs by fish. The increased freshwater solubility was more pronounced for low molecular weight 2- and 3-ringed PAH homologues relative to higher weight 4-ringed PAHs such as pyrene (Ramachandran et al. 2006). These findings may have implications for assessing bioavailability of oil components in different habitats as oil drifting into less saline coastal and estuarine areas becomes more bioavailable.

TOXICITY OF CONTAMINANTS

Toxicity can be defined as the negative effects on organisms caused by exposure to a chemical or other substance that may be lethal or sublethal. The concept of bioavailability is also important in determining toxicity which occurs when substances are absorbed by an organism and interact metabolically to cause harm. Both the chemical and physical characteristics of a substance in the environment determine its bioavailability. The concentration and duration of exposure also determine toxicity. Exposure can be acute (i.e., short period) or chronic (i.e., prolonged period). Typically, acute toxicity is measured in laboratory studies for fish over 24, 48 and 96 hours. Common acute toxicity testing employs the LC50 test which assesses the concentration of a toxicant that causes mortality to half of the test population under standard conditions (Dupuis and Ucan-Marin 2015).

Sublethal endpoints are also important measures of toxicity and may be identified by external and internal lesions, developmental abnormalities in early-life stages, or abnormal molecular-level activity, and behavioural changes in feeding and breeding. Toxic effects may eventually lead to death of the individual but, in many cases, sublethal effects cause change in populations without directly causing mortality of individuals. Delayed effects are also possible when an organism is exposed to a substance acutely and begins to exhibit measurable effects after a period of time. Sometimes long-term exposure leads to effects that are observed only later in life or in subsequent generations and may result from bioaccumulation (Dupuis and Ucan-Marin 2015).

The toxicity of oil to aquatic species depends on the extent of exposure to the toxic components, concentration, and life stage. In general, light oils higher in low molecular weight narcotic compounds, such as BTEX, are more lethal than medium or heavy oils. Heavy fuel oils with high proportions of 3- to 5-ringed alkyl PAHs disrupt embryonic development more than light oils (Lee et al. 2015). The concentration of polar and heterocyclic compounds in toxicity tests are rarely measured, so potential effects of these compounds (e.g., endocrine disruption) are not often assessed. Spills of diluted bitumen have raised concerns about toxicity as studies found signs of chronic effects on embryos at concentrations consistent with its alkyl PAH level (Lee et al. 2015)

LETHAL EFFECTS

Embryo and larval life stages of fish are more sensitive to oil toxicity than adults possibly due to smaller size, less developed metabolic capability and differences in cell permeability. They are also less mobile and unable to actively avoid spill areas. Also, many groundfish species have pelagic eggs and larvae that can be exposed to oil near the surface or in the water column. A range of concentrations of hydrocarbons has been found to cause mortality in fish. Very low concentrations of aqueous PAHs, in the parts per billion range, have been shown to cause mortality to early-life stages of fish. Carls et al. (1999) found that TPAH (0.7-7.6 ppb) caused mortality when Pacific Herring (*Clupea pallasi*) eggs were exposed to weathered Alaska North Slope crude oil. Similarly, The National Research Council (2005) reviewed publications reporting LC50s (from 24 to 96 h tests) resulting in larval fish mortality when exposed to chemically dispersed oil and using water-accommodated fractions ranging from 0.045 to 40.20 mg TPAH/L.

Lethal effects are manifest through narcosis which refers to the many possible biochemical reactions that may occur following ingestion of a toxicant. In aquatic organisms, narcosis is reversible and is similar to over anesthesia resulting from hydrophobic chemicals, partitioning into cell membranes and nervous tissue, disrupting central nervous system functions (Barron et al. 2004). Narcotic organic chemicals, such as individual components of oil, appear to be additively toxic related directly to the fraction of lipid-soluble hydrocarbons and their capacity to bio-concentrate (Dupuis and Urcan-Marin 2015). Although narcosis usually occurs within hours of a spill, delayed mortality is also possible, with effects appearing months later.

SUBLETHAL EFFECTS

Early-life stages of fish have low mobility and an inability to avoid contaminated areas making them very sensitive to oil exposure. In some species, the eggs are deposited on sediments where some of their development occurs and can elicit a toxic response if the sediments are already or subsequently contaminated. Other species, whose eggs float at or near the surface of the water showed a different toxic response compared to sinking eggs possibly due to exposure to different fractions of crude oil within the water column (Irie et al. 2011). Other research found that fish embryos and larvae are more susceptible to PAH exposure than juveniles and adults due to greater bioaccumulation in the early-life stages because of lower metabolism and higher lipid content (Petersen and Kristensen 1998). McIntosh et al. (2010) studied chemically dispersed oil toxicity in gametes, embryos and free-swimming embryos of Atlantic herring (*Clupea harengus*) finding that sensitivity to exposure was highest immediately following fertilization, decreasing with embryo age but then increasing again following hatching.

Harmful effects in early-life stages of fish can potentially lead to population-level effects. The decline in the Pacific Herring population in Prince William Sound, Alaska may be a result of harmful effects on embryos from the 1989 Exxon-Valdez oil spill. It was estimated that 25-32% of Pacific Herring embryos may have been damaged by the oil exposure (Carls et al. 2002). Similarly, the spawning of several pelagic fish species overlapped with the Deepwater Horizon spill in the Gulf of Mexico in 2010. Experiments on early-life stages of Atlantic bluefin tuna (*Thunnus thynnus*), yellowfin tuna (*Thunnus albacares*) and greater amberjack (*Seriola dumerili*) showed harmful effects when exposed to comparable oil (Incardona et al. 2014). The oil exposure was shown to cause harm to cardiac function and development potentially leading to broader impacts in wild populations (Incardona et al. 2014).

Deformities are a commonly observed effect of oil exposure in early-life stages of fish. Field collections of Pacific Herring larvae following the *Exxon-Valdez* spill showed an elevated proportion of larvae with skeletal defects, including reduced and abnormal jaw structures and abnormal otic capsules, compared to control fish from uncontaminated regions (Hose et al. 1996). Laboratory experiments have also shown relationships between hydrocarbon exposure and deformities in fish embryos and larvae (Boudreau et al. 2009; Incardona et al., 2014). A consistent finding in these studies is a suite of symptoms referred to as blue sac disease (BSD) often associated with developmental abnormalities including reduced growth, fluid accumulation in the yolk sac (edemas), pericardial edemas, spinal abnormalities, hemorrhages and mortality (Brinkworth et al. 2003; Boudreau et al. 2009). In a recent study, embryos of tunas and amberjacks developed pericardial edemas, deformed fins, curvatures in the body axis and reduced growth of eyes when exposed to concentrations of total PAHs ranging from 3.4-13.8 µg/L (Incardona et al. 2014). Similar effects would be expected to occur in Pacific Herring under comparable exposures.

Cardiotoxicity and deformities in early-life stages appears to be a common observation across several types of oils, and across many marine and freshwater fish species suggesting that underlying mechanisms are highly conserved across species (Dupuis and Ucan-Marin 2015). Wu et al. (2012) showed that characteristics of BSD were similar between four weathered light to medium crude oils for exposed rainbow trout embryos based on PAH concentration. Incardona et al. (2013) found indistinguishable differences in cardiotoxicity and morphological abnormalities in zebrafish (*Danio rerio*) exposed to crude oil from the Deepwater Horizon and *Exxon-Valdez* spills indicating similar toxicity for the two oil types.

Many of the toxic responses that have been documented in early-life stages of fish have been associated with binding of oil components to aryl hydrocarbon receptors (AhRs). The toxic mechanism of chemical binding to the aryl hydrocarbon receptor is not fully understood but involves cytochrome P4501A (CYP1A) protein induction. The ability of groups of invertebrates and vertebrates to metabolize and excrete PAHs is related to the binding of some PAHs to aryl receptors (Dupuis and Ucan-Marin 2015). Fish are able to metabolize non-chlorinated PAHs by activating transcription of genes such as the *cyp1a* leading to the increased synthesis of CYP1A proteins that transforms them into more soluble and readily excreted compounds (Dupuis and Ucan-Marin 2015). Binding of PAH to AhR can cause continuous or inappropriate expression of some of these genes, resulting in harm particularly during developmental stages. Toxicity can also occur from oxidative stress when reactive oxygen species are produced during metabolism of PAHs by CYP1A enzymes.

Cardiotoxicity has also been related to the disruption of heart conduction and the activation of the aryl hydrocarbon receptor in cardiac tissues. Three-ringed PAHs (e.g., fluorenes, dibenzothiophenes, phenanthrene) may cause direct toxicity to the developing heart of fish embryos by blocking potassium and calcium ion channels in cardiomyocytes (Brette et al. 2014). It causes disruption of normal electrical excitation and contraction in cardiac tissues leading to increases in action potential duration, a predictor of lethal cardiac arrhythmia (Brette et al. 2014). It was also shown that disruption of heart conduction and heartbeat preceded morphological deformities of the heart, pericardial and yolk-sac edemas, craniofacial malformations, body axis curvatures and fin shape defects (Incardona et al. 2014). These sublethal effects could lead to decreased growth and survival of juveniles.

Solar radiation also enhances toxicity of hydrocarbons in two ways: photooxidation occurs when sunlight produces soluble oxidized compounds from weathered oil while phototoxicity occurs internally after uptake of PAH. Photo-oxidized oil may produce several toxicants such as hyperperoxides, phenols, carboxylic acids and ketones (Dupuis and Ucan-Marin 2015). Phototoxicity results from the absorption of ultraviolet radiation by PAH and alkyl-PAH producing reactive oxygen compounds or chemical modifications in translucent embryos and larvae within the marine photic zone.

Recent evidence indicates that some PAHs may disrupt endocrine function and interfere with aspects of reproductive physiology. The extent of the impact is not known but may depend on the proportion of the population exposed. Studies of Dolly Varden Trout (*Salvelinus malma*) collected in regions affected by the *Exxon-Valdez* oil spill, found that 20% of the population showed depressed 17β-estradiol compared to 10% the following year (Sol et al. 2000). Other studies have found that exposure to low molecular weight PAHs can cause delays in sexual maturation and reduced gonadal growth. Exposure of Atlantic cod (*Gadus morhua*) to low concentrations of fractions of crude oil (mean of 15-49 ppb total hydrocarbon) for 38-92 days disrupted gonadal growth and delayed spermatogenesis in males (Khan 2012).

Endocrine disrupting chemicals can also alter concentrations of sex hormones in plasma. An effect of PAHs on plasma hormones is reduction of concentrations of 17β-estradiol which regulates the synthesis of vitellogenin, a protein necessary for oocyte maturation and yolk incorporation (Goksøyr 2006). PAHs such as phenanthrene, chrysene and naphthalene can cause a reduction in plasma 17β-estradiol concentrations in fish (Monteiro et al. 2000). A study of female English Sole (*Parophrys vetulus*) collected from contaminated sites in Puget Sound, Washington, showed depressed levels of plasma estradiol and higher incidence of inhibited ovarian development compared to control fish suggesting that depressed levels of sex hormones resulting from PAH exposure may lead to reduced spawning success (Johnson et al. 1988). There is some evidence that hydrocarbons may mimic hormones binding to estrogen receptors causing activation or inhibition of the receptor to disrupt regulation of genes involved in reproduction and sexual differentiation (Goksøyr 2006). Some PAH metabolites may compete against estradiol for estrogen receptors inhibiting synthesis of vitellogenin. Endocrine disruption in fish may also result from interference of the transport of natural hormones in plasma (Goksøyr 2006). PAHs have been shown to bind to sex steroid-binding proteins that play a role in circulating steroids in plasma. Tollefsen et al. (2011) suggest this increase in binding capacity leads to a decrease in bioavailable estradiol in the plasma causing disruption in hormone-regulated processes.

Petroleum hydrocarbons may also impact the normal function of gills. Rainbow trout exposed to an oil–water emulsion showed impairment of osmoregulation while other studies found morphological changes to gills following exposure including swelling of epithelial cells, epithelial lifting, hyperplasia, aneurisms, proliferation of mucocytes, and lamellar fusions (Dupuis and Ucan-Marin 2015). The structural alterations of the gills affect the regulation of ions and other physiological functions such as gas exchange resulting in hypoxemia and a decreased survival in low oxygen environments.

Hydrocarbons also affect normal metabolic functions disrupting fish growth. Experiments in mesocosms with oil-contaminated water and sediments resulted in reduced flatfish growth for months after exposure. Cellular adenosine triphosphate (ATP) and adenosine diphosphate (ADP) levels were depleted and were related to structural changes in gill epithelium and decreased contractibility of heart muscle. Other studies found that oil exposure disrupts active rates more than basal rates producing a net decrease in metabolic scope (Davoodi and Claireaux 2007). Similarly, oil has been shown to affect swimming abilities through sublethal effects on heart function and morphology (Brette et al. 2014; Incardona et al. 2014). These effects could affect survival by impacting the ability of predatory fish to reach speeds required for feeding. Studies also found other aspects of performance can be altered as a result of impaired energy budget or respiration. The ability of Pacific Herring to recover from bursts of swimming was impacted at low oil concentrations and effects increased in severity with increasing concentration and duration of oil exposure (Kennedy and Farrell 2006). Similar results were found for Coho Salmon (*Oncorhynchus kisutch*) even at low oil concentrations (Thomas and Rice 1987).

Exposure to hydrocarbons can damage genetic material including gamete loss and decrease in reproductive success, abnormal development, cancer, mutations leading to embryo mortality and changes in genetic diversity (Würgler and Kramers 1992). Long term exposure to PAHs and alkylated PAHs can cause genotoxicity. Benzopyrene is recognized as a PAH causing genetic damage in fish (Dupuis and Ucan-Marin 2015). Genotoxic impacts of PAH exposure to individuals and populations are not fully understood and some argue effects on populations are minimal given selective forces. However, studies post *Exxon-Valdez* found herring larvae that hatched from eggs exposed to crude oil had elevated probability of genetic damage, which could have contributed to decreases in survival (Hose et al. 1996; Hose and Brown 1998; Carls et al. 1999). There is also some evidence that genotoxicants like benzopyrene can impact subsequent generations through delayed effects on reproduction (Dupuis and Ucan-Marin 2015).

Genetic damage can also manifest itself as neoplasia (tumours) that may lead to cancers and studies have shown that fish inhabiting areas with contaminated sediments show higher frequency of liver and skin tumours (Dupuis and Ucan-Marin 2015). Benthic species are more likely to be affected due to closer contact with contaminated sediments and areas with high rates of neoplasia are often urbanized and industrial and subject to other stressors. However, few laboratory studies have shown a direct linkage between PAHs and tumour formation (Dupuis and Ucan-Marin 2015).

Genotoxicants can cause DNA damage and chromosomal alteration. Researchers studying Turbot (*Scophthalmus maximus*) and Atlantic Cod exposed to 0.5 ppm crude oil for three weeks showed significant increases in micronuclei in erythrocytes and other abnormalities of cellular nuclei in both species. Experiments following the *Exxon-Valdez* spill also showed that exposure to crude oil caused genetic damage in post-hatch Pacific Herring, as well as sublethal effects such as deformities (Hose et al. 1996). Newly-hatched larvae and incubated eggs from oil-affected areas had higher anaphase aberration rates relative to control sites. The ability to metabolize PAHs is believed to be the mechanism leading to DNA damage. PAH metabolism increases solubility of the metabolites and facilitates excretion but genotoxic metabolites may be formed in this process. DNA adducts (segments of DNA bound to a cancer-causing chemical) have been found in samples of fish from contaminated sites (Dupuis and Ucan-Marin 2015).

Exposure to oil and PAH has resulted in an immunotoxic response across species of invertebrates, fishes, birds and mammals. The effects are generally correlated with PAH components of oil and most studies have investigated 7,12-dimethylbenzanthracene, benzopyrene and 3-methylcholanthrene (Reynaud and Deschaux 2006). Immunotoxic responses to exposures across species are immunosuppression, inflammation, hemolytic anemia, decreased leukocytes and phagocytes, and impaired phagocytosis (see Reynaud and Deschaux 2006). Pacific Herring was a focus of research following the 1989 *Exxon-Valdez* spill and adult herring showed greater occurrence of liver damage from oil in affected regions compared to controls (Marty et al. 1999). Some authors have suggested that this liver damage may have resulted from increased susceptibility to viral infections in fish that were exposed to crude oil (Marty et al. 1999; Carls et al. 2002). T-lymphocytes are the primary cell type involved in cell-mediated immune response in fish and PAH exposure has caused both increases and decreases in their production which may be species dependent or a function of the tested compound (Reynaud and Deschaux 2006). Other immunotoxic responses to hydrocarbons include external lesions of fish gills, skin and fins and may represent opportunistic infections resulting from immunosuppression caused by exposure to PAHs (Dupuis and Ucan-Marin 2015). Some studies show that PAH exposure can compromise resistance to pathogens in fish. A laboratory experiment administered sublethal doses of PAH to juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) that had an increased susceptibility to a subsequent exposure to the bacterium pathogen, *Vibrio anguillarum* (Arkoosh and Casillas 1998). Similarly, Pacific Herring in Prince William Sound exhibited extensive lesions when becoming infected by viral hemorrhagic septicemia virus and *Ichthyophonus* sp. following the *Exxon-Valdez* spill (Marty et al. 2003).

Limited information suggests that some fish species may alter their behaviour to avoid oil. A few studies have shown that adult and juvenile Coho Salmon avoid monocyclic aromatic hydrocarbons, likely using their olfactory system (Maynard and Weber 1981; Weber et al. 1981). In laboratory experiments, Rice (1973) found that Pink Salmon fry avoided Prudhoe Bay crude oil above a threshold concentration of 1.6 mg/L in seawater. It is possible that these changes in behaviour in response to the presence of oil could be harmful to salmon populations by disrupting fish movement and seasonal migration. Exposure to waterborne and sediment-bound PAHs was also found to cause lethargy and other behavioural changes including anxiety level (Gonçalves et al., 2008). Further, observations of Pacific Herring behaviour following the *Nestucca* oil spill demonstrated a displacement from their typical spawning sites along the northwest shoreline of Barkley Sound that was impacted by oil to adjacent islands, a pattern not observed previously or since (Davis 1989).

PACIFIC HERRING

Pacific herring (*Clupea pallasii*) is found on the continental shelf and in coastal waters of the Pacific Ocean from Baja California in Mexico, northward along the North American coast to at least the Beaufort Sea in the Arctic Ocean (Hourston and Haegele 1980). On the Asian east coast, it is found from Korfu Bay throughout Kamchatka and the Sea of Okhotsk, throughout

Japan and as far south as Korea (Haegele and Schweigert 1985). Abundance on the eastern side of the Pacific is centered on the British Columbia coast between Puget Sound and Dixon Entrance in the north. Herring spawning occurs throughout the coast in BC, including the east and west coasts of Vancouver Island, many of the smaller islands in Georgia and Johnstone Straits, and along the mainland coast from the Washington to the Alaska borders including many of the coastal islands as well as Haida Gwaii (Haegele and Schweigert 1985). In excess of 3000 km of coastline have been utilized for spawning in BC at some time, and annually Pacific Herring deposit eggs along an average of 400 km of shoreline.

Pacific Herring follow a south to north cline in spawn timing. Spawning may begin in November in California and occur as late as July in Kotzebue Sound in Northern Alaska. Spawn timing also varies inter-annually within any major geographical area and may be partly related to temperature. Hay (1985) reported that spawning occurs in BC at water temperatures ranging from 6-11°C. Peak spawning activity generally occurs within a 3 to 6 wk period, but may extend over 2 months, typically March and April in BC (Haegele and Schweigert 1985). Initial and concluding spawns are generally quite small, while spawns in the peak period are extensive. Within the peak period, there may be two major waves or episodes separated by a 2 to 4 wk time period. In BC, the spawns of the first wave tend to be larger involving about three quarters of the spawning population in the area and usually consists of the larger older fish. The very earliest and latest spawning events are often associated with what are believed to be non-migratory resident stocks (Haegele and Schweigert 1985). On Haida Gwaii, spawns are always early (early March) in Naden Harbour and always late (mid-May) in Skidegate Inlet, while the majority of the spawning in other sounds and inlets of the islands, occurs in April (Hourston 1980; Hourston and Haegele 1980). In central BC, the stocks spawning in Burke Channel always do so in late May and early June, while on the outer coast at the entrance to this channel spawning occurs from mid-March to mid-April. Thus, there are some exceptions to the general cline in spawning time with latitude.

Throughout their range Pacific Herring spawn under very similar conditions and shorelines. Spawning rarely occurs on the open coastline but is restricted to inlets, sounds, bays, and estuaries that are somewhat sheltered from the open ocean. Some bays, inlets and stretches of coastline are used occasionally and many areas are never used although they appear to be ideal spawning habitat (Taylor 1964). The type of vegetation or substrate used depends mainly on the type of spawning locality. In sheltered bays and along sandy beaches the dominant substrate is eelgrass (*Zostera marina* and *Phyllospadix scoulerii*), along rocky shores it is typically rockweed (*Fucus distuchus*), and in some localities, such as the Strait of Georgia, sargassum (*Sargassum muticum*), a brown alga, while on the west coast of Vancouver Island, filamentous and foliose red algae are common spawning substrates. Some spawning events in slightly deeper water occur occasionally on broad leafed kelp (*Agarum* or *Laminaria sp.*), large brown alga, or on Haida Gwaii, on the giant kelp, *Macrocystis sp*. (Haegele et al. 1981; Haegele and Schweigert 1985).

Spawning occurs on the vegetation in sheltered bays, along steep or shelving rocky shores, or along open sand beaches. Herring eggs and sperm have a tolerance for a wide range of temperature and salinity, although most spawning takes place over a narrow range. Laboratory experiments found that the maximum viable hatch occurred at 8.3°C and between 12 and 26% salinity, while the lower thermal tolerance limit for eggs was 4°C (Alderice and Velsen 1971;

Alderdice and Hourston 1985). The sperm are able to survive for 4 days at salinities of 17-33%, and only below 5% does fertilization decrease markedly (Galkina1957). Measured spawning ground temperatures in British Columbia ranged from 6.5 to 9.8°C and salinities from 22.4 to 28.7% (Outram 1975; Hay et al. 1984). Changes in salinity ranging from 6 to 34% during the incubation period do not appear to adversely affect egg development (McMynn and Hoar 1953).

Pacific Herring eggs are adhesive and deposition occurs on vegetation in or immediately below the intertidal zone along the BC coast. About 80 percent of the egg deposition occurs at depths shallower than -1.5 m datum (approx. 6 m below high water). The density of egg deposition decreases rapidly at deeper depths but may extend to 25 m below high water (Hourston and Haegele 1980). Egg depositions at these depths have always been extensions of shallower spawns. Egg depositions usually range between 1 and 4 layers in thickness. However, if spawning is intense, eggs may be deposited in several to upwards of 20 layers. Experiments have found that hatching success decreases sharply with increasing egg thickness, so the numbers of healthy larvae hatching from an egg bed with 9 layers will be less than one with 4 layers of eggs. If the spawn is much thicker, all of the eggs may die from lack of oxygen (Hourston and Haegele 1980). Often the very heavy egg depositions become prone to fungal growths that lead to extensive egg mortality. Intertidal exposure also stresses the eggs from dehydration and fluctuations in temperature and salinity that can increase pre-hatching mortality. Jones (1972) estimated that pre-hatching mortality increased from 13% to 31% with twice daily 8-hour exposures. Predation is also significant on most herring egg beds particularly by gulls at low tide (Hourston and Haegele 1980). In addition, scoters and other diving ducks feast on the deeper egg depositions and in some locations grey whales have been seen scooping egg mats from the bottom. Mortality of herring eggs from all causes has been estimated at roughly 10% per day in Alaska and BC (Rooper et al. 1999; Schweigert and Haegele 2001). Infrequently, storm and wave action may also tear vegetation and attached eggs loose and deposit them in windrows on the beach where mortality of the eggs will be extensive (Hay and Miller 1982).

Pacific herring eggs are spherical in shape with a diameter of about 1.5 mm, weighing about 0.002 g (Hourston and Haegele 1980). They are transparent in appearance and slightly denser than seawater. The incubation period ranges between 10 and 21 d after fertilization, depending on water temperature. At 8°C, incubation lasts about 2 weeks and by the 3rd day an embryo is visible under a microscope (Hourston and Haegele 1980). By the end of the 1st week, the head is well developed and its large eyes are evident to the naked eye. During the last week of incubation, the larva continues its development and growth, curling around the yolk, and moving about. Finally, it breaks out of the weakened egg membrane head first at the end of the incubation period. Hatching is virtually simultaneous for eggs deposited in a single spawning (Hourston and Haegele 1980).

The whitish, thread-like larvae are about 9 mm long when they hatch from the eggs. They are fragile, transparent, with big eyes and a large yolk sac swimming awkwardly in a snake-like manner (Hourston and Haegele 1980). Immediately after hatching, the larvae are nourished mainly from the yolk sac for about 6 days. At this point, they gain swimming ability and learn to feed on smaller plankton. Larval herring tend to be concentrated near the surface of the water, being carried passively by the currents and experiencing very high rates of mortality (Stevenson, 1962). The main predators are comb jellies and arrow worms but starvation may also be important at times. Larval herring appear to tolerate fairly wide ranges of temperature and salinity which are unlikely to cause serious mortality (Taylor 1964). Over the next month, the body deepens, becoming an opaque, whitish colour, with rudimentary fins appearing. At a length of about 25 mm (10 weeks post hatching), metamorphosis into the adult form occurs over about 3 weeks. The body takes the appearance of a miniature adult deepening, thickening and becoming pigmented while the scales appear on the skin (Hourston and Haegele 1980). A major cause of the large larval mortality may be movement of larvae out of the sheltered bays and inlets to areas where they are unable to find appropriate types of food.

The remainder of the first year of life (July - March) has been referred to as the juvenile stage. At this point, the young herring look like the adults with a deeply forked tail, soft-rayed fins, no teeth, and a protruding lower jaw. The back is blue-green, fading to silvery white on the sides while the lateral line is clearly evident (Hourston and Haegele 1980). At the completion of metamorphosis (June-July) the juveniles are about 35 mm in length and weigh about 5 g. They grow quickly over the summer, approaching 100 mm in length and weighing about 40 g by fall. Little or no growth occurs over the winter. During this transformation the juveniles begin to aggregate into increasingly larger schools in inshore protected waters of bays and inlets in the general vicinity of the spawning grounds (Hourston and Haegele 1980). In Barkley Sound, for example, the majority of the spawning occurs along northwest side (Macoah Passage) while the juveniles are found mainly in the southeast (Trevor Channel) area. During this time the schools will begin diurnal migrations into deeper waters during the day followed by shallower excursions at night following the movement of the plankton (Hourston and Haegele 1980). Beginning in September, these large schools, gradually move seaward to offshore wintering grounds where they are found mainly at depths of 150-200 m (Hourston and Haegele 1980). During their second summer, the immature herring increase in length and weight by as much as 50 percent (150 mm and 60 g). They remain in the same offshore feeding areas as the adults but at somewhat shallower depths (100-150 m) and appear to mix more with adult schools than with juveniles (Hourston and Haegele 1980).

Although a small proportion of the fish will become sexually mature at the end of their second year of life, the bulk of the herring in BC mature and spawn for the first time at the end of their third year having reached a length of about 185 mm and 90 g, while in northern BC a small proportion mature in their fourth or even fifth year (Taylor 1964). Unlike salmon, most herring do not die after spawning and will continue to grow in length and weight to between 175 and 250 mm in length and 70 to 200 g in weight between ages 4 and 7 or 8 (Hourston and Haegele 1980). Occasionally, herring may live to an age of 10 or older and they continue to spawn each spring. As the fish age they invest more of their energy into reproduction and the proportion of their body that consists of gonads increases from about 20 percent to over 30 percent at the oldest ages (Hay 1985). Herring ovaries begin to invest energy in the maturation of eggs in the fall in preparation for spawning in March. As a general rule, herring produce about 200 eggs/g of female weight that translates to roughly 20000-40000 eggs being produced by each female herring (Hay 1985).

All herring are migratory, travelling annually between summer feeding areas and spring spawning sites. Some migrations are relatively short from spawning sites at the head of an inlet to feeding areas near the mouth of the inlet while other migrations are extensive travelling from spawning sites in the middle of Georgia Strait to feeding areas off the west coast of Vancouver Island (Taylor 1964; Hay 1985). Adult herring are believed to leave the spawning areas shortly after releasing their eggs and milt returning to offshore feeding areas in April and May. The precise locations of the feeding areas are not known but appear to be on the continental shelf off the west coast of Vancouver Island in the south and within Hecate Strait in the north (Taylor 1964; Hourston and Haegele 1980). Over the summer the herring remain in the feeding areas accumulating fat for reproduction the following spring. In the fall, October-November, adult and some maturing sub-adult herring begin their inshore migrations congregating in large schools near the spawning grounds and then dispersing to ultimate spawning locations a few days to weeks prior to spawning (Haegele and Schweigert 1985). As spawning time approaches, these aggregations separate into dense fast-moving schools that approach the shore swimming rapidly and seemingly at random possibly sampling the local water and substrate (Hay 1985). The stimuli that ultimately initiate spawning are not well understood although spawning times are synchronized with water temperatures and in northern latitudes incubation temperatures must be above 6°C for spawning to occur (Haegele and Schweigert 1985). Laboratory studies demonstrated that pheromones in ripe testes stimulated behavioural and physiological responses leading to spawning. It is likely that the release of milt by males initiates spawning, and the females interact with the substrate to attach the sticky eggs, that are fertilized by milt that has been released broadly in the water column (Hay 1985). During active spawning the fish are so densely packed that some are pushed out of the water and easily captured by gulls. However, the widespread release of milt discolours the water to a milky or turquoise that is indicative of Pacific Herring spawning beds and also provides camouflage for the spawning fish (Haegele and Schweigert 1985).

Pacific Herring have been shown to home to the general area of spawning in subsequent years. The homing is not as precise as that found in Pacific salmon but nevertheless results in the concentration of spawning in a number of key locations that are revisited on an ongoing basis (Hay et al. 2001). However, it has also been found that some areas are used intermittently, with fish abandoning sites for up to a decade and then returning to the site in subsequent years (Ware and Tovey 2004). As a consequence, defining discrete populations for preservation and planning for fisheries management is complicated by the inability to predict or forecast precisely where herring are most likely to concentrate their spawning activity in any given year. Nevertheless, Fisheries and Oceans staff and others have monitored the timing, location, and extent of Pacific Herring spawning and egg deposition for almost a century permitting generalizations of the key or critical areas of the BC coast that should be protected from unintended introductions of toxicants (Hay and Kronlund 1987). The timing of spawning events and their locations are detailed below and in the appendices.

HERRING DISTRIBUTION AND ABUNDANCE

Fisheries and Oceans manages the Pacific Herring resource based on five major and two minor assessment regions consisting of major migratory populations (Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), and West Coast of Vancouver Island (WCVI)), and minor populations (Area 2W on the west coast of Haida Gwaii, Area 27 on the northwest coast of Vancouver Island), in addition to which there are many other populations in Johnstone Strait and elsewhere that are not assessed annually (Taylor 1964; Cleary et al. 2017, DFO 2021). The abundance of the assessed populations is determined annually using statistical catch-at-age models that incorporate information on the abundance and distribution of Pacific Herring spawn, age structure data from the collection of biological samples from the fishery landings and the population, and finally data on the total landings of Pacific Herring by location. The abundance of Pacific Herring in each area can fluctuate dramatically inter-annually due to the influx of first time spawning three-year old fish referred to as recruits or recruitment into the population (Figure 1). The abundance of Pacific Herring that are spawned in each area is determined by environmental conditions that affect the survival from the egg to the sexually mature stage and components of the ecosystem such as food, predators, and disease (Schweigert et al. 2010, 2013). In addition, human activities such as the fishery have an impact on the populations. The nature of the fishery and the landings have changed substantially over time. From the 1930s to the late 1960s, it consisted of a reduction fishery for oil and meal that harvested all ages of the populations at high rates with limited control (Taylor 1964). The collapse and closure of the fishery in 1968 was followed by the introduction of the current roe fishery in the early 1970s whose focus is on the reproductive component of the population using a more conservative harvest based on the precautionary approach (DFO 2021). Nevertheless, the populations in HG and WCVI have remained at reduced levels for almost two decades despite fishery closures while the SOG has remained near historic high levels with ongoing fisheries (Figure 1). Populations in PRD are reduced but stable while those in CC are increasing rapidly from recent lows. Unfortunately, data are not available at the localized scale that would permit modelling to estimate abundance by bay or inlet for oil spill response activities. However, information on the distribution and relative abundance of Pacific Herring egg deposition provides a proxy for biomass that can serve this function and is described below.

The distribution and relative abundance of Pacific Herring egg deposition has been monitored annually from as early as 1928 in parts of the BC coast and almost universally since at least 1950 (Hourston 1980). Hay and Kronlund (1987) reviewed the collection and reliability of the surface spawn data through to 1986 and developed a habitat index that reflected the importance of each one km section of the British Columbia coastline as herring spawning substrate (Hay et al. 1989, Volumes I-VI). The information was originally collected and reported at the level of location which refers to a general geographic entity representing a portion of shoreline and included the length, width, intensity and date of the observation of spawning activity. Usually, the observation included an attached map permitting the data to be georeferenced to standardized kilometre intervals of the BC coast. The data on spawning location could then be aggregated at a larger spatial scale referred to as the herring section which represented a subdivision of the Statistical Areas used for salmon management in BC. The herring sections can also be aggregated to Assessment Regions that represent the major herring populations or stocks that are managed as separate biological groups within these larger geographical areas.

Beginning in 1988 the bulk of the monitoring of spawn deposition was conducted using divers equipped with SCUBA. The objective was to collect more accurate estimates of spawning activity in the locations that supported the annual roe fishery because of concerns that the earlier surface-based surveys were unable to detect and quantify some of the deeper egg deposition (Haegele et al. 1981). Unfortunately, these surveys were more focused and concentrated in a shorter time window than earlier surface-based surveys and there are indications that some of the earliest and latest spawning events were not identified or surveyed. Additionally, in the early 1990s in many locations of the coast, Fishery Officers that had historically been involved in monitoring the timing and abundance of Pacific Herring egg deposition became more focused on enforcement duties further reducing the monitoring efforts that had occurred previously. Updated details of the spawning distribution to 2016 and the limitations of the data can be found here: https://waves-vagues.dfo-mpo.gc.ca/Library/349949.pdf. Hay and McCarter (2006) note that 19 percent or more of the BC coast has been used as Pacific Herring spawning substrate at some point over the past several decades but only 1-2 percent is used repetitively over many years and so these are the critical habitats that need to be preserved and protected along with immediately adjacent areas.

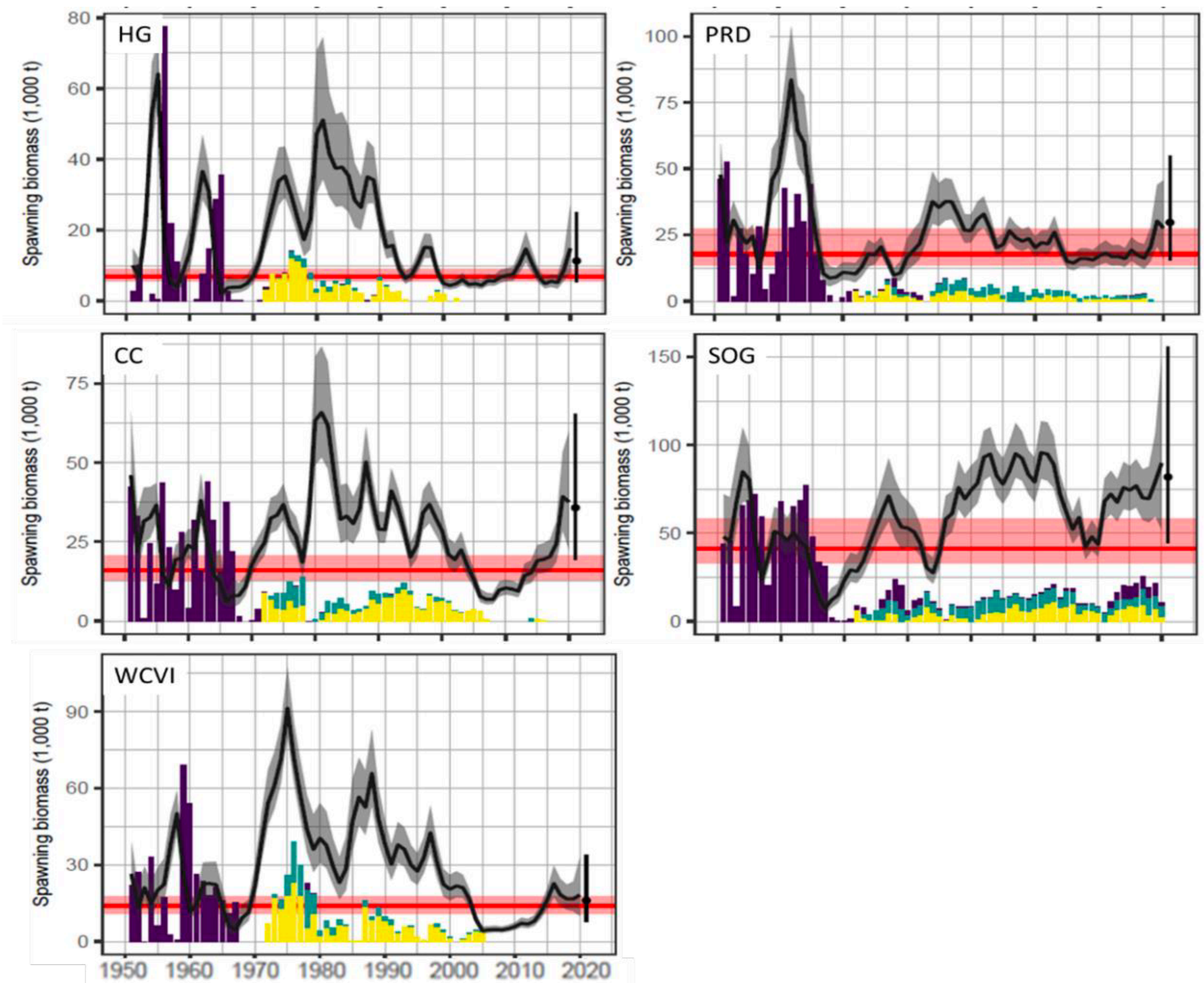


Figure 1. Summary of the dynamics of the five Pacific Herring stocks from 1951 to 2020, where solid lines with surrounding grey envelopes, represent medians and 5-95 % credible intervals. Also shown is the reconstruction of spawning biomass for each year, with unfished values shown at far left (solid circle and vertical lines) and the projected spawning biomass given zero catch shown at the far right (solid circle and vertical lines). Time series of thin vertical lines denote commercial catch (excluding commercial spawn-on-kelp; colours indicate different gear types; see DFO 2021). Red line= limit reference point (0.3B0). B0 = unfished biomass. Figure reproduced from Boldt et al. (2021).

HAIDA GWAII – STATISTICAL AREAS 0-2

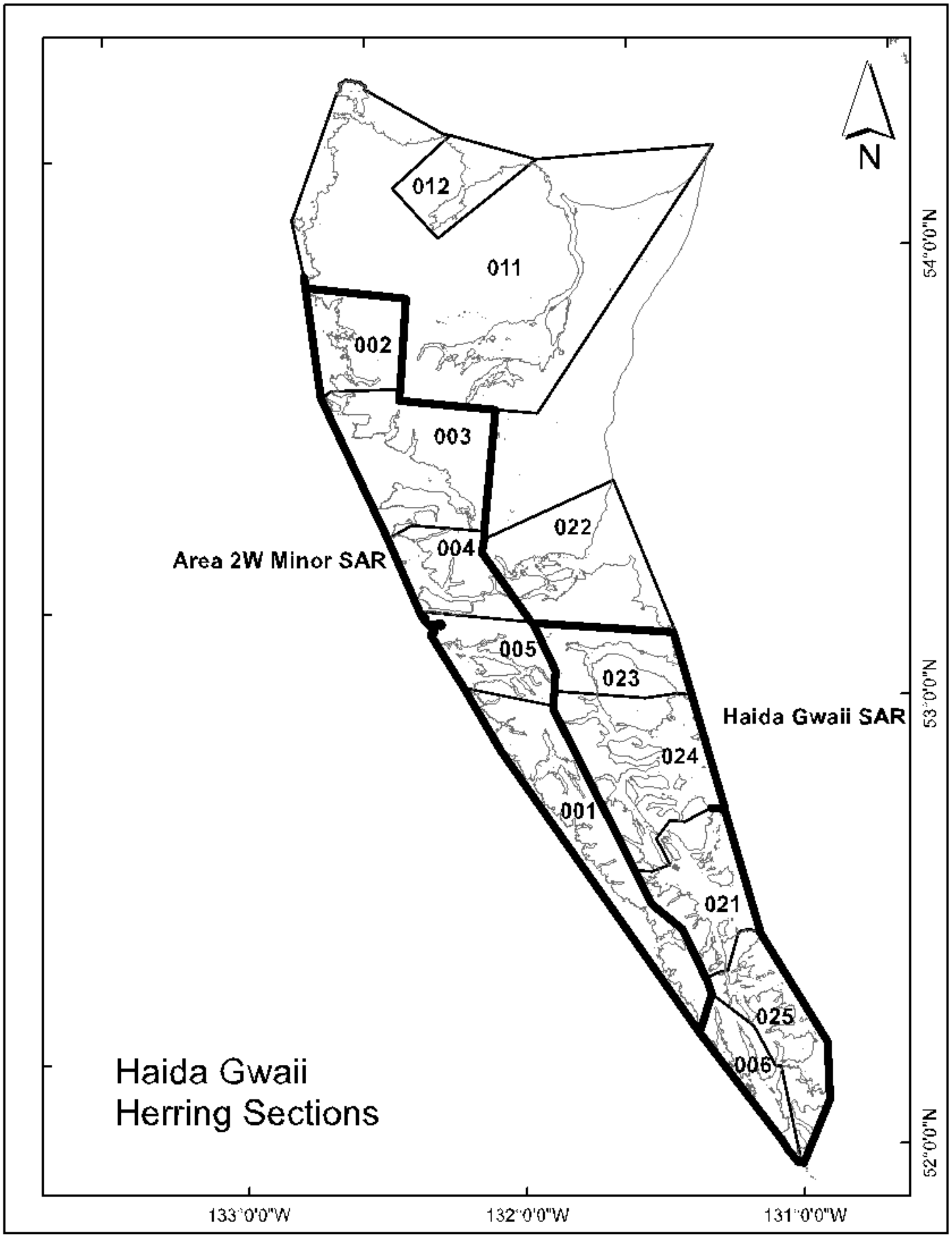


Figure 2. Pacific Herring Sections for Statistical Areas 0-2 in Haida Gwaii.

Pacific Herring spawning activity is widely distributed throughout Haida Gwaii (Figure 2) and has possibly the broadest range in spawn timing of any area of the BC coast which is a legacy of the last glaciation (Liu et al. 2011). Spawning may occur in Naden Harbour in early February while Massett Inlet often does not see spawning activity until well into June.

The spawning activity in Statistical Area 0 on the west coast of Haida Gwaii occurs predominately (70%) in three main locations: Port Louis (Section 002), Rennell Sound (Section 003), and Englefield Bay (Section 005) (Figure 3). The extent of the spawning and timing is described in detail in Appendix 1. Louscoone Inlet (Section 006) at the southern tip of Haida Gwaii is also important spawning habitat (20%) but forms part of the major migratory population on the east coast of the islands. The spawning in Louscoone Inlet may occur as early as February 26 but average timing varies between March 28 (Louscoone Inlet) to April 12 (Cartwright Sound) while it may occur as late as May 3 (Cartwright Sound and Englefield Bay). The distribution and behaviour of the young-of-the-year Pacific Herring is not well known but it seems likely that they remain in or near the inlets or bays where they hatched during their first year of life (Hay and McCarter 1997a, b). Subsequently, they may be expected to begin a movement into offshore waters to join the immature and adult populations. The offshore distribution of immature and adult herring is not well known in this area. Indications are that Pacific Herring distribution is constrained to a large degree to the continental shelf areas (Hay and McCarter 1997c) and given the restricted shelf area on the west coast of Haida Gwaii, the adult Pacific Herring either remain near their spawning areas or migrate north into Dixon Entrance or south to feeding grounds at the bottom end of the archipelago.

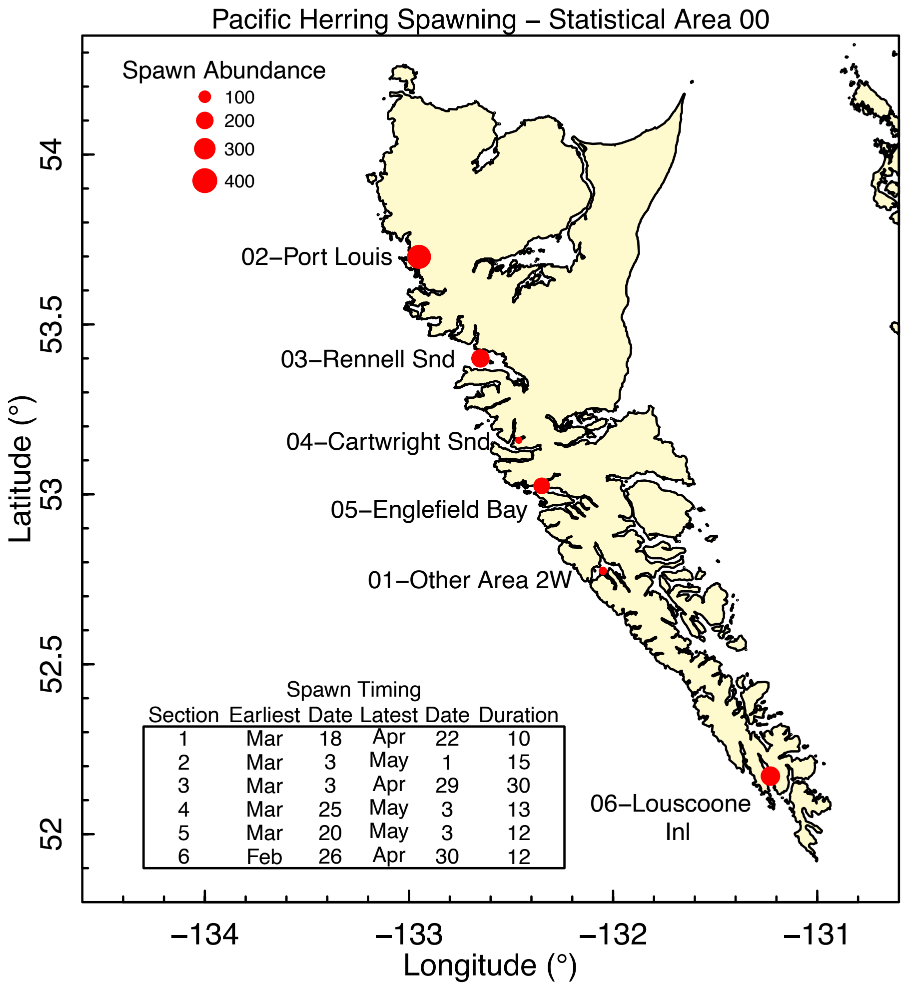


Figure 3. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 00. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

In Statistical Area 1, at the north end of Haida Gwaii spawning may occur as early as February 1 in Naden Harbour and on average occurs between March 9 (Naden Harbour) to June 24 in Massett Inlet but may occur as late as July 1 here (Figure 4, Appendix 1). The spawn deposition in these areas is less frequent and less extensive compared to either Statistical Areas 0 or 2. The distribution of the young-of-the-year Pacific Herring is likely constrained within Massett Inlet and Naden Harbour during their first year of life. Subsequently, they may be expected to begin a movement into offshore waters to join the immature and adult populations. The offshore distribution of immature and adult Pacific Herring is not well known in this area but it is likely that the adults either remain within the inlets or migrate out to Dixon Entrance to feeding grounds.

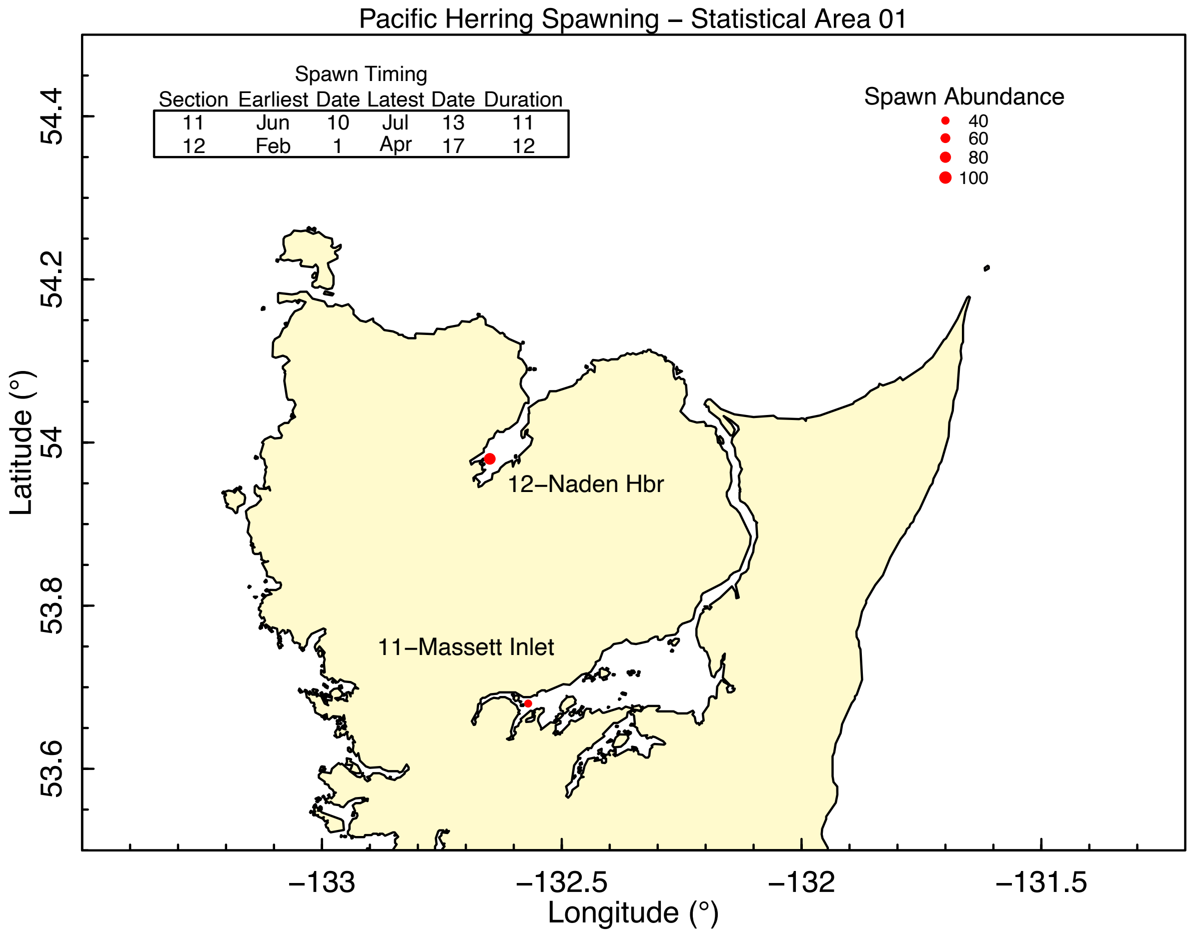


Figure 4. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 01. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

In Statistical Area 2, on the east coast of Haida Gwaii the most significant spawning activity (70%) is divided equally between Juan Perez Sound (Section 21) and Skincuttle Inlet (Section 25). However, extensive spawning also occurs in the other three sections (Figure 5, Appendix 1). The earliest observed spawning occurred in Laskeek Bay (Section 04) on February 3 while the average timing varies between March 27 in Skincuttle Inlet and April 23 in Cumshewa Inlet (Section 23). Spawning may occur as late as July 19 in Skidegate Inlet (Section 22). The distribution and behaviour of the young-of-the-year Pacific Herring is not well known but it is evident that they remain in or near the inlets or bays where they hatched during their first year of life (Hay and McCarter 1997a, b). Subsequently, they begin a movement into offshore waters to join the immature and adult populations that feed in Hecate Strait or into northern Queen Charlotte Sound (Hay and McCarter 1997c).

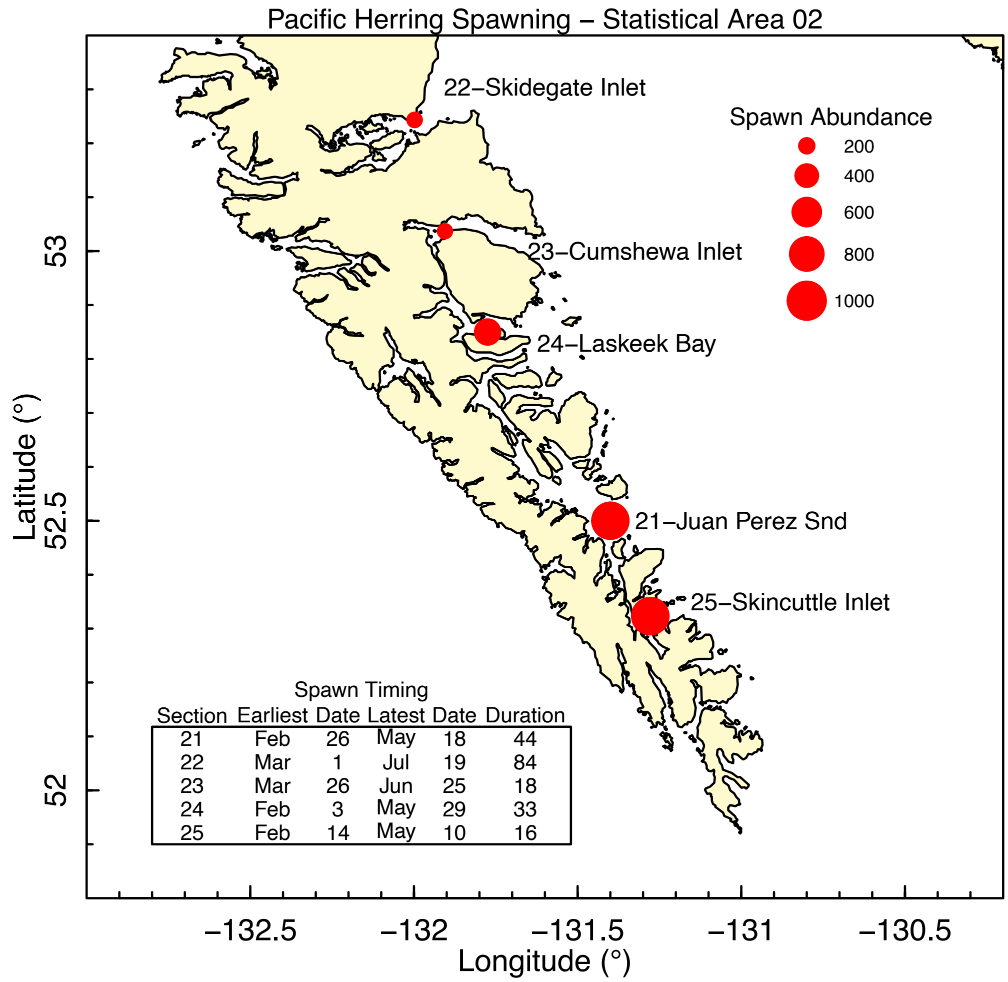


Figure 5. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 02. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

PRINCE RUPERT DISTRICT – STATISTICAL AREAS 03-05

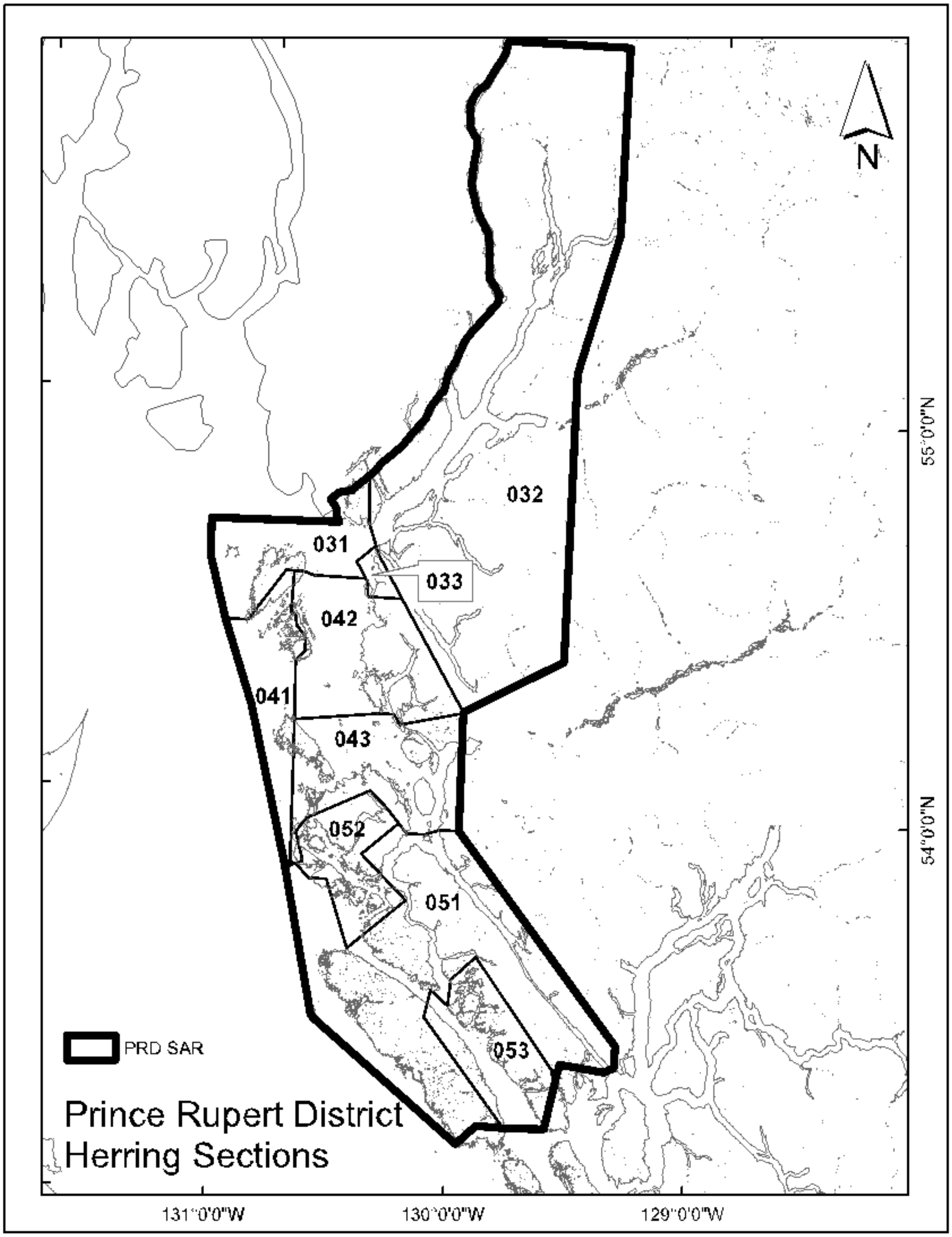


Figure 6. Pacific Herring Sections for Statistical Areas 3-5 in Prince Rupert District.

Pacific Herring spawning activity occurs in each of Statistical Areas 3 to 5 (Figure 6) with the bulk of it in Area 4 (Big Bay) and Area 5 (Kitkatla Inlet). The spawning in Statistical Area 3 occurs predominately in the Port Simpson (Section 33) area (Figure 7, Appendix 2). Spawning in Section 33 accounts for more than 90 percent of the recorded observations in Area 3. Spawning may occur as early as March 7 in Portland Inlet (Section 32) but average timing varies between March 27 and 28 in these two sections. Spawning may occur as late as June 3 in Section 32. The distribution of the larval and young-of-the-year Pacific Herring appears to be primarily inshore adjacent to the spawning areas (Hay and McCarter 1997a, b). Subsequently, juvenile Pacific Herring may be expected to begin a movement into offshore waters to join the immature and adult populations. The offshore distribution of immature and adult Pacific Herring is not well known in this area but they may be expected to remain in the Nass River plume to feed or migrate farther into Dixon Entrance and northern Hecate Strait.

In Statistical Area 4, the majority of spawning activity occurs in the vicinity of Prince Rupert (Section 42) and at the northern tip of Porcher Island at Hunt Inlet (Section 43). The spawning in Section 42 accounts for about 80 percent of the observations in the statistical area (Figure 7, Appendix 2). Spawning may occur as early as March 10 in Big Bay (Section 42) but average timing varies between April 1 (Section 42) and April 15 (Section 43) and may occur as late as June 28 in Section 42. The distribution of the larval and young-of-the-year Pacific Herring appears to be primarily inshore adjacent to the spawning areas of north Porcher Island and Duncan and Big Bays (Hay and McCarter 1997a, b). Subsequently, they may be expected to begin a movement into more offshore waters of Chatham Sound and the Skeena River estuary to join the immature and adult populations. The offshore distribution of immature and adult Pacific Herring is not well known in this area but they may be expected to remain in the estuary of the Skeena River or move out into Hecate Strait for feeding. Overwintering aggregations have been found to inhabit the vicinity of Browning Entrance near Porcher Island (McCarter et al. 1991).

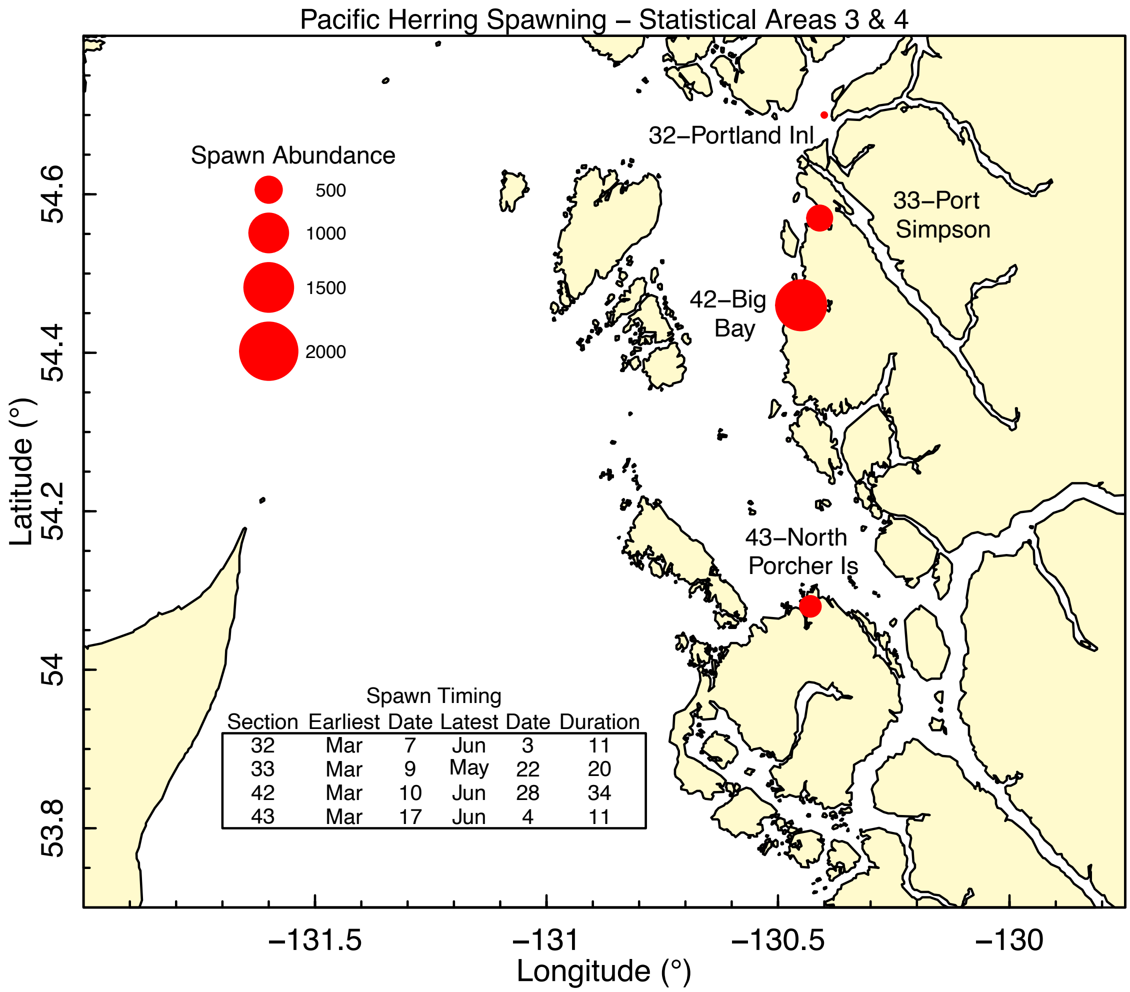


Figure 7. Map of the key Pacific Herring spawning locations in each Section in Statistical Areas 03 and 04. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

In Statistical Area 5, the great majority of spawning occurs in the vicinity of Kitkatla Inlet (Section 52) with much reduced amounts at Anger Island (Section 53) and Banks Island (Section 51). The spawning in Section 52 accounts for about 90 percent of the spawning in the statistical area with minor amounts in Section 51 and Section 53 (Figure 8, Appendix 2). Spawning may occur as early as March 7 in Kitkatla Inlet (Section 52) but on average occurs between April 8 (Section 52) and April 20 (Section 53). Spawning may occur as late as May 21 in Kitkatla Inlet (Section 52). The distribution of the larval and young-of-the-year Pacific Herring appears to be primarily inshore adjacent to the spawning areas at the mouth of or within Kitkatla Inlet or along the southwest shore of Porcher Island (Hay and McCarter 1997a, b). Subsequently, juvenile Pacific Herring may remain within the inlet or undertake movement into offshore waters to join the immature and adult populations in Browning Entrance or the broader Hecate Strait.

Overwintering aggregations have been found to inhabit the vicinity of Browning Entrance near Porcher Island (McCarter et al. 1991).

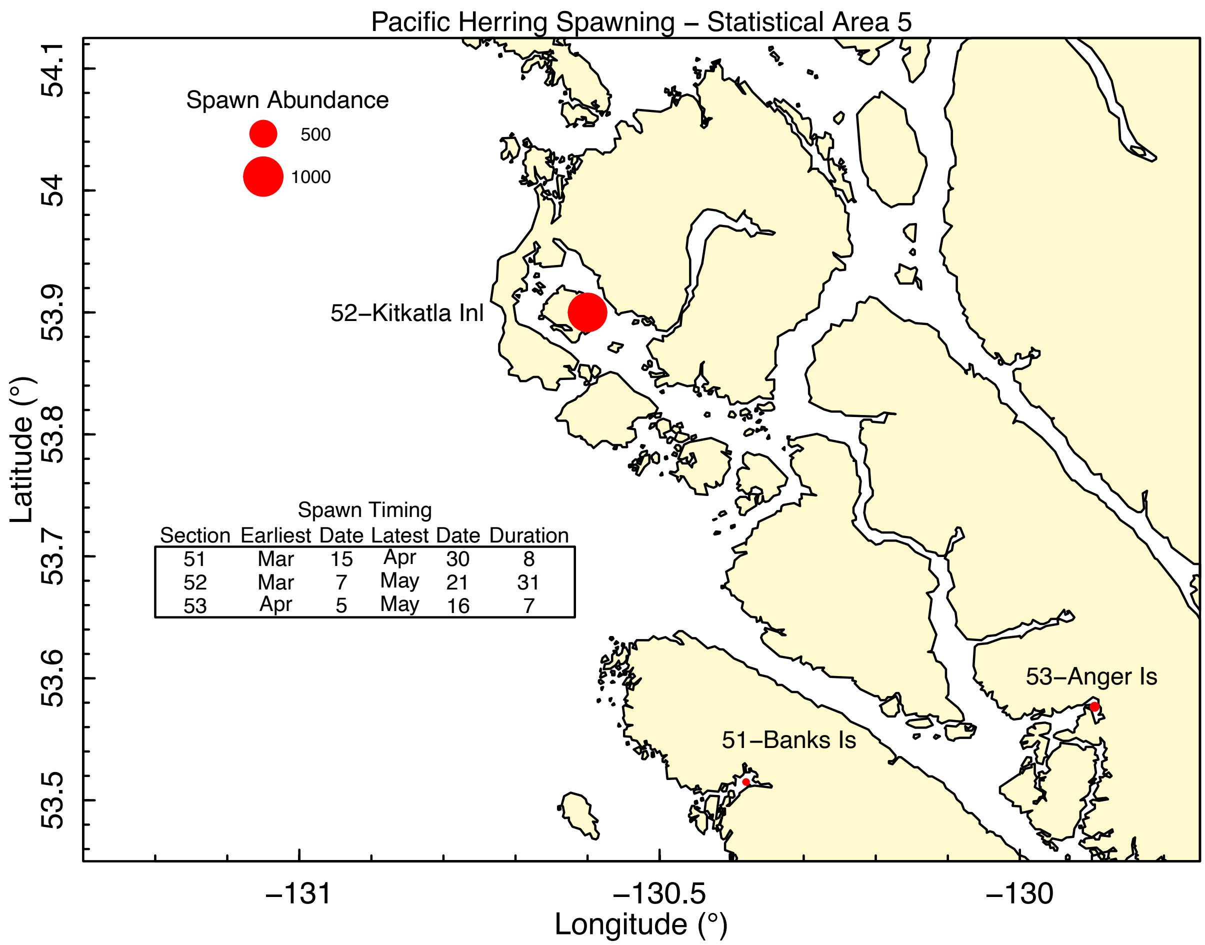


Figure 8. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 05. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

CENTRAL COAST – STATISTICAL AREAS 06-10

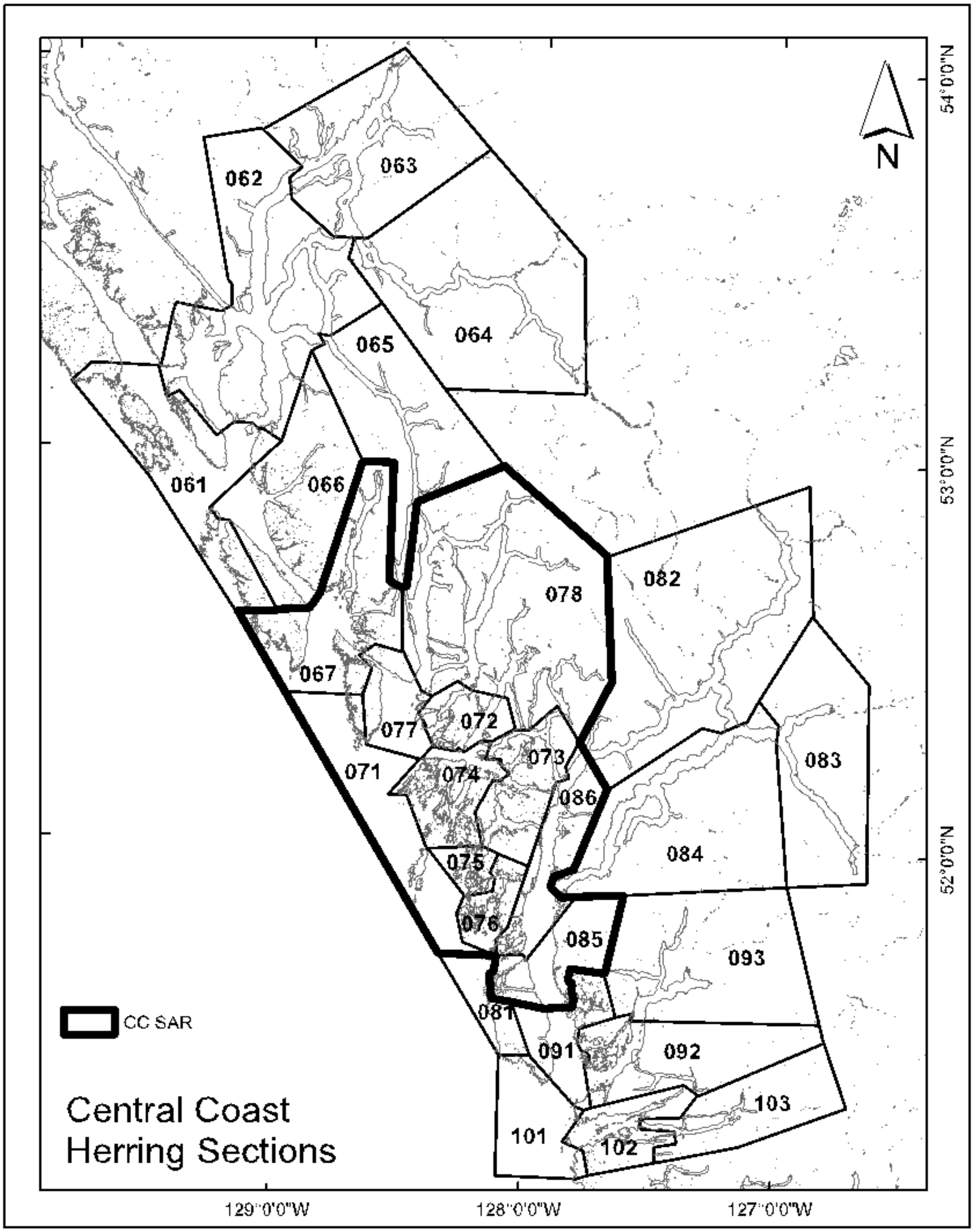


Figure 9. Pacific Herring Sections for Statistical Areas 6-10 in the Central Coast.

Pacific Herring spawning activity occurs in each of Statistical Areas 6 to 10 (Figure 9) with by far the majority occurring in Statistical Area 7 followed by areas 6, 8, 9 and 10 (Appendix 3). In Area 6 most of the spawning activity (83%) occurs in the vicinity of Kitasu Bay (Section 67), roughly twenty times the extent and frequency of that at either Gil Island (Section 62) or Kitimat Arm (Section 63) (Figure 10). Spawning in the other sections (Caamano Sound, Gardner Canal, Princess Royal Channel, and Surf Inlet) is relatively infrequent with fewer than 100 records over the past several decades (Appendix 3). Spawning may occur as early as February 5 in Kitimat Arm (Section 63) but on average varies between March 10 in Caamano Sound (Section 61) and May 15 at Gil Island (Section 62). Spawning may also occur as late as June 22 in Section 62. The distribution of the larval and young-of-the-year Pacific Herring is not well known in this area but appears to be primarily inshore adjacent to the spawning areas in Kitasu Bay (Section 67). In the other sections which encompass channels and inlets it is probable that larvae and young-of-the-year Pacific Herring remain entrained in the area and near the spawning sites. Young-of-the-year Pacific Herring in the vicinity of Kitasu Bay likely move offshore in their second year to join immature and adult schools that are feeding in Hecate Strait. The extent of movement of the young Pacific Herring in the other sections associated with inlets and channels is not known and these schools likely continue to feed within the inlets and channels and eventually join immature and adult schools as they grow and mature. There is some evidence that the adults may migrate to the mouths of inlets where upwelling and turbulence increases productivity and provides better feeding conditions and some may venture out into Hecate Strait proper.

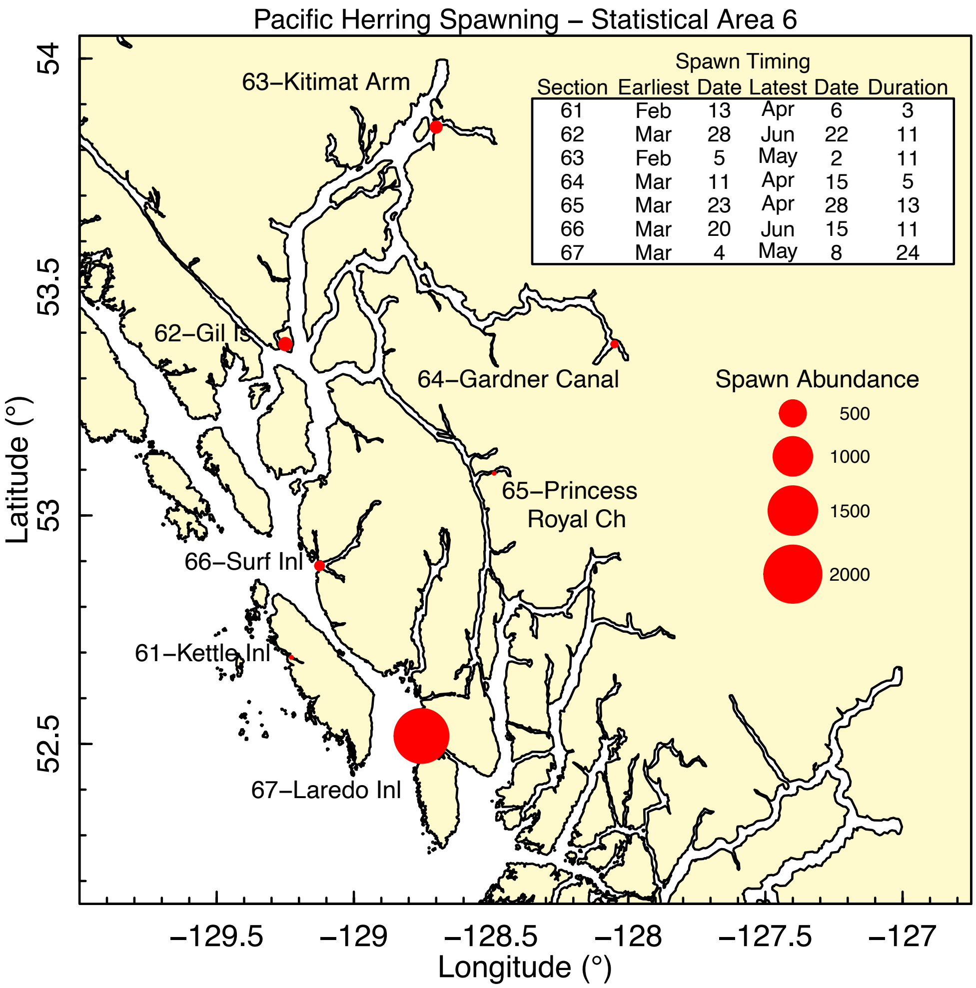


Figure 10. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 06. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

In Statistical Area 7, the majority of spawning activity occurs in Powell Anchorage (Section 72) and Thompson Bay (Section 74) followed by Mathieson/Spiller Channel (Section 78) and then Bella Bella (Section 73) and Kildidt Sound (Section 76). Lesser activity occurs in Milbanke Sound (Section 77) and the McNaughton Group (Section 75). The spawning in Sections 72 and 74 accounts for almost 60 percent of the total for the statistical area (Figure 11, Appendix 3). Section 78 accounts for an additional fifteen percent as do Sections 73 and 76 combined. Spawning may occur as early as February 19 in Thompson Bay (Section 74) but average timing varies between March 28 (Section 73 and 78) and April 3 (Section 75) and may occur as late as May 2 in Section 74. Larval and young-of-the-year Pacific Herring are widely distributed in this statistical area both near spawning sites and more broadly in the nearshore environment (Thompson et al. 2015). They appear to remain in the nearshore at least during their first year of life and subsequently move further offshore to join immature and adult schools feeding in

Milbanke and Queens Sounds and ultimately Hecate Strait.

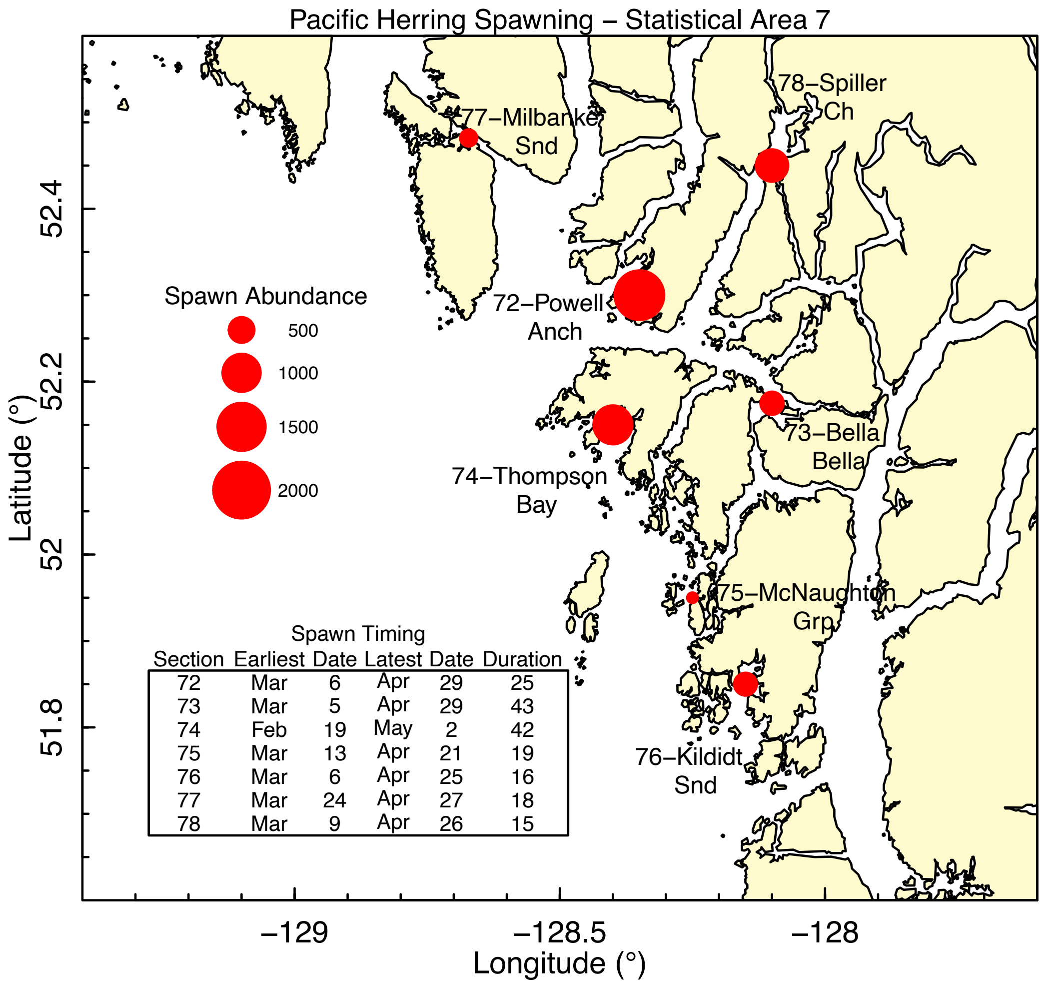
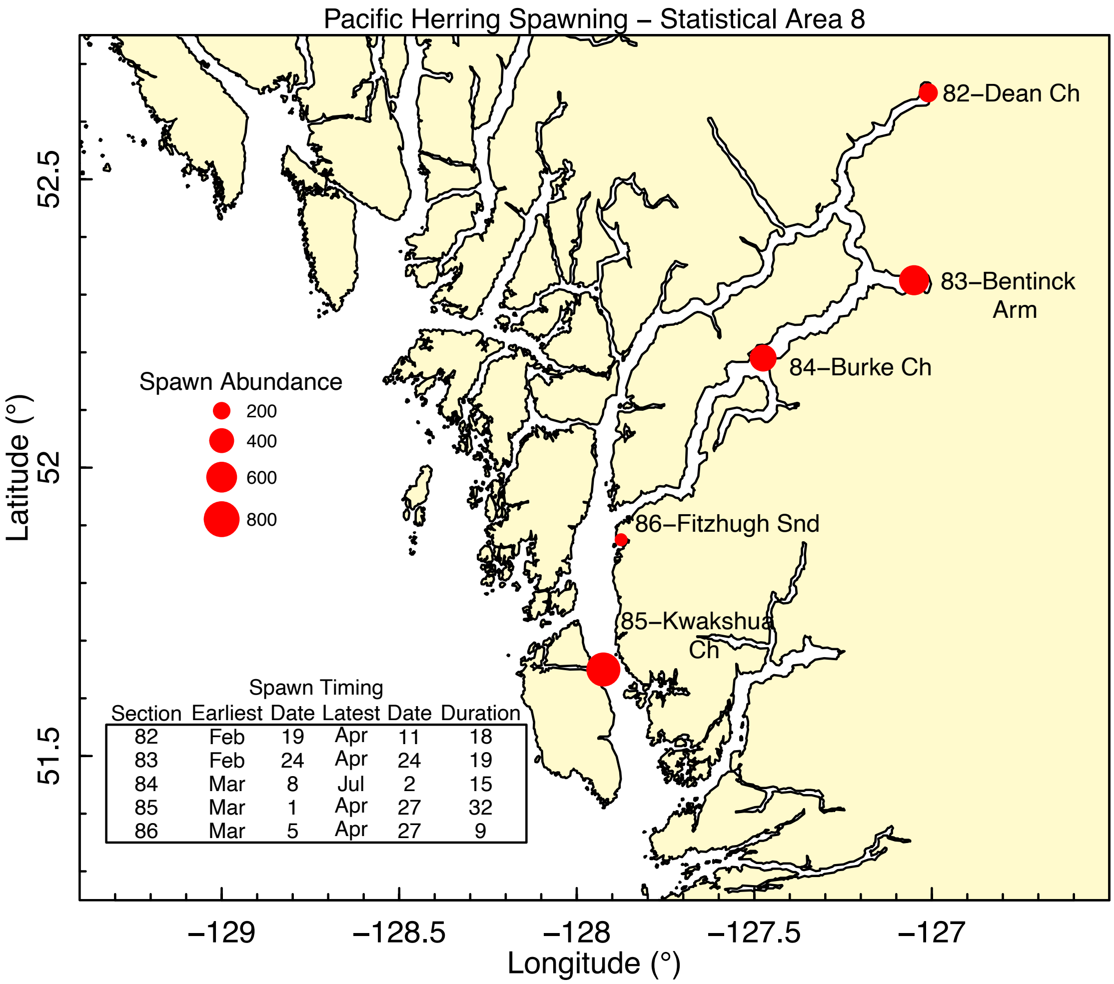


Figure 11. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 07. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

Spawning activity in Statistical Area 8 mostly occurs in the vicinity of Kwakshua Channel (Section 85) with lesser activity in some of the fjords (Bentinck Arms, Burke Channel, and Dean Channel) and occasional spawning in Fitzhugh Sound (Section 86). The spawning in Section 85 accounts for about 35 percent and the fjords about 60 percent of the total for the statistical area (Figure 12, Appendix 3). Spawning may occur as early as February 19 in Cousins Inlet (Section 82) but on average occurs between March 14 (Section 83) and May 31 in Burke Channel (Sections 84). Spawning may also occur as late as July 2 in Burke Channel (Section 84). Larval and young-of-the-year Pacific Herring were widely distributed in the inshore areas near the spawning sites in the statistical area (Thompson et al. 2015). Young-of-the-year Pacific Herring in Section 85 likely move offshore in the winter of their first year or in the following spring to join immature and adult schools feeding in Hecate Strait. Thompson et al. (2015) found young-of-the-year and also older ages of herring in the channels of Sections 82 and 84 suggesting that many of these Pacific Herring spend their entire lives in areas not far removed from spawning sites and never migrate into Hecate Strait.



Section	Earliest Date		Latest Date		Duration
82	Feb	19	Apr	11	18
83	Feb	24	Apr	24	19
84	Mar	8	Jul	2	15
85	Mar	1	Apr	27	32
86	Mar	5	Apr	27	9

Figure 12. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 08. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

In Statistical Area 9, the majority of spawning occurs near the head of Rivers Inlet (Section 93) with lesser activity near the mouth of the inlet (Section 92) or in the adjacent Fish Egg Inlet (Section 91). The spawning in Section 93 accounts for roughly 80 percent of the total for the statistical area (Figure 13, Appendix 3). Spawning may occur as early as February 25 in Fish Egg Inlet (Section 91) but on average occurs between March 22 (Section 93) and April 5 (Section

92). Spawning may occur as late as May 5 near the entrance to Rivers Inlet (Section 92). Young-of-the-year Pacific Herring have been found adjacent to spawning sites in Section 91 and 92. It appears that no Pacific Herring remain in Fish Egg Inlet after their first summer (Thompson et al. 2015) migrating into Fitzhugh Sound although some older Pacific Herring appear to remain in Rivers Inlet (Sections 92 and 93). Some adults may eventually migrate to feed in the northern section of Queen Charlotte Sound off northern Vancouver Island.

The majority of spawning activity in Statistical Area 10 is concentrated in Takush Harbour (Section 102) with lesser activity in adjacent Smith Inlet (Section 103). The spawning in Section 102 accounts for roughly 85 percent of the total for the statistical area (Figure 13, Appendix 3). Spawning may occur as early as February 27 in Takush Harbour (Section 102) but on average occurs between March 30 (Section 102) and April 8 (Section 103). Spawning may occur as late as July 4 in Takush Harbour (Section 102). Hay and McCarter (1997b) found herring larvae broadly distributed near the mouth of Smith Inlet and it is likely that young-of-the-year Pacific Herring are also present in this area. They report most of the larvae were found within 3 km of shore but often up to 20 km from the shore. Immature and adult Pacific Herring likely migrate offshore to feed off the northern tip of Vancouver Island.

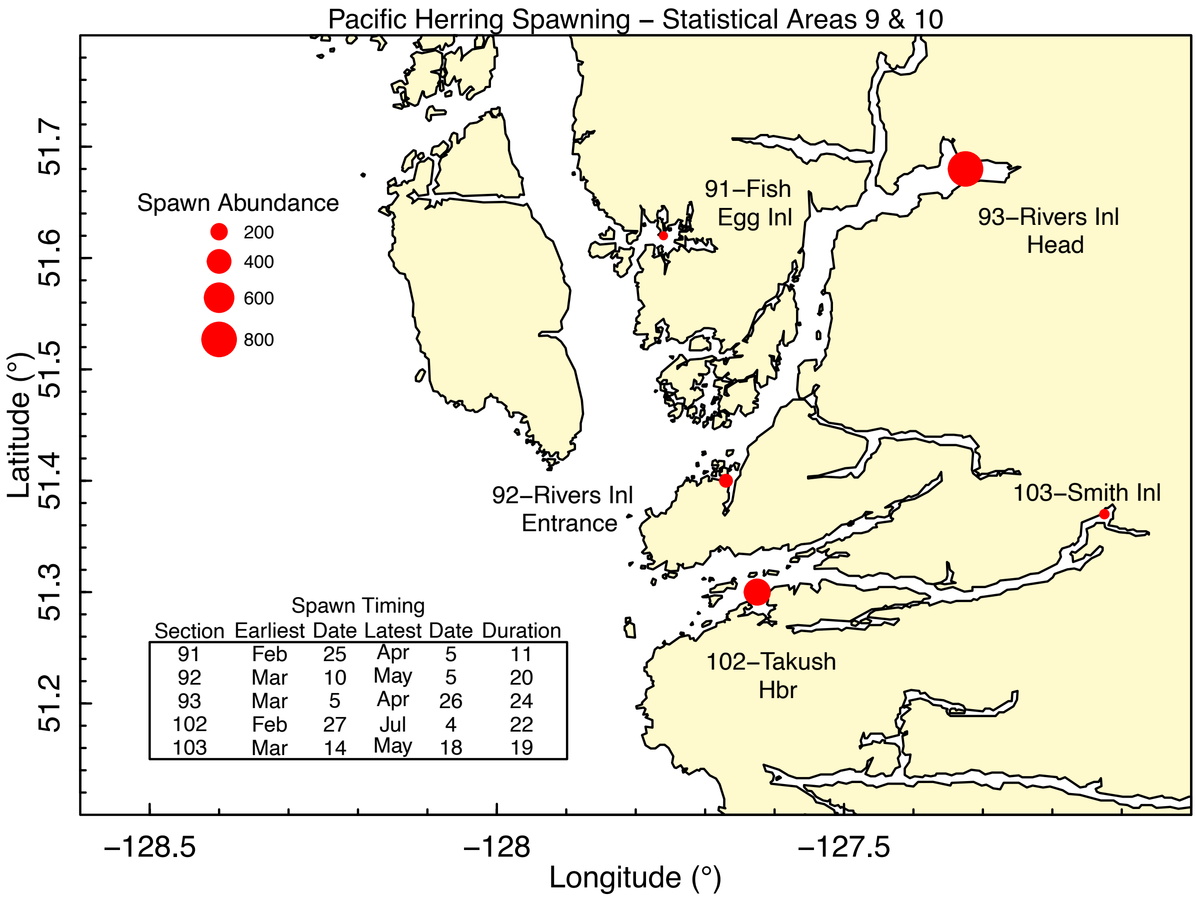


Figure 13. Map of the key Pacific Herring spawning locations in each Section in Statistical Areas 09 and 10. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

JOHNSTONE STRAIT – STATISTICAL AREAS 11-13

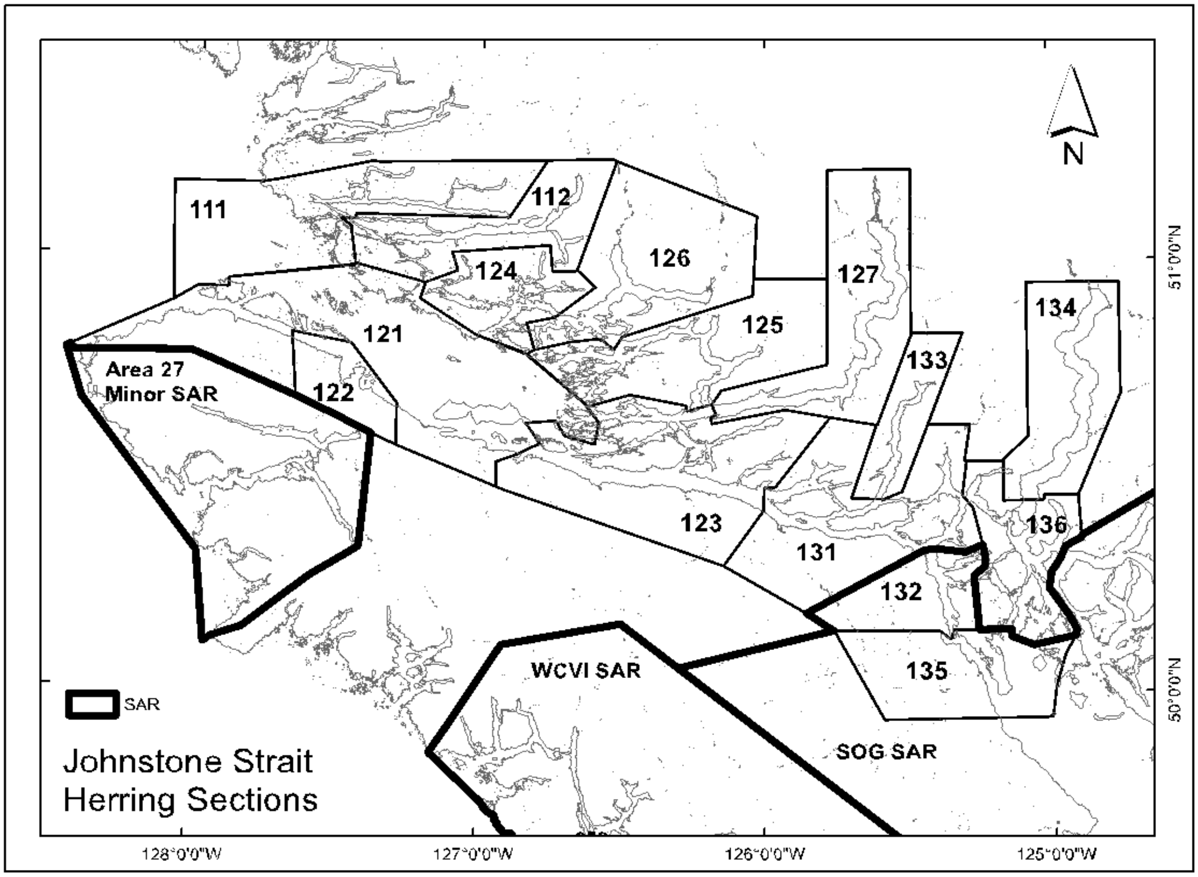


Figure 14. Pacific Herring Sections for Statistical Areas 11-13 in Johnstone Strait.

Pacific Herring spawning activity occurs in each of Statistical Areas 11 to 13 (Figure 14) with the majority occurring in Statistical Area 12 followed by Area 13, and a small amount in Area 11 (Appendix 4). In Statistical Area 11 the vast majority of the spawning activity occurs in the vicinity of Nugent Sound/Seymour Inlet (Section 112) with only eight records of spawning reported for Belize Inlet (Section 111) (Figure 15). Spawning may occur as early as February 4 in Nugent Sound/Seymour Inlet (Section 112) but on average varies between April 6 in Section 112 and April 25 in Belize Inlet (Section 111). Spawning may also occur as late as May 12 in either section. Relatively limited spawning has been reported in this statistical area and Hay and McCarter (1997b) do not report any larval Pacific Herring catches in this area. It is likely that young-of-the-year and second year Pacific Herring migrating out of the Strait of Georgia are to be found off the mouth of these inlets together with smaller local populations. Adult herring would be expected to migrate out of the inlets to feed in northern Queen Charlotte Strait.

Spawning activity in Statistical Area 12 mostly occurs in Kingcome Inlet (Section 126) and Knight Inlet (Section 127) with much less frequency and extent of spawning in the other five sections in this area (Figure 15, Appendix 4). Kingcome (43%) and Knight (35%) Inlets account for almost 80 percent of the total observed spawning activity in the area. Gilford Island (Section

125), West Cracroft Island (Section 123), and Beaver Harbour (Section 122) have substantially lesser spawning activity while Wells Passage (Section 124) and Queen Charlotte Strait (Section 121) each have fewer than a hundred reports of spawning during the past several decades of observation. Spawning has occurred as early as February 17 at West Cracroft Island and Queen Charlotte Strait but on average occurs between March 20 in Knight Inlet (Section 127) and April 22 (Section 121). Spawning may occur as late as mid-May in most sections but has been reported on June 1 in Queen Charlotte Strait (Section 121). Hay and McCarter (1997b) reported some incidence of larval herring within the major inlets and channel of this statistical area. Large numbers of young-of-the-year Pacific Herring have also been reported throughout the area, the majority possibly outmigrants from Georgia Strait (Haegele et al. 2005). Immature and adult Pacific Herring within this statistical area likely migrate to the mouths of the major inlets or more broadly into southern Queen Charlotte Strait.

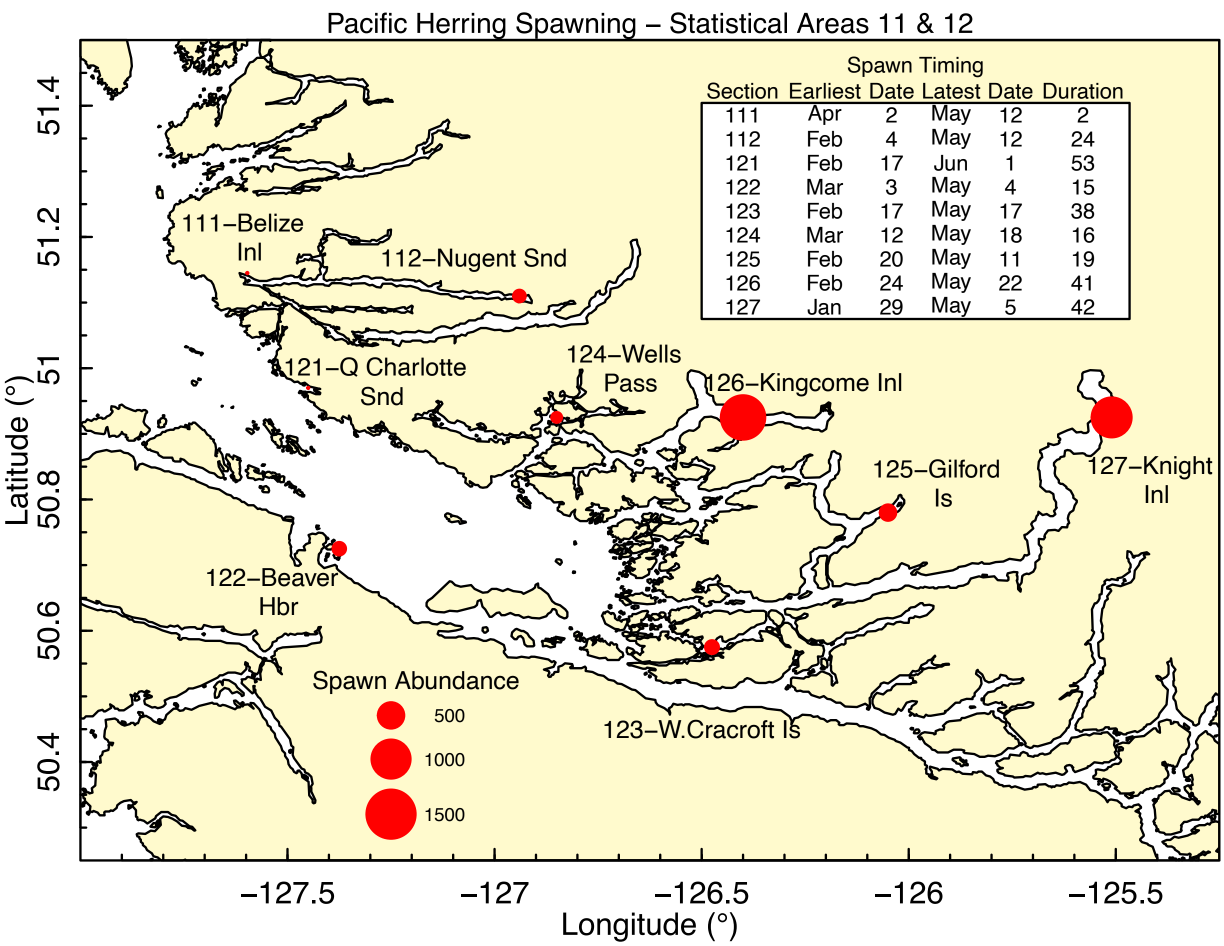


Figure 15. Map of the key Pacific Herring spawning locations in each Section in Statistical Areas 11 and 12. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

In Statistical Area 13, the majority of spawning activity (64%) has been reported in Bute Inlet (Section 134) and Cape Mudge (18%), with lesser frequency and extent of spawning in the other three sections in this area (Figure 16, Appendix 4). Spawning has occurred as early as January 7 in Deepwater Bay (Section 132) but on average occurs between March 14 in Bute Inlet (Section 134) and March 28 at Cape Mudge (Section 135). Spawning typically occurs well into April and has been reported as late as May 1 in Loughborough Inlet ((Section 133). Hay and McCarter (1997b) report small numbers of larval Pacific Herring in the inlets of the statistical area and substantial numbers in the sections adjoining the northern edge of Georgia Strait. Young-of-the-year Pacific Herring are broadly distributed throughout this area (Haegele et al. 2005). Immature and adult herring from Sections 133 and 134 likely migrate to the mouths of the inlets to feed and may disperse more broadly within the surrounding channels. Adults in the other sections may disperse within the adjoining channels or migrate into northern Strait of Georgia to feed during the summer period. Evidence from the bait fishery indicates the presence of some immature and adult Pacific Herring within the statistical area throughout the year rather than migrating offshore with those from other areas within the Strait of Georgia (Schweigert and Linekin 1990).

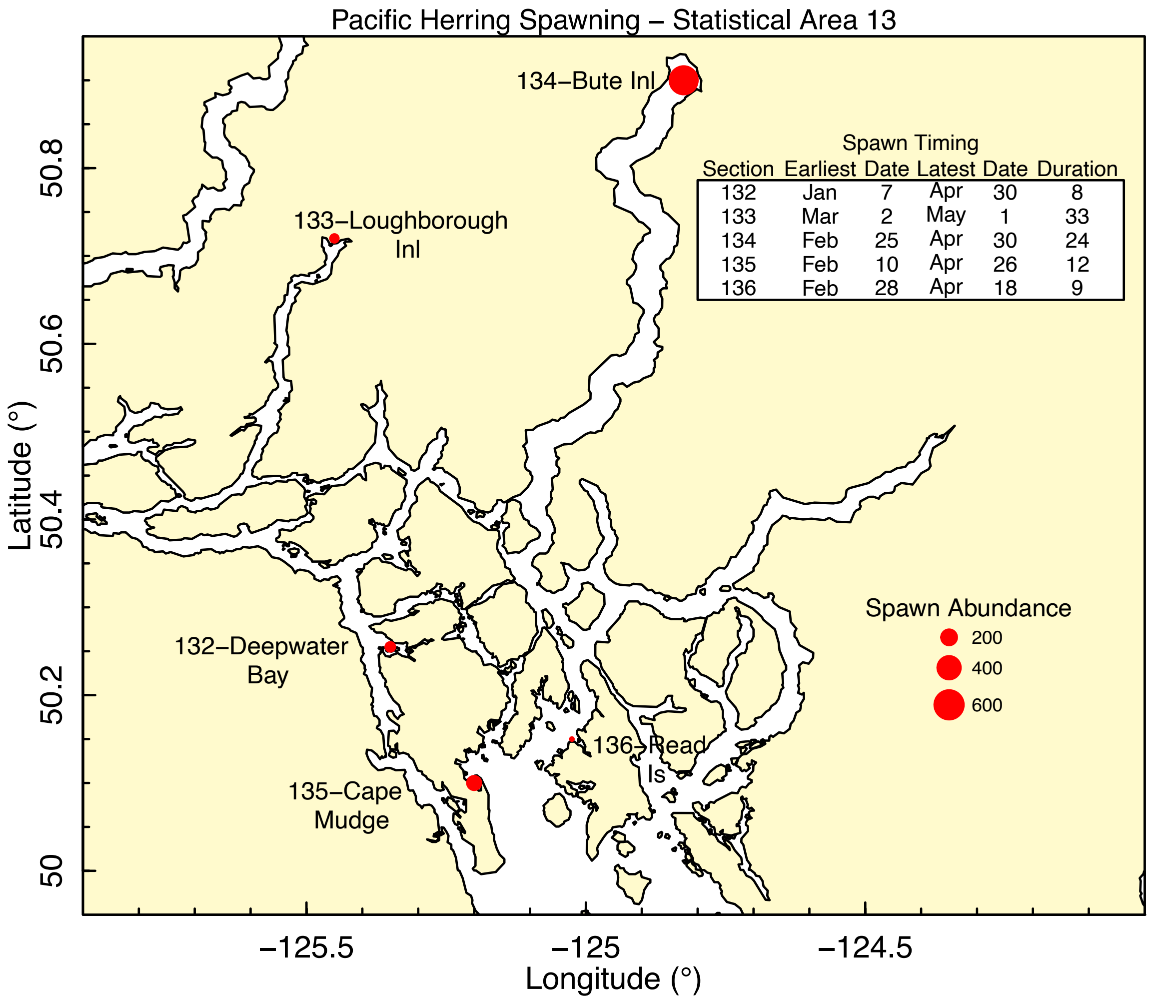


Figure 16. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 13. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

STRAIT OF GEORGIA – STATISTICAL AREAS 14-29

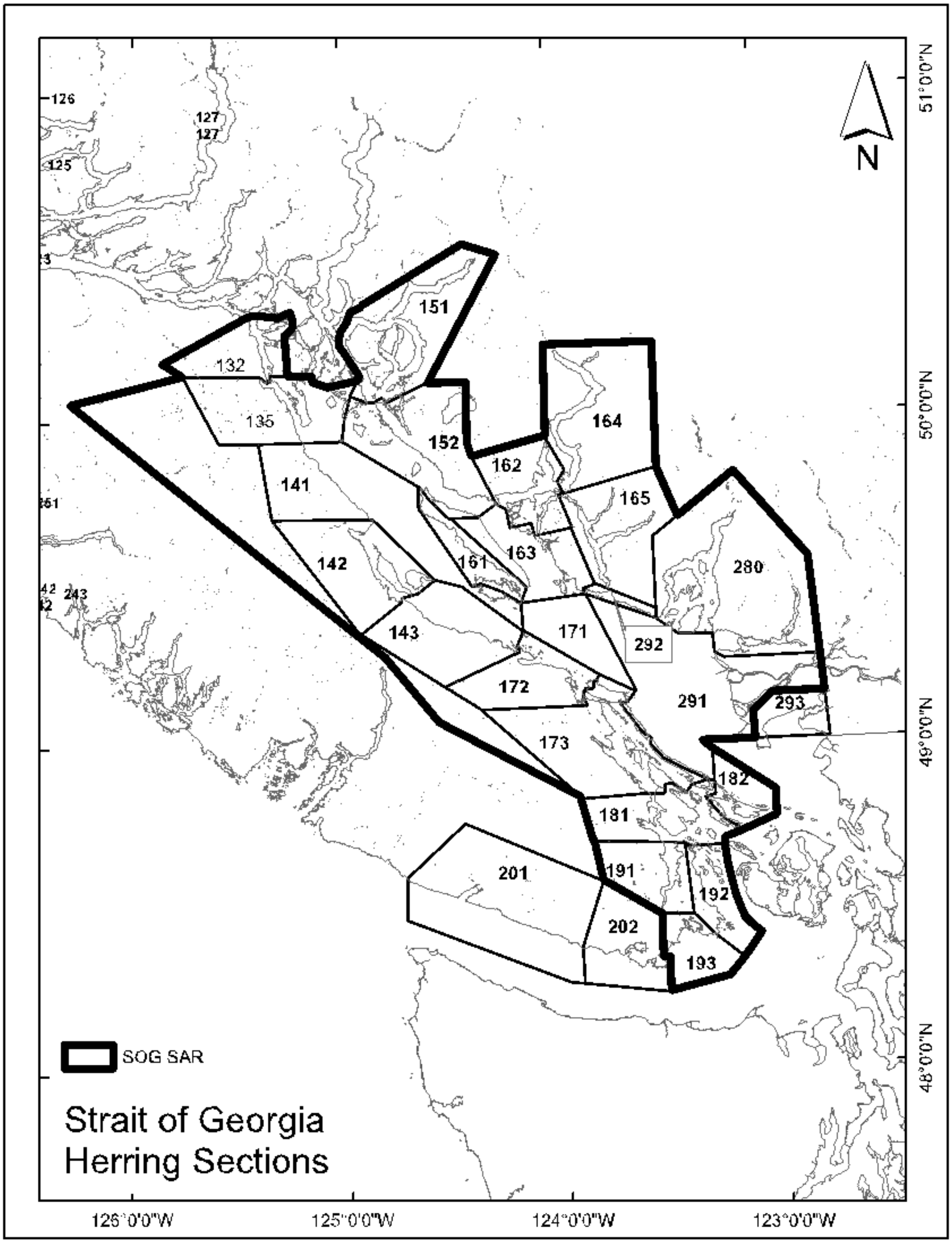


Figure 17. Pacific Herring Sections for Statistical Areas 14-29 in the Strait of Georgia.

The Strait of Georgia supports the largest Pacific Herring population in BC (Figure 17) and the bulk of the spawning activity occurs in the vicinity of Comox on and around Denman and Hornby Islands. About 60 percent of the observed spawning activity has occurred in Baynes Sound (Section 142) with another 35 percent in the Qualicum vicinity (Section 143). A minor amount of spawning (68 records) has been observed in Section 141 during the several decades of monitoring (Figure 18, Appendix 5). Spawning has occurred as early as February 13 in Baynes Sound (Section 142) but on average occurs between March 12 in Oyster Bay (Section 141) and March 14 in Qualicum (Section 143). Spawning has been reported as late as May 28 in Baynes Sound (Section 142). Larval Pacific Herring from the extensive spawning in this statistical area are broadly distributed along the shoreline of eastern Vancouver Island (Hay and McCarter 1997b). Young-of-the-year Pacific Herring are also widely distributed throughout the Strait of Georgia but tend to be concentrated within 5 km of the shore (Haegele et al. 2005). The bulk of the young-of-the-year Pacific Herring migrate out of the Strait of Georgia to join the immature and adult populations feeding off the west coast of Vancouver Island. The outmigration occurs both through Johnstone and Juan de Fuca Straits (Stevenson 1954; Taylor 1964).

In Statistical Area 15, virtually all of the spawning activity occurs in the vicinity of Powell River (Section 152) with fewer than a hundred reported spawning events at Redonda Island (Section 151) (Figure 18, Appendix 5). Spawning has occurred as early as February 27 at Redonda Island (Section 151) but on average occurs between March 19 at Redonda Island and March 20 at Powell River (Section 152). Spawning may occur as late as May 16 at Powell River (Section 152). Larval Pacific Herring from these spawning events appear to be localized along the shore adjacent to the spawning sites (Hay and McCarter 1997b). Young-of-the-year Pacific Herring are widely distributed throughout the Strait of Georgia and some schools may be associated with these spawns (Haegele et al. 2005). The bulk of the young-of-the-year Pacific Herring migrate out of the Strait of Georgia the following spring and it is likely they also join the immature and adult populations feeding off the west coast of Vancouver Island although some may remain in the southern Johnstone Strait area to feed and mature (Schweigert and Linekin 1990).

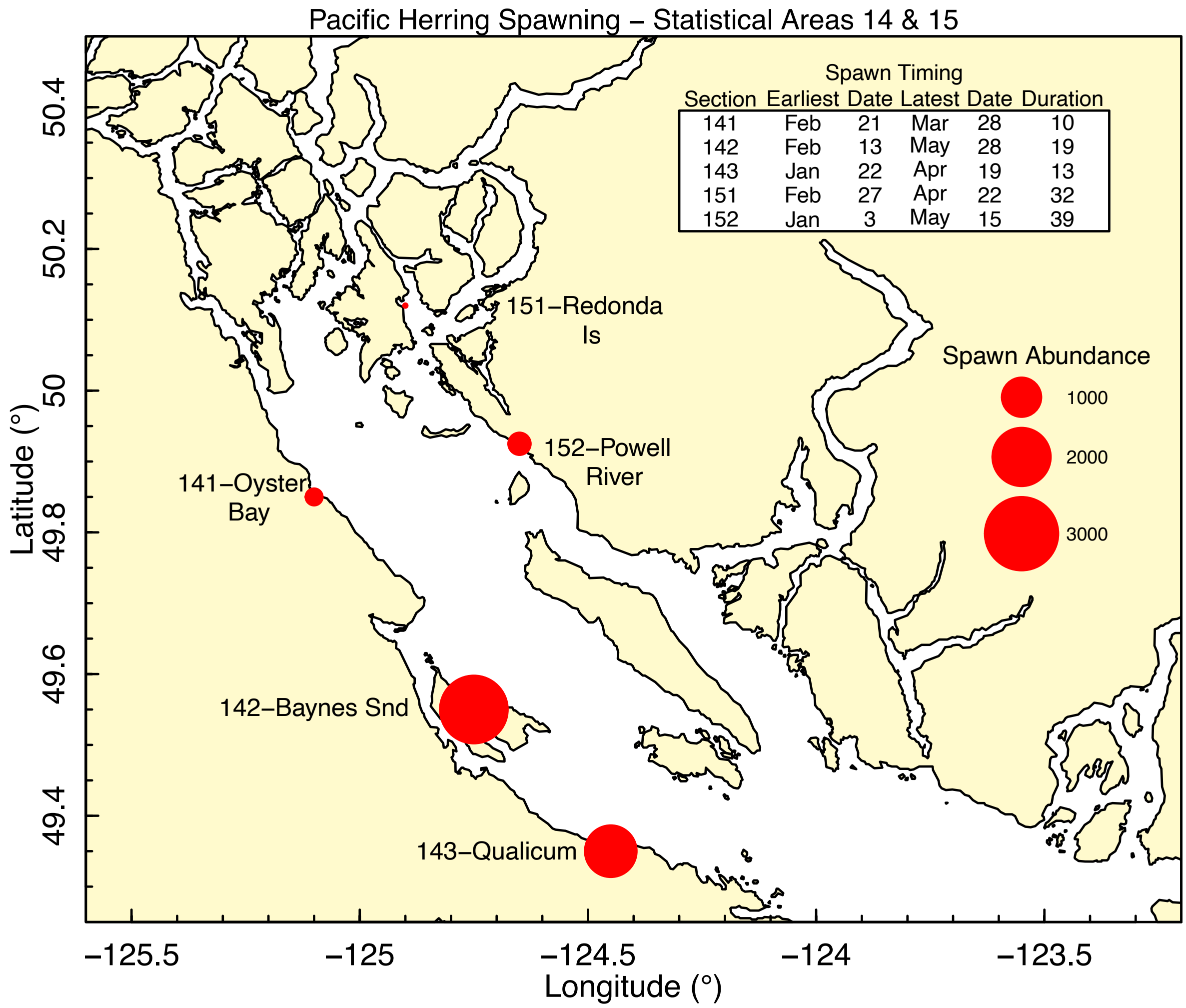


Figure 18. Map of the key Pacific Herring spawning locations in each Section in Statistical Areas 14 and 15. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

Spawning activity in Statistical Area 16 occurs in four sections on the mainland coast between Howe Sound and Powell River (Figure 19, Appendix 5). Similar amounts of spawning activity have been observed in Malaspina Strait (Section 163), Sechelt Inlet (Section 165), and Jervis Inlet (Section 164), with a reduced frequency and extent of spawning in Hotham Sound (Section 162). Spawning has occurred as early as January 17 in Malaspina Strait (Section 163) but on average occurs between March 18 in Malaspina Strait and Hotham Sound (Section 162) and April 3 in Jervis Inlet (Section 164). Spawning typically occurs into early May and has been reported on May 9 in Sechelt Inlet (Section 165). Hay and McCarter (1997b) found relatively few larval Pacific Herring adjacent to these spawning sites in most years. Young-of-the-year Pacific Herring are widely distributed throughout the Strait of Georgia and some schools may be associated with these spawns (Haegele et al. 2005). The bulk of the young-of-the-year Pacific

Herring migrate out of the Strait of Georgia and it is likely that Pacific Herring spawned in this area also join the immature and adult populations feeding off the west coast of Vancouver Island although some may remain in the southern Strait of Georgia feeding in Howe Sound or the Fraser River estuary.

In Statistical Area 17 spawning activity is fairly evenly distributed between Yellow Point (Section 173) and Nanoose Bay (Section 172) although in the past decade there has been little or no spawning activity in Section 173 (Figure 19, Appendix 5). It remains unknown whether this is a function of climate change displacing spawning activity northward or to a loss of viable spawning habitat in Section 173. Spawning has occurred as early as January 29 in Yellow Point (Section 173) but on average occurs between March 17 in Nanoose Bay (Section 172) and March 20 in Yellow Point (Section 173). Spawning typically occurs well into early May and has been reported as late as May 6 in Section 173. Hay and McCarter (1997b) reported large numbers of Pacific Herring larvae along the spawning shoreline for Section 172 although generally fewer associated with Section 173. Young-of-the-year Pacific Herring are widely distributed throughout the Strait of Georgia and are generally abundant in this statistical area (Haegele et al. 2005). The bulk of the young-of-the-year Pacific Herring migrate out of the Strait of Georgia to join the immature and adult populations feeding off the west coast of Vancouver Island (Stevenson 1954; Hourston and Haegele 1980).

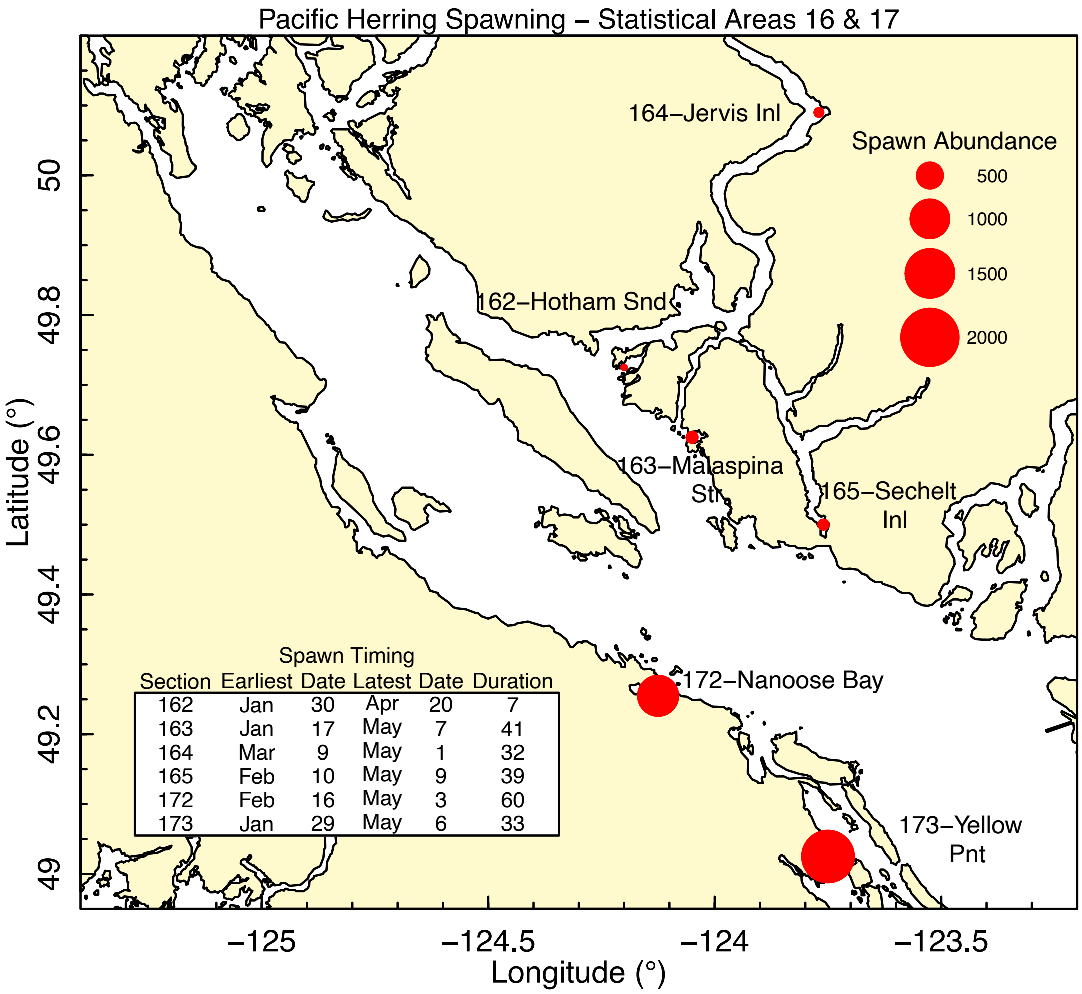


Figure 19. Map of the key Pacific Herring spawning locations in each Section in Statistical Areas 16 and 17. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

Spawning activity in Statistical Area 18 is concentrated in the vicinity of Swanson Channel (Section 182) with considerably less extensive or frequent activity in Plumper Sound (Section 181) (Figure 20, Appendix 5). Spawning has occurred as early as January 15 in Swanson Channel (Section 181) but on average occurs between March 3 in Swanson Channel and March 9 in Plumper Sound (Section 182). Spawning may occur at late as April 16 in Swanson Channel (Section 181). Hay and McCarter (1997b) reported substantial numbers of Pacific Herring larvae throughout the Gulf Islands area likely associated with these spawning sites. Young-of-the-year Pacific Herring are also common throughout the area (Haegele et al. 2005). It is likely that the bulk of the young-of-the-year Pacific Herring from this area migrate out of the Strait of Georgia through the Strait of Juan de Fuca to join the immature and adult populations feeding off the west coast of Vancouver Island (Stevenson 1954; Hourston and Haegele 1980).

Spawning activity in Statistical Area 19 is modest relative to the other Statistical Areas in the Strait of Georgia (Figure 20, Appendix 5). The bulk of recorded spawning activity (88%) has occurred in Saanich Inlet (Section 191) with less frequent or extensive observations in the vicinity of Victoria Harbour (Section 193). Only four records of spawning have been obtained in Cordova Bay (Section 192). Spawning has occurred as early as February 1 in Victoria Harbour (Section 193) but on average occurs between March 14 in Cordova Bay (Section 192) and March 29 in Saanich Inlet (Section 191). Spawning activity has extended well into April and May, being reported on April 25 in Saanich Inlet (Section 191) and May 29 in Victoria Harbour (Section 193). Hay and McCarter (1997b) reported very few Pacific Herring larvae associated with these spawning sites. Information on young-of-the-year Pacific Herring in this area are lacking but it is possible that the schools remain in Saanich Inlet and the vicinity of Victoria Harbour. The somewhat ephemeral nature of the spawning events in this area suggests that these Pacific Herring do not join the large migratory population feeding off the west coast of Vancouver Island and remain in the vicinity of their spawning sites.

Pacific Herring spawning in Statistical Area 20 appears to be ephemeral with only 7 records of activity between 1951 and 1995 (Figure 20, Appendix 5). The recorded spawning activity is concentrated within Sooke Harbour (Section 202). Spawning has occurred as early as March 5 in Becher Bay. The average date for the beginning of spawning ranges between March 28 in Sooke Inlet and April 13 in Anderson Cove but has been observed as late as April 26 also in Anderson Cove. There is no information on the larvae, young-of-the-year or adult Pacific Herring associated with this spawning population.

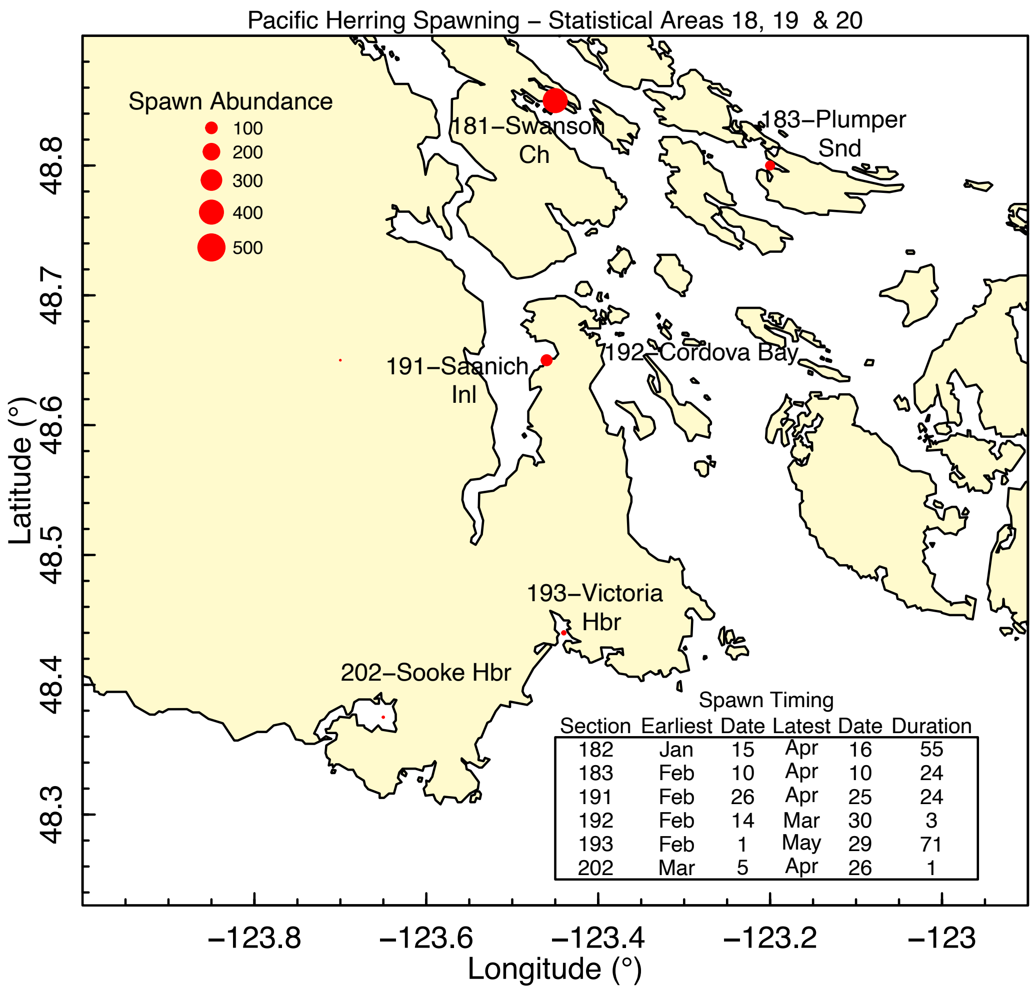


Figure 20. Map of the key Pacific Herring spawning locations in each Section in Statistical Areas 18, 19 and 20. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

Spawning activity in Statistical Area 28 is very modest relative to the other statistical areas in the Strait of Georgia (Figure 21, Appendix 5). The bulk of recorded spawning activity (47%) has occurred in the vicinity of Squamish with the remainder occurring at Port Graves (Gambier Island) and near the mouth of Howe Sound or Burrard Inlet. Spawning has occurred as early as January 15 in False Creek. The average date for the beginning of spawning is March 17 but extends well into May. Spawning has been reported as late as May 19 in Indian Arm. Hay and McCarter (1997b) report few if any Pacific Herring larvae associated with these spawning sites. Limited sampling of young-of-the-year Pacific Herring indicates their presence in the Fraser River estuary and the mouth of Howe Sound (Haegele et al. 2005). It is probable that there are schools within Howe Sound as well. The limited number of observed spawning events suggests that this may be a local population that does not join the large migratory population feeding on the west coast of Vancouver Island.

In Statistical Area 29 spawning activity is concentrated in Boundary Bay (Section 293) with only 13 observations reported near Sechelt (Section 292). Spawning has occurred as early as February 14 in Boundary Bay while the average date for the beginning of spawning ranges between March 2 in Boundary Bay and March 24 in Sechelt. Similarly, spawning may occur as late as April 6 in Boundary Bay and April 17 near Sechelt (Figure 21, Appendix 5). The sections in the statistical area are disjointed and information on larval Pacific Herring for Boundary Bay (Section 193) is lacking. It is likely that larval and young-of-the-year Pacific Herring may be retained within the bay but the relationship of these and older immature and adult Pacific Herring to the large migratory Strait of Georgia population is unknown.

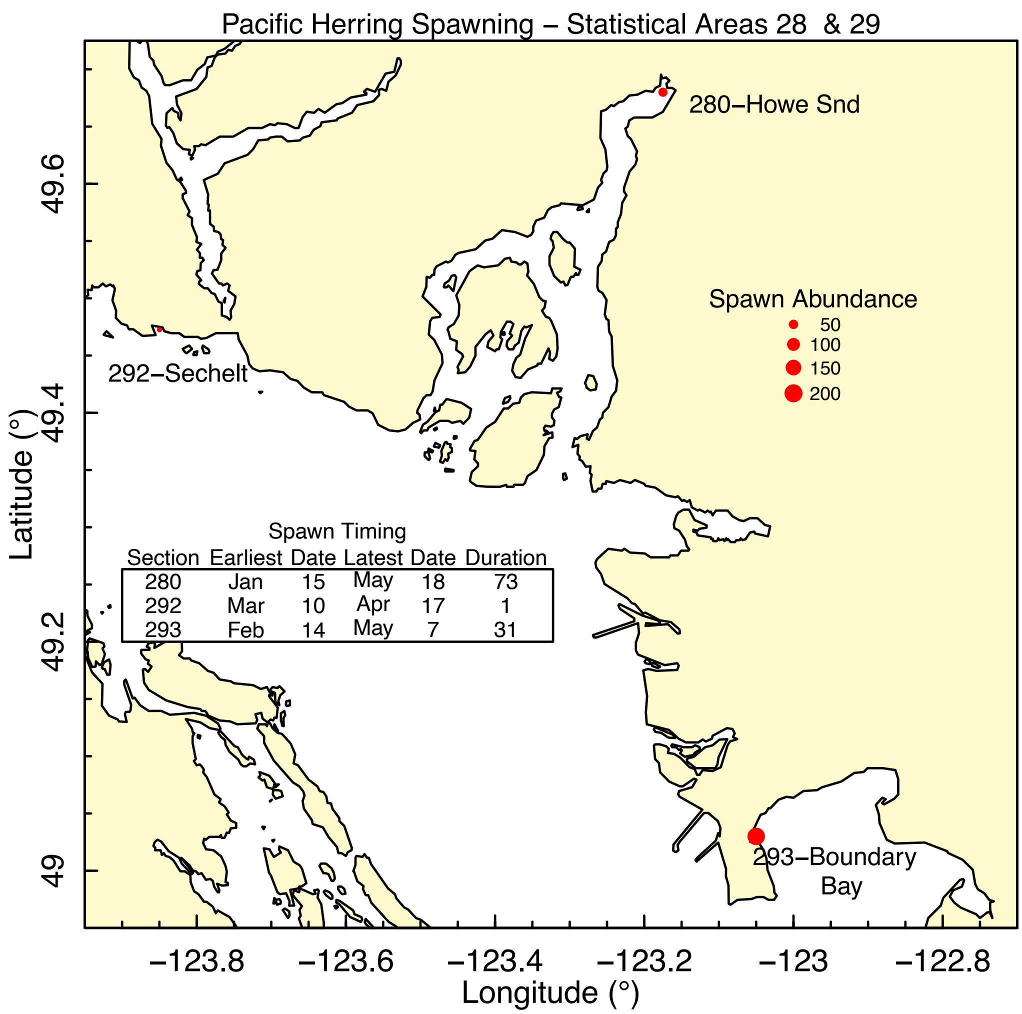


Figure 21. Map of the key Pacific Herring spawning locations in each Section in Statistical Areas 28 and 29. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

WEST COAST OF VANCOUVER ISLAND – STATISTICAL AREAS 23-27

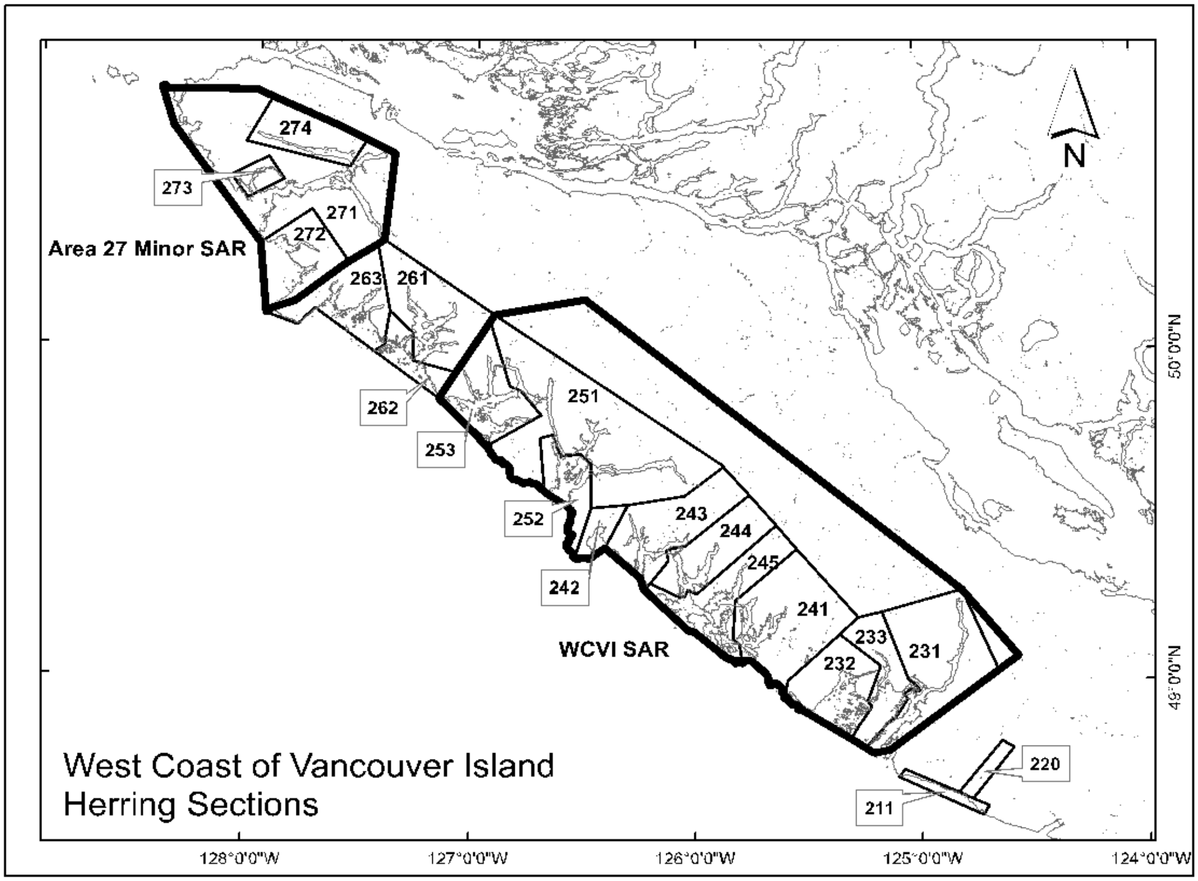


Figure 22. Pacific Herring Sections for Statistical Areas 23-27 on the West Coast of Vancouver Island.

Pacific Herring spawning activity on the west coast of Vancouver Island (Figure 22) is broadly distributed among the several major inlets and sounds. The majority of the recorded spawning activity has occurred in Statistical Area 23 (Barkley Sound) followed closely by Statistical Areas 24 and 25 (Clayoquot and Nootka Sounds). Lesser amounts of spawning activity have been reported for Statistical Area 27 (Quatsino Sound) and limited activity in Statistical Area 26 (Kyuquot Sound).

In Statistical Area 23 more than 90 percent of the spawning activity has occurred in Section 232 on the northwest side of Barkley Sound (Figure 23, Appendix 6). The remainder of the spawning is distributed evenly between Section 231 on the southeast side of Barkley Sound and Section 233 at the mouth of Alberni Inlet. Spawning has occurred as early as January 7 in Useless Inlet but the average date for the beginning of spawning varies between March 4 in Section 233 to March 13 in Section 232. Spawning activity may extend into April and has been reported as late as April 20 in Useless Inlet (Section 233). Studies of larval Pacific Herring were conducted in Barkley Sound by Stevenson (1962) and indicated that larvae appeared to be moved passively with currents within the Sound but many also appeared to be transported out of the area.

Hourston (1958, 1959) investigated the young-of-the-year or juvenile Pacific Herring population and demonstrated that the schools tended to be concentrated in the southeast portion of Barkley Sound and remained near the shore in bays and inlets. It was suggested that they moved out of the sound in the fall to offshore feeding grounds. The immature and adult Pacific Herring feed in the offshore areas such as Swiftsure Bank during the summer migrating back into Barkley Sound during the fall and winter in preparation for spring spawning (Stevenson 1954; Taylor 1964).

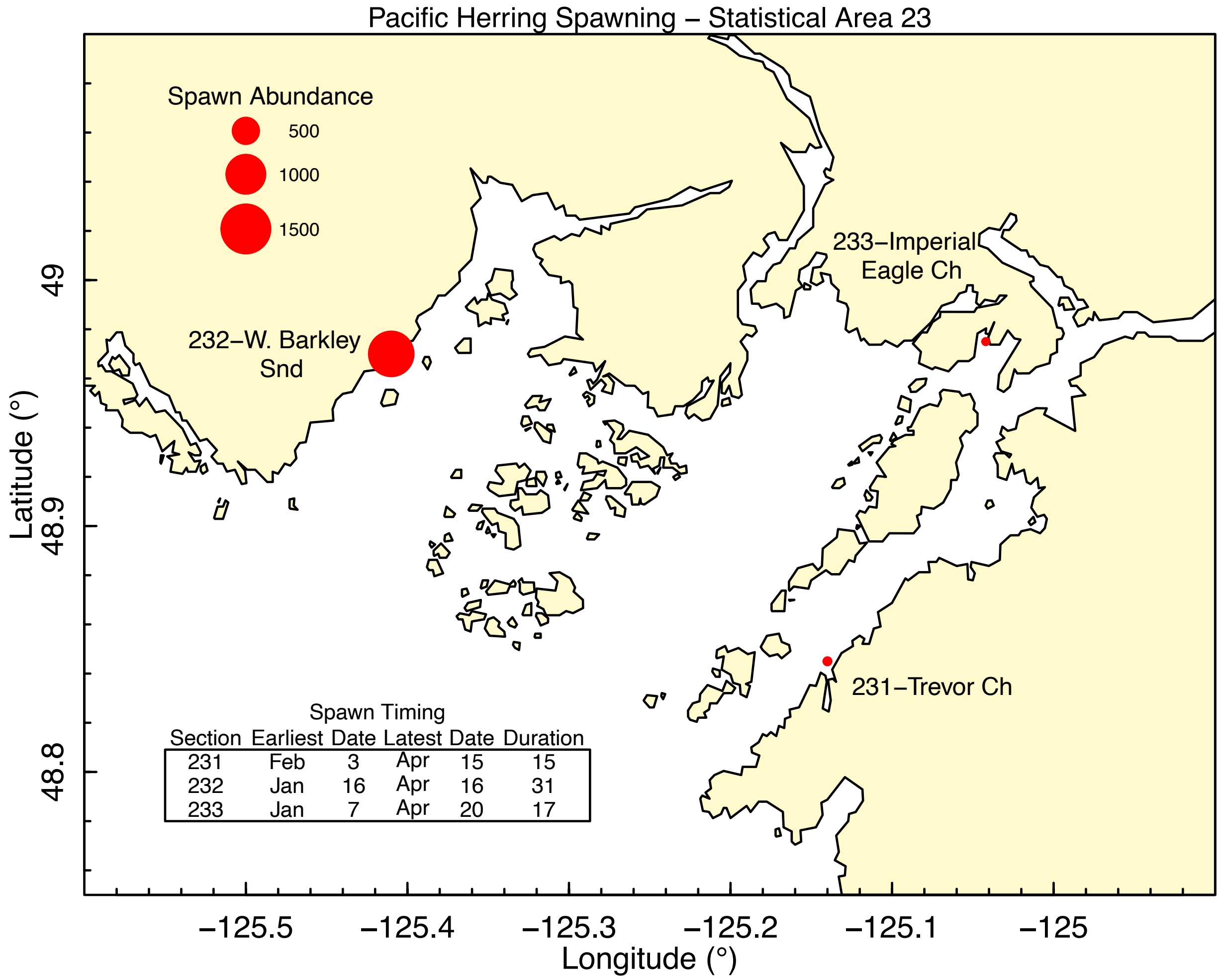


Figure 23. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 23. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

A significant portion of Pacific Herring spawning activity in Statistical Area 24 (31%) is concentrated in Section 245 (Vargas Island) (Figure 24, Appendix 6). Lesser activity is fairly evenly distributed among Sections 242 (Hesquiat Harbour), Section 243 (Sydney Inlet), and Section 244 (Miller Channel). The remaining 3 percent of recorded spawning activity occurred in Section 241 (Tofino Inlet). Spawning has been reported as early as January 7 in Hesquiat

Harbour but on average occurs between March 4 in Tofino Inlet (Mosquito Harbour) and March 20 in Miller Channel (Little Whitepine Cove). The latest spawning date reported in the statistical area is May 1 in Bedwell Sound (Section 245). Little is known about the distribution of larval and young-of-the-year Pacific Herring in the statistical area but it is likely that larvae and young Pacific Herring remain largely within Clayoquot Sound during the first year of life followed by gradual movement into the offshore areas for feeding during and following the first winter (Hourston 1958, 1959). Immature and adult Pacific Herring migrate to the offshore feeding grounds following spawning and return to the vicinity of the spawning areas in the fall and winter (Stevenson 1954).

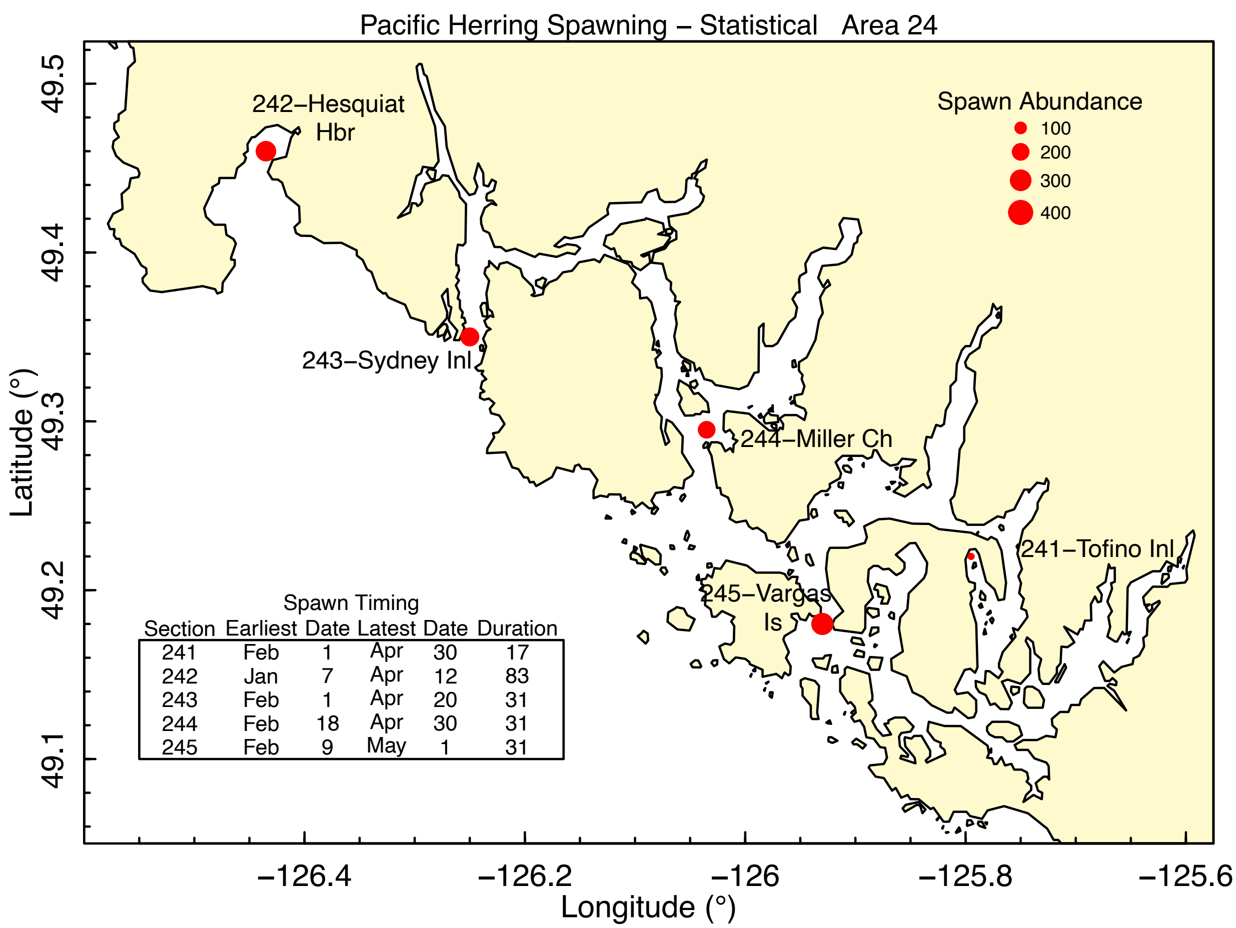


Figure 24. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 24. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

In Statistical Area 25 the majority of spawning activity (66%) is concentrated in Section 252 (Nootka Sound) (Figure 6, Appendix 6). The remainder occurs in Section 253 (Esperanza Inlet) with only 11 records reported for Section 251 (Tahsis Inlet). Spawning has occurred as early as January 19 in Mary Basin (Nuchatlitz Inlet) but the average date for the beginning of spawning varies between March 10 in Section 253 to March 25 in Section 252 (Appendix 6). Spawning activity may extend into May and has been reported as late as June 15 in Section 252 (Friendly Cove). Larvae and young-of-the-year Pacific Herring likely remain in the vicinity of the spawning sites with subsequent dispersion throughout lower Nootka Sound and Esperanza and Nuchatlitz Inlets (Hourston 1958, 1959). Gradual dispersion to offshore feeding grounds occurs during and following the first winter. Maturing and adult Pacific Herring migrate inshore from the feeding grounds congregating near the mouths of Nootka and Esperanza Inlets during the fall and winter in preparation for spring spawning (Stevenson 1954).

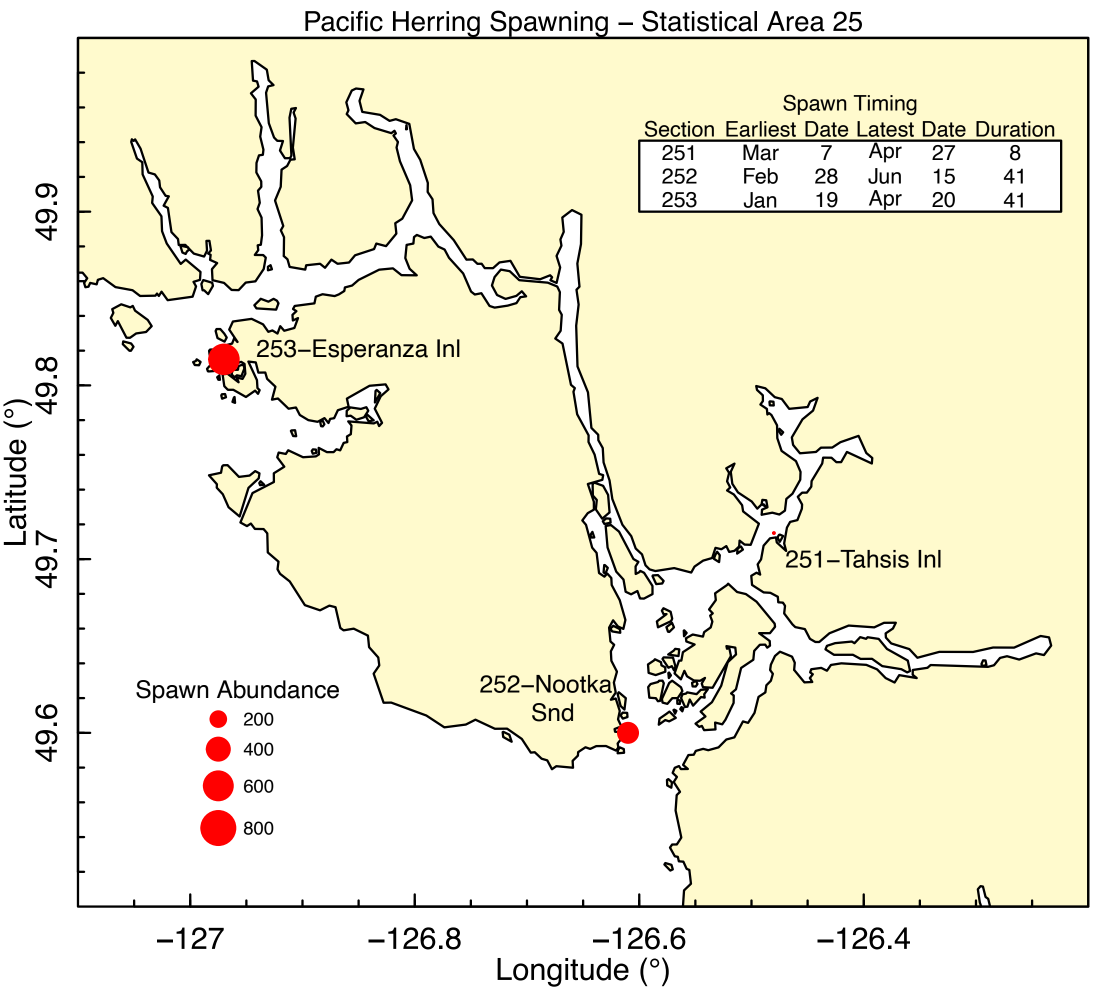


Figure 25. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 25. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

Statistical Area 26 at the southern edge of the Brooks Peninsula is remote and spawning reports may be incomplete. Nevertheless, it represents an area with the least amount of spawning activity on the west coast of Vancouver Island (Figure 26, Appendix 6). The majority of spawning activity (58%) is concentrated in Section 262 (Clanninick Cove) in Kyuquot Sound. Most of the remainder occurs in Section 263 (Checleset Bay) with only 58 records reported for Section 261 (Amai Inlet). Spawning has occurred as early as January 26 in Section 263 (Malksope Inlet) but the average date for the beginning of spawning varies between March 6 in Section 263 to March 22 in Section 261 (Appendix 6). Spawning activity often extends into April and has been reported as late as April 19 in Section 261 (Amai Inlet). Hay and McCarter (1997b) demonstrated that Pacific Herring larvae tend to be found in close proximity to spawning sites in unprotected areas of northern BC. Similar distribution would be expected in this area with young-of-the-year fish moving into the inlets within this statistical area (Nasparti, Ououkinsh, Malksope) and Kyuquot Sound. Gradual dispersion to offshore feeding grounds likely occurs during and following the first winter. The offshore feeding grounds for this area are not well known and with the narrowing of the continental shelf towards the northern edge of Vancouver Island it is likely that these are closer to the coast (Stevenson 1954). Nevertheless, maturing and adult Pacific Herring migrate inshore from the feeding grounds congregating in overwintering schools in Kyuquot Sound and Checleset Bay.

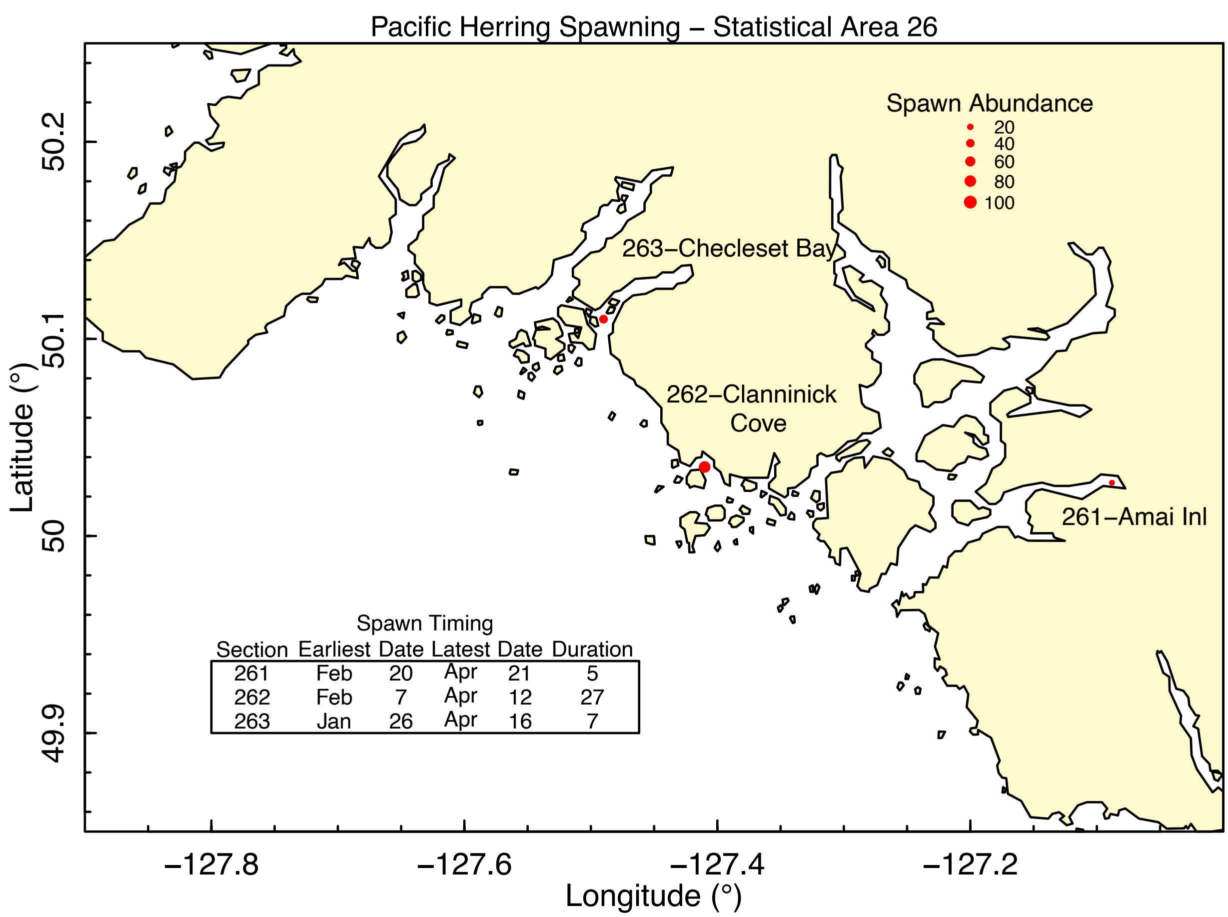


Figure 26. Map of the key Pacific Herring spawning locations in each Section in Statistical Areas 16 and 17. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as

possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

The majority of Pacific Herring spawning activity in Statistical Area 27 (78%) is concentrated in Section 273 (Forward Inlet) (Figure 27, Appendix 6). Most of the remainder (20%) occurs in Section 272 (Klaskish Inlet) with only 29 and 7 records reported for Sections 274 (Holberg Inlet) and 271 (Quatsino Sound). Spawning has occurred as early as February 1 in Section 273 (Forward Inlet) but the average date for the beginning of spawning varies between March 8 in Section 272 to April 13 in Section 274 (Appendix 6). Spawning activity can extend into May and has been reported as late as May 15 in Sections 271 and 273. Once hatched, the larval Pacific Herring are expected to initially remain near the spawning sites (Hay and McCarter 1997b) and as they grow aggregate into schools of young-of-the-year fish that also remain in the protected inshore waters of Klaskish Inlet and Quatsino Sound. Gradual dispersion to offshore feeding grounds likely occurs during and following the first winter (Hourston 1958, 1959). The offshore feeding grounds for this area are not well known but likely are north of Brooks Peninsula perhaps near the productive area off the northern tip of Vancouver Island (Stevenson 1954). Maturing and adult Pacific Herring are expected to migrate inshore from the feeding grounds congregating in overwintering schools in the vicinity of Klaskish and Quatsino Sounds.

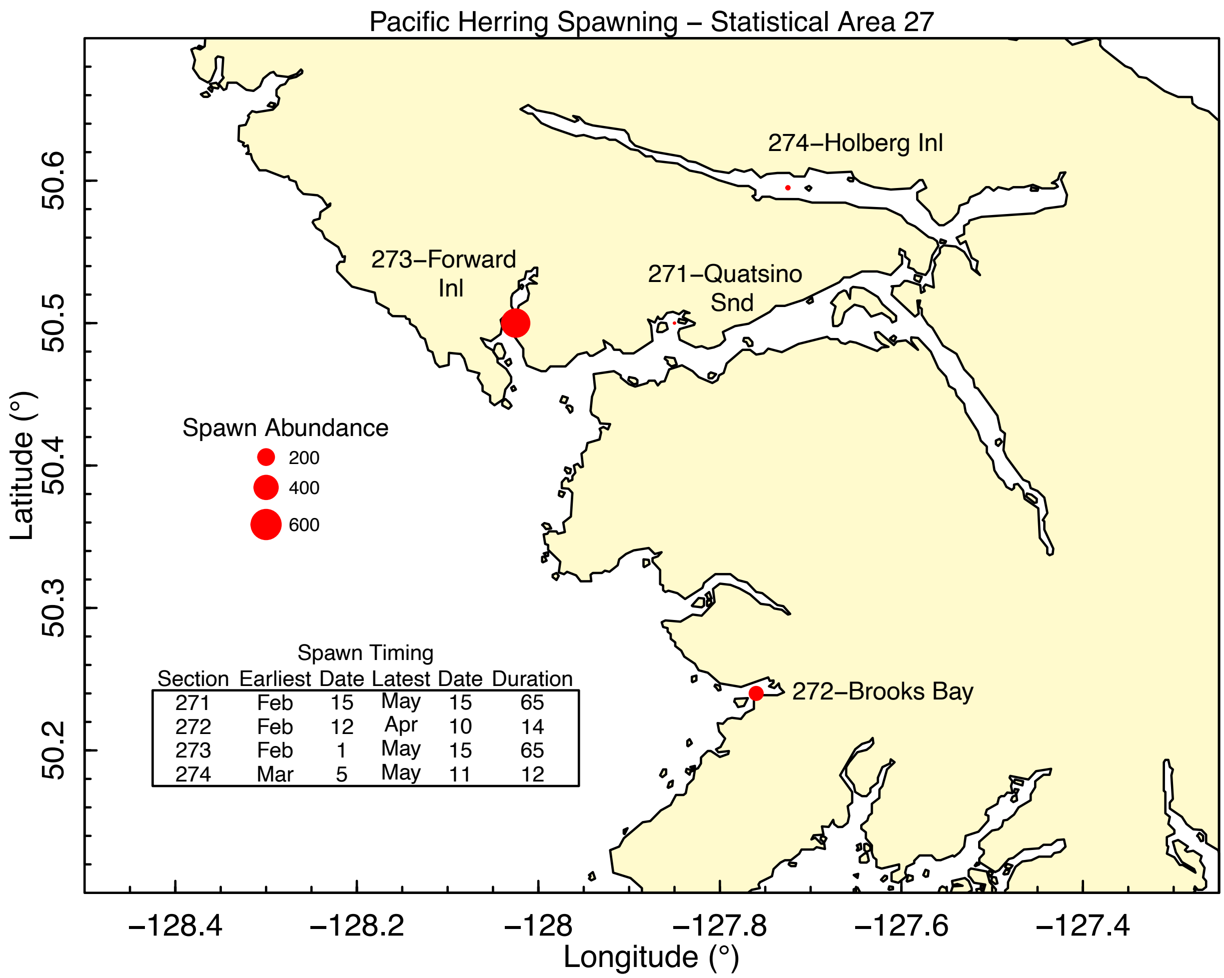


Figure 27. Map of the key Pacific Herring spawning locations in each Section in Statistical Area 27. The spawn abundance is a relative estimate based on the cumulative length of spawn standardized across all maps and the dots are situated as near to the known spawning locations as possible although spawn may be more widely distributed in the Section. The spawn timing indicates the earliest and latest dates of spawning observed in each Section and the maximum duration of spawning activity recorded from 1928-2020.

IMPACTS OF HYDROCARBON EXPOSURE

Pacific Herring and other aquatic species may be negatively impacted by exposure to hydrocarbons at various stages of their life cycle. The most common exposure to hydrocarbons is due to the accidental release of oil through terrestrial or marine mishaps. A well-studied incident impacting Pacific Herring was the *Exxon Valdez* Oil Spill (EVOS) that occurred in Prince William Sound (PWS), Alaska on March 24, 1989 directly covering herring eggs and exposing the adult spawning fish to hydrocarbons. The *Exxon Valdez* Trustee Council was established following the spill and has supported considerable oil spill impact research on Pacific Herring and the ecosystem to increase understanding of the resulting impacts of oil exposure on the ecosystem and to explain the subsequent collapse of the entire surrounding Pacific Herring population. After thirty years of study, an explanation for the collapse of the Pacific Herring populations remains under debate (Pearson et al. 1999; Marty et al. 2003; Deriso et al. 2008; Thomas and Thorne 2008; Pearson et al. 2012; Ward et al. 2017). However, the effects of other factors have been supported by many studies.

Pacific Herring eggs and larvae, studied extensively following EVOS, are sensitive to the effects of direct oil exposure. Their life history makes them susceptible to oil exposure in inshore environments. Pacific Herring in the eastern North Pacific Ocean typically spawn in March and April (Haegele and Schweigert 1985; Hay 1985), the eggs are adhesive remaining attached to various vegetation or other substrates and so would be subject to direct exposure to released oils. Adverse reactions of Pacific Herring eggs to *Exxon Valdez* oil in PWS were documented at hatching and in newly hatched larvae by Natural Resource Damage Assessment (NRDA) studies (Brown et al. 1996), while an oil industry study concluded oil effects were generally negligible (Pearson et al. 1995). Laboratory hatch of eggs from oiled sites survival was lower than for those from non-oiled sites but was not statistically significant (Brown et al. 1996). The response to oil exposure in all studies primarily considered the condition of Pacific Herring larvae hatched from exposed eggs. Eggs spawned in PWS were collected towards the end of development by both NRDA and industry and incubated in laboratories to hatch. Premature hatching and abnormalities in Pacific Herring larvae (Brown et al. 1996, Hose et al. 1996), consistent with exposure to crude oil, were significantly more frequent in oiled areas than in control areas of PWS (Carls et al. 1999). Oiled larvae were longer at hatch, but weighed less than reference larvae (Brown et al. 1996). Other studies found the severity of skeletal, craniofacial, and finfold abnormalities to be significantly higher in oiled areas (Hose et al.1996; Kocan et al. 1996). The severity of skeletal abnormalities, certain types of craniofacial defects (jaw abnormalities, microphthalmia, and absence of otic capsules), and a total severity index were significantly correlated to TPAH concentrations measured in adjacent mussels (Hose et al. 1996). The resulting effects on survival were substantial suggesting a 52 percent loss of total larval Pacific Herring production due to interaction with oil.

Once hatched, the Pacific Herring larvae have little or no motility and remain in the water column roughly through April and into June at which time they have absorbed the yolk sac and metamorphose into the adult form joining mobile schools in inshore waters. The eggs and larvae are thus sensitive to the effects of direct oil exposure which has been studied extensively following EVOS. The response with the most specificity to crude oil contamination is genetic damage measured by the anaphase aberration rate (Kocan et al. 1982). Brown et al. (1996) report that aberration rates in newly hatched Pacific Herring larvae were strongly correlated with the concentration of EVO-PAH in adjacent mussels and with every other PAH measured except naphthalene which is non-mutagenic. Carls et al. (1999) also studied the effects of oil exposure on Pacific Herring eggs in a laboratory setting mimicking conditions in PWS and found similar outcomes of malformation and reduced survival of larvae. They also noted the presence of cardiac edema that would be expected to impact survival of larvae in the wild. More recent studies of Pacific Herring embryos following EVOS and the *Cosco Busan* spill in San Francisco Bay in 2007 have demonstrated that relatively low concentrations of hydrocarbons are associated with developmental abnormalities noted earlier. In addition, a number of studies have demonstrated adverse developmental effects on cardiac morphology resulting in reduced aerobic capacity in adult Pacific Herring and contributing to reduced survival of all affected life stages

(Incardona et al. 2004; Hicken et al. 2011; Incardona et al. 2009, 2012, 2015). A recent study also provides evidence of impacts due to oil exposure on the embryonic development of the eye (particularly the retina) potentially resulting in reduced ability of Pacific Herring larvae to feed and avoid predation (Magnuson et al. 2020).

Following metamorphosis and transition to the adult form in early summer, June-July, the young-of-the-year Pacific Herring are mobile and have joined schools in the inshore sections of the bays and inlets of the northeast Pacific Ocean. At this life stage they have the physical ability to avoid direct contact with accidental releases of oil into the marine environment but whether they have the physiological ability to detect and avoid areas containing even dilute concentrations of hydrocarbons from a spill is unknown. Relatively little research has focused on the effects of such incidental oil exposure and so inferences must be restricted to the results associated with adult exposure. A number of studies have assessed the effects of oil exposure on adult Pacific Herring. Following the *Exxon Valdez* spill in 1989, Pacific Herring were present in or beginning to congregate in shallow bays of PWS for annual mass spawning in April. The adult Pacific Herring in oiled areas of PWS exhibited significant oil-associated lesions and evidence of hydrocarbon exposure not evident from those in reference sites (Marty et al. 1999). Pacific Herring from oiled sites had hepatic necrosis and elevated PAH concentrations (primarily naphthalenes) in their tissues (Marty et al. 1999). Naphthalenes also accumulated in muscle tissue in laboratory exposures of adult Pacific Herring to PAH in water, evidence of metabolism and differential uptake (Carls et al. 2002). Pacific Herring from oil-exposed areas also contained fewer nematode parasites in their body cavities than non-exposed individuals suggesting movement into the muscle tissue. Pacific Herring captured in oiled areas had a higher prevalence of hepatic necrosis, and viral hemorrhagic septicemia virus (VHSV) leading to mortality than control fish in a laboratory study (Carls et al. 1998). Direct significant mortality of adult Pacific Herring in 1989 as a result of the oil spill in PWS was not documented. However, lesions in Pacific Herring sampled from oiled sites in 1989 were consistent with lesions in fish from which VHSV was isolated in subsequent studies (Marty et al. 1998, 1999), and some portion of the population likely succumbed to the viral outbreak. These effects either resulted in mortality or were transitory since samples collected in 1990 and 1991, had no oil related lesions nor significant PAH concentrations in their tissue (Marty et al. 1999). Debate continues regarding the role oil exposure may have had on the expression of VHSV disease and *Ichthyophonus hoferi* infections in Pacific Herring in PWS (Marty et al. 2010; Pearson et al. 2012). It has been demonstrated that VHSV is endemic to Pacific Herring and most prevalent in younger fish that appear to develop immunity following non-lethal exposure and that disease occurrence seems to be facilitated by various environmental stressors (Hershberger et al. 2016). Both VHSV and *I. hoferi* infection can lead to mortality but the extent of its overall impact on the Pacific Herring population in PWS remains unclear. The available evidence suggests that direct exposure to oil from a spill may have short term impacts on adult and possibly immature Pacific Herring but the effects appear to be transient (Pearson et al. 2012). Therefore, the timing of a spill event in the annual life cycle of Pacific Herring will affect the seriousness of any impacts. For much of the year (roughly May to October), immature and adult Pacific Herring are expected to occur in offshore feeding areas in BC and so be remote from most likely inshore spill events. In the fall, as Pacific Herring begin an annual inshore migration, they aggregate into large schools near to but away from ultimate spawning beaches (Haegele and Schweigert 1985). During January and February schools begin to disaggregate and approach nearer to their spawning sites. At this point, adult and immature Pacific Herring may be susceptible to a significant spill event but have the capacity to avoid direct oil exposure. For example, following the *Nestucca* oil spill off Washington State in December 1988, oil was carried along the coastline of Vancouver Island and some entered the inlets including Barkley Sound (Davis 1989; Harding 2015). Herring typically spawn along the northwestern shore of the sound along Macoah Passage. However, in 1989 they avoided the area entirely, spawning throughout the adjacent Broken Island archipelago which had never previously or since been a spawning site (Davis 1989). Spawning was also delayed by approximately 7-10 days from the average timing suggesting that perhaps the fish were avoiding known oil deposits in their preferred spawning locations. Thus, it suggests that adult Pacific Herring in spawning condition may remain near their usual spawning beaches searching for appropriate spawning locations but attempting to avoid oil to the extent possible. In the case of EVOS it appears that adult Pacific Herring spawners had already moved into bays in preparation for spawning and either would not or could not leave these areas thereby being directly exposed to oil from the spill.

In summary, Pacific Herring are most vulnerable to oil spill events as eggs and post-hatch larvae before they become more mobile. Young-of-the-year or juvenile Pacific Herring remain inshore or nearshore and so could be exposed to a large local spill event but have some capacity to avoid direct contact with oil. Immature and adult Pacific Herring spend the bulk of the year in the offshore and so are somewhat remote from nearshore oil spill events except during a shorter time window during March or April in BC when they are near or on spawning beaches and reluctant to leave the area as occurred in PWS following the *Exxon Valdez* spill.

ACKNOWLEDGMENTS

The Exxon Valdez Trustee Council has funded a broad range of research studies on Pacific Herring and other species that have greatly increased the understanding of possible hydrocarbon impacts on Pacific Herring in the marine ecosystem of Prince William Sound and elsewhere. Matt Thompson and Matt Grinnell of DFO provided advice on aspects of the Pacific Herring spawn deposition database. Reviews and comments by Shannon Stuyt and Sarah Power of DFO are appreciated and have improved the accuracy and completeness of the report.

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APPENDICES

APPENDIX 1. HAIDA GWAII SUMMARY OF PACIFIC HERRING SPAWNING LOCATIONS, FREQUENCY, SIZE, AND TIMING BY SECTION WITHIN STATISTICAL AREAS

Information on spawning locations of Pacific Herring has been collected in portions of Haida Gwaii since the 1930s but considerably later in some of the more remote areas. Summaries provided below are of all available records of spawning although any that are incomplete were excluded. The summaries and tables below provide a count of the number of spawning observations in each section, a tally of the total cumulative shoreline length of egg deposition from all available complete records as a proxy for relative abundance, an estimate of the average length of an egg bed along the shore, an estimate of the average date of beginning of spawning in the section, the reported earliest date of spawning at any location within the section, the latest date reported for the end of spawning activity in any location in the section, and the longest reported duration of spawning at any location in the section. Fishery landings are reported on a seasonal basis from July 1 in year one to June 30 in year two. In the narrative below fishery landings are referred to by the second year of the season, e.g., 1950-51 is noted as a 1951 landing.

STATISTICAL AREA 00

Section 001 – Other Area 2W

Pacific Herring spawning occurs in two areas within this section, Tasu Sound (Newcombe Inlet and Two Mountain Bay) and Gowgaia Bay. However, all observations for Gowgaia Bay occurred in 1971 (Hay et al. 1989a). The spawning reports span the period from 1959 to 1993 and are intermittent within the section. No spawn has been reported in the Section since the early 1990s (Newcombe Inlet). The average DOY (day of the year) for the beginning of spawning is April 6 (DOY 96). Spawning may occur as early as March 18 (DOY 77) and end as late as April 22 (DOY 112). The longest duration of spawning observed in the section is 10 days in Newcombe Inlet. One reduction fishery period landing is reported for 1966. No spawn-on-kelp fishery landings are reported in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Section 002 Port Louis

Pacific Herring spawning occurs in two areas within this section, Port Louis and Port Chanal and Otard Bay. There are no reported spawnings prior to 1959 but they have been fairly consistent through to 2020. It appears that the size and extent of spawning since 1990 is greater than earlier. The average date for the beginning of spawning is March 27 (DOY 86). Spawning occurs as early as March 3 (DOY 62) in Otard Bay and ended as late as May 1 (DOY 121) in Port Louis. The longest duration of spawning observed in the section was 15 days in Port Chanal and Port Louis. Reduction fishery landings are reported in 1964 and 1965 but no roe fisheries are expected to occur in the area although spawn-on-kelp fisheries have occurred in the area intermittently since 1998 including 2020. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Section 003 Rennell Sound

Pacific Herring spawning has occurred in four main areas within this section, Seal Inlet, Tartu Inlet, Shields Bay and Kano Inlet. (Hay et al. 1989a). The spawning reports span the period 1953 to 2013 and are generally continuous throughout. The earliest reported spawning occurred in Shields Bay and Seal Inlet whereas spawning since 1990 has been concentrated in Kano Inlet and Seal Inlet and Shields Bay. The average date for the beginning of spawning is April 3 (DOY 93). Spawning may occur as early as March 3 (DOY 62) in Seal Inlet and end as late as April 29 (DOY 119) also in Seal Inlet. The longest duration of spawning observed in the section was 30 days in Seal Inlet. One reduction fishery landing is reported in 1957 and sporadic roe fishery landings were reported from 1974 through 1993 but none are currently anticipated. Spawn-on-kelp fisheries have occurred infrequently since 2008 including 2020. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Section 004 Cartwright Sound

Pacific Herring spawning has occurred in one area at the mouth of Skidegate Channel (Downie Island, Dawson Harbour, and Skidegate Channel West) (Hay et al. 1989a). The spawning reports are intermittent throughout the period from 1942 to 2010. The average date for the beginning of spawning is April 10 (DOY 100). Spawning occurred as early as March 25 (DOY 84) at Downie Island and ended as late as May 3 (DOY 123). The longest duration of spawning observed in the section was 13 days. No roe or spawn-on-kelp fisheries have occurred in this area and none are anticipated. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Section 005 Englefield Bay

Pacific Herring spawning has occurred primarily within Inskip Channel/Peel Inlet (Hay et al. 1989a). The records of spawning activity span the period from 1958 to 2018 and are mostly continuous from 1958 to 1994 and intermittent since. The average date for the beginning of spawning is April 8 (DOY 98). Spawning occurred as early as March 20 (DOY 79) in MacKenzie Cove and ended as late as May 3 (DOY 123) also in MacKenzie Cove. The longest duration of spawning observed in the section was 12 days in MacKenzie Cove. One reduction fishery landing was reported in 1965 and roe fishery landings were sporadic from 1973 to 1993 and none are currently anticipated. No spawn-on-kelp fisheries have occurred here. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Section 006 Louscoone Inlet

Pacific Herring spawning has occurred in two main areas in this section, Louscoone and Flamingo Inlets (Hay et al. 1989a). Spawning records span the period 1940 to 2019 and have been mostly continuous since 1970. The average date for the beginning of spawning is March 26 (DOY 85). Spawning occurred as early as February 26 (DOY 57) and ended as late as April 30 (DOY 120). The longest duration of spawning observed in the section was 12 days in Louscoone Inlet. Reduction fishery landings are reported in 1957, 1964, 1965, and 1967. Roe fishery landings have been reported sporadically from 1972 to 1992 and none are currently anticipated.

No spawn-on-kelp landings have been reported for the area. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Table 1. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 00, Haida Gwaii, 1928 to 2021.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 001, Other Area 2W	63	39973	634	April 6	March 18	April 22	10
Section 002, Port Louis	452	359099	794	March 27	March 3	May 1	15
Section 003, Rennell Sound	299	211823	708	April 3	March 3	April 29	30
Section 004, Cartwright Snd	53	27616	521	April 10	March 25	May 3	13
Section 005, Englefield Bay	208	180641	868	April 8	March 20	May 3	12
Section 006, Louscoone In	270	241590	895	March 26	February 26	April 30	12

STATISTICAL AREA 01

Section 011 Other Area 01

Pacific Herring spawning has occurred primarily in two locations within Massett Inlet, Juskatla Inlet and Awun Bay (Hay et al. 1989a). Spawning records span the period from 1934 to 1996 but are intermittent with a single record since 1985. The area hosts the latest known spawnings on the BC coast. The earliest reported spawning occurred here in Awun Bay on June 10 (DOY 161). The average date for the spawning in the area is June 21 (DOY 172) in Juskatla Inlet. Spawning ended as late as July 1 (DOY 182) also in Juskatla Inlet. The longest duration of spawning observed in the section was 11 days in Juskatla Inlet and Massett Inlet proper. Two reduction fishery landings are reported for 1957 and 1958 and scattered bait fishery landings from 1972 through 1989. A single roe landing was reported in 1976 but none are currently anticipated. No spawn-on-kelp fisheries have occurred here. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Section 012 Naden Harbour

Pacific Herring spawning has occurred in two main locations in this area, Isabella Point and Naden Harbour (Hay et al. 1989a). The spawning in this section is among the earliest on the BC coast. The observations or reports of spawning span the period from 1970 to 2005 and are mostly continuous from 1974 to 1983. The earliest reported spawning occurred within Naden Harbour on February 1 (DOY 32). The average date for the beginning of spawning is March 3 (DOY 62) and spawning ended as late as April 17 (DOY 107). The longest duration of spawning observed in the section was 12 days at Bain Point. A handful of fisheries have occurred in the area, 1956 and 1958 for reduction, and gillnet roe during the late 1970s but none are currently anticipated.

No spawn-on-kelp fisheries have occurred here. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Table 2. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 01, Haida Gwaii, 1928 to 2021.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 011, Massett Inlet	25	36989	1480	June 21	June 10	July 1	11
Section 012, Naden Hbr	137	87869	641	March 3	Feb 1	April 17	12

STATISTICAL AREA 02

Section 021 Juan Perez Sound

Prior to 1988, Section 21 was part of Section 24 but was subsequently split off to include the northern half of Burnaby Island to the southern half of Lyell Island essentially encompassing Sedgwick Bay (Haist and Rosenfeld 1988). Within this area, Pacific Herring spawning has occurred primarily within Burnaby Strait, Alder Island, and Huxley Island (Hay et al. 1989a). Spawning records span the period 1940 to 2020 and are mostly continuous throughout except 1972 to 1976. The earliest reported spawning occurred within Burnaby Strait on February 26 (DOY 57). The average date for the beginning of spawning is April 3 (DOY 93) the end of spawning occurred as late as May 18 (DOY 138) in Section Cove. The longest duration of spawning observed in the section was 44 days also in Section Cove. Reduction fishery landings are reported regularly for the area from 1951 to 1965 and roe landings from 1972 through 2002 and none are currently anticipated. The spawn-on-kelp fishery operated in the area only in 1989. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Section 022 Skidgate Inlet

The major Pacific Herring spawning locations with this area are near Skidegate Village. Herring spawning has occurred primarily at Maude Island and Image Point and Torrens Island (Hay et al. 1989a). The number of locations at which spawning has occurred is much reduced since 1990. The record of spawning is mostly continuous from 1937 to 1988 and then intermittent through 2019. The earliest spawning was reported in Skidegate Inlet on March 1 (DOY 60). The average date for the beginning of spawning is May 13 (DOY 133). The end of spawning occurred as late as July 19 (DOY 200) at Image Point. The longest duration of spawning observed in the section was 84 days. Reduction fishery landings are reported almost annually from 1954 to 1967, bait fishery landings periodically from 1952 to 1994, and roe landings regularly from 1972 to 1988. However, no fisheries are currently anticipated. The spawn-on-kelp fishery operated in the area on an experimental basis only in 1975. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Section 023 Cumshewa Inlet

Pacific Herring spawning has occurred in two main locations in this area: Conglomerate Point and Beattie Anchorage (Hay et al. 1989a). The record of spawn observations spans the period from 1943 to 2020 and is mostly consistent from 1970 to 1995 and sporadic afterwards. The average date for the beginning of spawning is April 21 (DOY 111). Spawning occurred as early as March 26 (DOY 85) at Davie Islets and ended as late as June 25 (DOY 176) at Beattie Anchorage. The longest duration of spawning observed in the section was 18 days at Conglomerate Point. A single reduction fishery landing is reported in 1956, four food or bait landing from 1971 to 1977, and annual roe landings from 1971 to 1976. No fishery landings are currently anticipated. No spawn-on-kelp fisheries have occurred in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Section 024 Laskeek Bay

The major Pacific Herring spawning locations with this area are near Sewell and Selwyn Inlets and Sedgewick Bay (Hay et al. 1989a). The spawn record extends from 1940 to 2020 and is fairly complete. However, the number of locations at which spawning is reported has decreased since 1990. The earliest spawning was reported in Lagoon Inlet on February 3 (DOY 34). The average date for the beginning of spawning is April 11 (DOY 101). The end of spawning has occurred as late as May 29 (DOY 149) in Selwyn Inlet. The longest duration of spawning observed in the section was 33 days in Klunkwoi Bay. Reduction fishery landings are reported sporadically between 1952 and 1968, six bait and food landings from 1966 to 1983, and four roe landing between 1981 and 1994 and none are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Section 025 Skincuttle Inlet

There are four major Pacific Herring spawning locations with this area: Huxley-Alder Island, Bag Harbour-Slim Inlet, north and south shores of Skincuttle Inlet (Hay et al. 1989a). The record of spawning activity extends from 1940 to 2020 and is reported almost annually. The earliest spawning was reported in Huston Inlet on February 14 (DOY 45). The average date for the beginning of spawning is March 26 (DOY 85). The end of spawning activity has occurred as late as May 10 (DOY 130) at Jedway. The longest duration of spawning observed in the section was 16 days. Reduction fishery landings are reported between 1956 and 1967, seven bait landings between 1975 and 1988, and almost annual roe landing from 1972 to 1986 and sporadically to 2000. No fisheries are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989a).

Table 3 Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 02, Haida Gwaii, 1928 to 2021.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 021, Juan Perez Sound	857	914870	1068	April 3	February 26	May 18	44
Section 022, Skidegate Inlet	385	180403	469	May 13	March 1	July 19	84
Section 023, Cumshewa Inlt	243	174236	717	April 21	March 26	June 25	18
Section 024, Laskeek Bay	453	484372	1069	April 11	February 3	May 29	33
Section 025, Skincuttle Inlet	796	911090	1145	March 26	February 14	May 10	16

APPENDIX 2. PRINCE RUPERT DISTRICT SUMMARY OF PACIFIC HERRING SPAWNING LOCATIONS, FREQUENCY, SIZE, AND TIMING BY SECTION WITHIN STATISTICAL AREAS

Information on Pacific Herring spawning locations has been collected in portions of Prince Rupert District since the 1930s. Summaries provided below are of all available records of spawning although any that are incomplete were excluded. The summaries and tables below provide a count of the number of spawning observations in each section, a tally of the total cumulative shoreline length of egg deposition from all available complete records as a proxy for relative abundance, an estimate of the average length of an egg bed along the shore, an estimate of the average date of beginning of spawning in the section, the reported earliest date of spawning at any location within the section, the latest date reported for the end of spawning activity in any location in the section, and the longest reported duration of spawning at any location in the section. Fishery landings are reported on a seasonal basis from July 1 in year one to June 30 in year two. In the narrative below fishery landings are referred to by the second year of the season, e.g. 1950-51 is noted as a 1951 landing.

STATISTICAL AREA 03

Section 032 Portland Inlet

The two main Pacific Herring spawning locations within this area are in the upper reach, Hastings and Alice Arms, and in the lower reach, Work Channel and Nasoga Gulf (Hay et al. 1989b). The record of spawning spans from 1933 to 1996 with only a single record prior to 1958 and after 1983 and intervening spawning reports are intermittent. The earliest spawning was reported in Marmot Bay on March 7 (DOY 66). The average date for the beginning of spawning is March 27 (DOY 86) and spawning has occurred as late as June 3 (DOY 154) in Nasoga Gulf. The longest duration of spawning observed in the section was 11 days. Reduction fishery landings are reported annually from 1958 to 1967, almost annual bait landings from 1959 to 1972 and one in 1984. A single roe fishery landing was reported in 1972 and no further landings are anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989b).

Section 033 Port Simpson

The main Pacific Herring spawning location in this section is focused in Stumaun Bay (Hay et al. 1989b). The record of spawning activity spans 1933 to 2020 and is reported regularly from 1950 to 2020. The earliest spawning was reported in Port Simpson on March 9 (DOY 68). The average date for the beginning of spawning is April 5 (DOY 95) and end of spawning activity has occurred as late as May 22 (DOY 142) at Finlayson Island West. The longest duration of spawning observed in the section was 20 days at Port Simpson. Food fishery landings are reported between 1970 and 1974 and roe fishery landings periodically between 1972 and 2006. The spawn-on-kelp fishery has operated in the area in 1982 and 1983. Maps of the spawning locations and additional information are available in Hay et al. (1989b).

Table 4 Table 4. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 03, Prince Rupert District, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 032 Portland Inlet	38	30089	792	March 27	March 7	June 3	11
Section 033, Port Simpson	435	461618	1061	April 5	March 9	May 22	20

STATISTICAL AREA 04

Section 042 Big Bay

The two main Pacific Herring spawning locations within this area are between Otter Anchorage and Tugwell Island centered at Big Bay and a smaller one between Metlakatla and Prince Rupert Harbour (Hay et al. 1989b). The record of spawning activity extends from 1931 to 2020 and is reported almost annually throughout this period. The earliest spawning was reported in the vicinity of both Duncan Bay and Pearl Harbour on March 10 (DOY 69). The average date for the beginning of spawning is April 1 (DOY 91) and the end of spawning has occurred as late as June 28 (DOY 179) at Swamp Island. The longest duration of spawning observed in the section was 34 days in Pearl Harbour. Almost annual reduction fishery landings are reported from 1954 to 1968, food and bait landings from 1953 to 1993, and regular roe fishery landings from 1974 to 2018. Future roe fishery landings may be anticipated in this area. The spawn-on-kelp fishery has operated intermittently in the area since 1982. Maps of the spawning locations and additional information are available in Hay et al. (1989b).

Section 043 North Porcher Island

The two main Pacific Herring spawning locations within this area are between Hunts Inlet and Malacca Passage and Chismore Passage (Hay et al. 1989b). The record of spawning spans the period from 1931 to 2020 and is reasonably complete except for gaps in the 1950s and 1960s and fewer reports since 2000. The earliest spawning was reported at Butler Cove on March 17 (DOY 76). The average date for the beginning of spawning is April 15 (DOY 105) and the end of spawning has occurred as late as June 4 (DOY 155) at Bedford Island. The longest duration of spawning observed in the section was 11 days in Hunts Inlet. Regular reduction fishery landings were reported between 1951 and 1968, sporadic food and bait landings from 1953 to 1986, and seven roe fishery landings from 1974 to 1997. No future roe fishery landings are anticipated as the area is a focus of spawn-on-kelp production. The spawn-on-kelp fishery has operated intermittently in the area since beginning in 1975. Maps of the spawning locations and additional information are available in Hay et al. (1989b).

Table 5 Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 04, Prince Rupert District, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 042 Big Bay	1163	1571514	1351	April 1	March 10	June 28	34
Section 043, N. Porcher Is	435	461618	1061	April 15	March 17	June 4	11

STATISTICAL AREA 05

Section 051 Banks Island

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier summary of the spawning observations by Hay et al. (1989b). The two main Pacific Herring spawning locations within this area are Kingkown Inlet at the northwest tip of Banks Island and Joachim Point at the southwest coast of Goschen Island which should be considered with Kitkatla Inlet below (Hay et al. 1989b). Reports of spawning span the period from 1937 to 2020 but are sporadic likely because of the remote location. The earliest spawning was reported on March 15 (DOY 74) at Indian Harbour. The average date for the beginning of spawning is April 10 (DOY 100) and the end of spawning has occurred as late as April 30 (DOY 120) in Kingkown Inlet. The longest duration of spawning observed in the section was 8 days in Ogden Channel. Reduction fishery landings are reported regularly from 1951 to 1968, bait fishery landings regularly from 1951 to 1971 and sporadically through to 1992, food landings from 1978 to 1984, and three roe fishery landings in 2000, 2005, and 2006. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989b).

Section 052 Kitkatla Inlet

Pacific Herring spawning observations are focused in three main areas: Kitkatla Inlet-Gurd Island, Freeman Passage, and Billy Bay-Gasboat Passage (Hay et al. 1989b). The observations of spawning activity are continuous from 1937 to 2020. The earliest spawning was reported on March 7 (DOY 66) at Kitkatla Creek. The average date for the beginning of spawning is April 8 (DOY 98) and end of spawning has occurred as late as May 21 (DOY 141) in Gunboat Passage. The longest duration of spawning observed in the section was 31 days at Pelham Island in Gunboat Passage. Reduction fishery landings are reported regularly from 1951 to 1967, sporadic bait fishery landings are reported from 1955 to 1988, intermittent food landings from 1971 to 1986, with almost annual roe fishery landings from 1971 to 2017 and future landings are anticipated. The spawn-on-kelp fishery has operated in the area consistently since the beginning in 1975 and is expected to continue. Maps of the spawning locations and additional information are available in Hay et al. (1989b).

Section 053 Anger Island

Pacific Herring spawning occurs in two main areas in the section: Wilson Inlet-Tangent Island and Curtis Inlet (Hay et al. 1989b). The record of spawning activity spans the period from 1955 to 2002 and is intermittent throughout. The earliest spawning was reported on April 5 (DOY 95) at Wilson Inlet. The average date for the beginning of spawning is April 20 (DOY 110) and the end of spawning has occurred as late as May 16 (DOY 136) at Tangent Island. The longest duration of spawning observed in the section was 7 days. A handful of reduction fishery landings are reported from 1957 to 1967, two bait landings in 1964 and 1976, and one roe fishery landing in 1978, but no landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989b).

Table 6 Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 05, Prince Rupert District, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 051 Banks Island	52	31141	599	April 10	March 15	April 30	8
Section 052, Kitkatla Inlet	1064	961465	904	April 8	March 7	May 21	31
Section 053 Anger Island	117	59898	512	April 20	April 5	May 16	7

APPENDIX 3. CENTRAL COAST SUMMARY OF PACIFIC HERRING SPAWNING LOCATIONS, FREQUENCY, SIZE, AND TIMING BY SECTION WITHIN STATISTICAL AREAS

Information on Pacific Herring spawning locations has been collected in portions of the Central Coast since the 1930s. Summaries provided below are of all available records of spawning although any that are incomplete were excluded. The summaries and tables below provide a count of the number of spawning observations in each section, a tally of the total cumulative shoreline length of egg deposition from all available complete records as a proxy for relative abundance, an estimate of the average length of an egg bed along the shore, an estimate of the average date of beginning of spawning in the section, the reported earliest date of spawning at any location within the section, the latest date reported for the end of spawning activity in any location in the section, and the longest reported duration of spawning at any location in the section. Fishery landings are reported on a seasonal basis from July 1 in year one to June 30 in year two. In the narrative below fishery landings are referred to by the second year of the season, e.g. 1950-51 is noted as a 1951 landing.

STATISTICAL AREA 06

Section 061 Caamano Sound

The only Pacific Herring spawning location within this section is Kettle Inlet (Hay et al. 1989c) and there are only 15 total observations. There are no spawning records prior to 1982, and they are sporadic through 2004 and absent since (Hay et al. 1989c). The earliest spawning was reported on February 13 (DOY 44). The average date for the beginning of spawning is March 10 (DOY 69) and the end of spawning has occurred as late as April 6 (DOY 96). The longest duration of spawning observed in the section was 3 days. Annual reduction fishery landings are reported from 1957 to 1968, and three years of bait landings between 1978 and 1982. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Section 062 Gil Island

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier summary of the spawning observations by Hay et al. (1989c). The main Pacific Herring spawning locations within this section are Hawkesbury Island, Promise Island, and Barnard Harbour (previously in Section 061). The spawning records span the period from 1931 to 1983 but are intermittent and spotty prior to 1973. The earliest spawning was reported in Douglas Channel on March 28 (DOY 87). The average date for the beginning of spawning is May 15 (DOY 135) and the end of spawning has occurred as late as June 22 (DOY 173) at Gil Island. The longest duration of spawning observed in the section was 11 days at Hawkesbury Island. Annual reduction fishery landings are reported from 1954 to 1968, and a single bait landing in 1967. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Section 063 Kitimat Arm

The section has three main Pacific Herring spawning locations at Kitimat, Minette Bay, and Kildala Arm (Hay et al. 1989c). The records of spawning activity span 1934 to 1993 and are mostly continuous through to 1978 and 1990 to 1993 but absent since. The earliest spawning was reported in Minette Bay on February 5 (DOY 36). The average date for the beginning of spawning is March 22 (DOY 81) and the latest spawning has occurred on May 2 (DOY 122) at Gilttoyees Inlet. The longest duration of spawning observed in the section was 11 days at Kitimat Mission. Reduction fishery landings are reported in 1955 and annually from 1959 to 1968 but no fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Section 064 Gardner Canal

The section has three main Pacific Herring spawning locations at Kemano, Chief Matthews Bay and Price Cove (Hay et al. 1989c). The spawning records are incomplete but mostly continuous during the period between 1949 and1971 with no recent observations. The earliest spawning was reported in Gardner Canal on March 11 (DOY 70). The average date for the beginning of spawning is March 28 (DOY 87) and latest spawning date is April 15 (DOY 105). The longest duration of spawning observed in the section was 5 days. A handful of fishery landings occurred in this area in the reduction period from the 1950s and 1960s. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Section 065 Princess Royal Channel

The section has two main Pacific Herring spawning locations at Aaltanhash and Khutze Inlets (Hay et al. 1989c). The spawning records are incomplete (only 15 observations) and intermittent spanning the period 1959 to 1977. The earliest spawning was reported in Khutze Inlet on March 23 (DOY 82). The average date for the beginning of spawning is April 12 (DOY 102) and the end of spawning has occurred as late as April 28 (DOY 118) at Klekane Inlet. The longest duration of spawning observed in the section was 13 days at Klekane Inlet. Reduction fishery landings were reported in eight years between 1952 and 1967 but no fishert landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Section 066 Surf Inlet

The observations of Pacific Herring spawning are concentrated in Racey and Surf Inlets and at Emily Carr Inlet-Duckers Island on the west side of Princess Royal Island (Hay et al. 1989c). The area is remote and observations of spawning are sporadic from 1934 to 1999. The earliest spawning was reported in Surf Inlet on March 20 (DOY 79). The average date for the beginning of spawning is April 10 (DOY 100) and end of spawning has occurred as late as May 14 (DOY 134) in Surf Inlet. The longest duration of spawning observed in the section was 11 days. Reduction fishery landings are reported in five years between 1951 and 1966, and two bait landings in 1962 and 1970, but no fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Section 067 Laredo Inlet

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier summary of the spawning observations by Hay et al. (1989c). The records of Pacific Herring spawning activity are concentrated in two main locations in the section: Kitasu Bay and Weeteam Bay. The records of spawning activity are mostly continuous spanning the years 1934 to 2020. The earliest spawning was reported at Marvin Island in Kitasu Bay on March 4 (DOY 63). The average date for the beginning of spawning is March 29 (DOY 88) and the end of spawning has occurred as late as May 5 (DOY 128) at Thistle Passage. The longest duration of spawning observed in the section was 24 days at Wilby Point in Kitasu Bay. Annual reduction fishery landings were reported between 1951 and 1967, sporadic food or bait landings between 1952 and 1988, and annual roe landings from 1974 to 1990 and sporadically to 2014 and may be anticipated sometime in the future. The spawn-on-kelp fishery has operated in the area consistently from 1981 to present except for 2008 to 2013. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Table 7 Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 06, Central Coast, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 061 Caamano Snd	15	9462	631	March 10	February 13	April 6	3
Section 062, Gil Island	99	130316	1316	May 15	March 28	June 22	11
Section 063 Kitimat Arm	140	109760	784	March 22	February 5	May 2	11
Section 064 Gardner Canal	35	38811	1109	March 28	March 11	April 15	5
Section 065 Princess Royal Channel	15	8226	548	April 12	March 23	April 28	13
Section 066 Surf Inlet	48	72668	1514	April 10	March 20	Jun 15	11
Section 067 Laredo Inlet	1277	1802955	1412	March 29	March 4	May 8	24

STATISTICAL AREA 07

Section 072 Powell Anchorage

The boundary of this section has been updated to include Spiller Channel (Haist and Rosenfeld 1988) since an earlier report that summarized Pacific Herring spawning activity for this area by

Hay et al. (1989c). There are several important spawning areas in the section: Lady Trutch Passage, Lambard Inlet, Reid Passage, Blair and Berry Inlets, and Spiller Channel. The record of spawning activity spans the period from 1933 to 2020 and is mostly continuous from 1948 and intermittent in earlier years. The earliest date of spawning was reported at Cecilia Island on March 6 (DOY 65). The average date for the beginning of spawning is March 30 (DOY 89) and the end of spawning has occurred as late as April 29 (DOY 119) at Berry Inlet. The longest duration of spawning observed in the section was 25 days at Berry Inlet. Eight years of reduction fishery landings are reported between 1952 and1968, one bait landing in 1956, and almost annual roe fishery landings from 1973 to 2006 and 2015. Additional fishery landings may be anticipated at some future date. The spawn-on-kelp fishery has operated in the area regularly from 1977 to 2020 except 2008 to 2013. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

<u>Section 073 Bella Bella</u>

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989c) summarizing Pacific Herring spawning activity for this area. The important spawning locations in the section are Deer Lagoon, Gunboat Passage and Ormidale Harbour. The spawning records span the period from 1931 to 2020 but are intermittent from 1969 to 2008. The earliest date of spawning was reported at Bella Bella on March 5 (DOY 64). The average date for the beginning of spawning is March 28 (DOY 87) and spawning has occurred as late as April 29 (DOY 119) at Kakushdish Harbour. The longest duration of spawning observed in the section was 43 days at Bella Bella. Annual reduction fishery landings are reported from 1952 to 1968, sporadic food or bait landings from 1952 to 1966 and 1981, and intermittent roe fishery landings from 1972 to 1995, but none are currently anticipated. A small amount of spawn-on-kelp product was landed in the area in 2017. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

<u>Section 074 Thompson Bay</u>

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989c) summarizing Pacific Herring spawning records for this area. There are several important spawning sites in the section: Dundivan Inlet-Joassa Channel, Raymond Passage, Boddy Narrows, Stryker Bay, Waskesiu Passage, Cape Mark-St. John Harbour, and Hochstader Basin. The observations of spawning activity span the period 1933 to 2020 and are mostly continuous. The earliest date of spawning was reported in Joassa Channel on February 19 (DOY 50). The average date for the beginning of spawning is March 31 (DOY 90) and spawning has occurred as late as May 2 (DOY 122) at Stryker Island. The longest duration of spawning observed in the section was 42 days in Seaforth Channel. Reduction fishery landings are reported annually from 1951 to 1967, sporadic food or bait landings from 1953 to 1988, and nearly annual roe fishery landings from 1971 to 2008, and future fishery landings may be anticipated. The spawn-on-kelp fishery has operated in the area intermittently from 1983 to 1990 and 2016 to 2019. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Section 075 McNaughton Group

Pacific Herring spawning records for this section are concentrated in two main areas, Cultus Sound and the McNaughton Island grouping (Hay et al. 1989c). The records span the period 1943 to 2005 and are mostly continuous from 1970 to 1986 and intermittent otherwise. The earliest date of spawning was reported in the McNaughton Group on March 13 (DOY 72). The average date for the beginning of spawning is April 3 (DOY 93), and spawning has occurred as late as April 21 (DOY 111) in Cultus Sound. The longest duration of spawning observed in the section was 19 days at Sans Peur (Choked) Passage. Reduction or bait fishery landings were reported in six seasons between 1954 and 1967, roe fishery landings annually from 1973 to 1978, 1989 and 1993, but none are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Section 076 Kildidt Sound

Pacific Herring spawning records for this section are concentrated in three areas, Spider Anchorage, Kildidt Sound, and Mustang Bay (Hay et al. 1989c). The record of spawning activity spans the period 1939 to 2017 and is continuous except for 1987 although coverage appears incomplete in many years. The earliest date of spawning was reported at Hurricane Island on March 6 (DOY 65). The average date for the beginning of spawning is April 1 (DOY 91) and spawning has occurred as late as April 25 (DOY 115) in Goodlad Bay. The longest duration of spawning observed in the section was 16 days in Kildidt Lagoon. Annual reduction fishery landings are reported from 1951 to 1967, intermittent bait or food landings from 1952 to 1992, and annual roe fishery landings from 1972 to 1978 and sporadically to 1994, but none are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Section 077 Milbanke Sound

The spawning records for this section were previously included with Section 067 by Hay et al. (1989c). The focus of Pacific Herring spawning in this section is concentrated in east Higgins Passage. The records span the period 1984 to 2019 and are mostly continuous. The earliest date of spawning was reported in the area on March 24 (DOY 83). The average date for the beginning of spawning is April 2 (DOY 92) and spawning has occurred as late as April 27 (DOY 117) in Higgins Lagoon. The longest duration of spawning observed in the section was 18 days. Roe fishery landings are reported sporadically between 1984 to 2007 and in 2016, but none are currently anticipated. The spawn-on-kelp fishery has operated in the area periodically. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Section 078 Mathieson and Spiller Channels

The section was previously included within a larger Section 071 (Haist and Rosenfeld 1988) and not part of the earlier summary of spawning records by Hay et al. (1989c). The focus of Pacific Herring spawning in this section is the upper portions of Mathieson and Spiller Channels. The available records span the period 1939 to 2020 and are continuous for Spiller Channel since 1989 and intermittent for Mathieson Channel. Prior to 1989 records are sporadic in both locations. The earliest spawning was reported in Ellerslie Bay (Spiller Channel) on March 9 (DOY 68). The average date for the beginning of spawning is March 28 (DOY 87) and spawning has occurred as late as April 26 (DOY 116) in Culpepper Lagoon (head of Mathieson Channel). The longest duration of spawning observed in the section was 15 days in Ellerslie Bay. Annual reduction fishery landings are reported for 1951 and 1954 to 1968, bait landings in 1961, 1965, and 1971, and sporadic roe fishery landings from 1977 to 1991 followed by intermittent landings from 1993 to 2006 and additional landings may occur in the future. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989c).

Table 8. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 07, Central Coast, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 072 Powell Anch	1151	1586507	1378	March 30	March 6	April 29	25
Section 073 Bella Bella	172	418363	2432	March 28	March 5	April 29	43
Section 074 Thompson Bay	1302	1035649	795	March 31	February 19	May 2	42
Section 075 McNaughton Grp	194	105536	544	April 3	March 13	April 21	19
Section 076 Kildidt Sound	524	404713	772	April 1	March 6	April 25	16
Section 077 Milbanke Sound	181	243015	1343	April 2	March 24	April 27	18
Section 078 Mathieson Ch, Spiller Ch	259	752649	2906	March 28	March 9	April 26	15

STATISTICAL AREA 08

Section 082 Dean Channel and Cousins Inlet

The boundary of this section has been updated to include all of Dean Channel (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The main Pacific Herring spawning area is Kimsquit Bay at the head of Dean Channel. The record of spawning activity is sporadic from 1931 to 2016. The earliest spawning was reported in Dean Channel on February 19 (DOY 50). The average date for the beginning of spawning is March 19 (DOY 78) and the end of spawning has occurred as late as April 11 (DOY 101). The longest duration of spawning observed in the section was 18 days. Intermittent reduction fishery landings are reported from 1952 to 1967, one bait landing in 1962, and no additional landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 083 Bentinck Arms (North and South)

The main Pacific Herring spawning areas for this section are at the head of Burke Channel, north Bentinck Arm at Bella Coola and south Bentinck Arm (Hay et al. 1989d). The spawning records span the period 1931 to 2019 and are mostly continuous from 1936 to1994, followed by observations in 2000 and 2019. The earliest spawning was reported in North Bentinck Arms on February 24 (DOY 55). The average date for the beginning of spawning is March 14 (DOY 73) and the end of spawning has occurred as late as April 24 (DOY 114) in North Bentinck Arm. The longest duration of spawning observed in the section was 19 days in both Arms. Annual reduction fishery landings are reported from 1954 to 1968, but no additional landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 084 Burke Channel

The main Pacific Herring spawning area for this section is in the vicinity of Nyggard Point in Burke Channel (Hay et al. 1989d). The spawning records span the period 1931 to 2011 and are mostly continuous from 1965 to 1997 with a recent observation in 2011. The earliest spawning was reported on March 8 (DOY 67) which is unusual as this population represents one of the latest spawning areas on the coast. The average date for the beginning of spawning is May 31 (DOY 151) and the end of spawning has occurred as late as July 2 (DOY 183). The longest duration of spawning observed in the section was 15 days. Annual reduction fishery landings are reported for 1964 to 1967 and roe fishery landings from 1973 to 1976, but no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 085 Kwakshua Channel

The boundary of this section has been altered to include all Kwakshua Channel and Kwakume and Illahie Inlets but excludes Fish Egg Inlet (Haist and Rosenfeld 1988) since the earlier report by Hay et al. (1989d) summarizing spawning records for this area. The main Pacific Herring spawning areas for this section are Kwakshua Passage-Keith Anchorage on Calvert Island and Kwakume and Illahie Inlets on the mainland. The spawning records span the period from 1937 to 2020 and are mostly continuous since 1952. The earliest spawning was reported in Keith Anchorage on March 11 (DOY 60). The average date for the beginning of spawning is March 30 (DOY 89) and the end of spawning has occurred as late as April 27 (DOY 117) in Illahie Inlet. The longest duration of spawning observed in the section was 32 days in Pruth Bay. Intermittent reduction fishery landings are reported from 1951 to 1968, four food or bait landings in 1963, 1964, 1966, and 1966, and sporadic roe fishery landings from 1973 to 1992. Future fishery landings may be anticipated. The spawn-on-kelp fishery has operated in the area intermittently from 1992 to 2007. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 086 Fitzhugh Sound

The section boundaries have been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The bulk of the area was previously included in Section 81. The section includes both sides of Fitzhugh Sound from Warrior Cove to the mouth of Dean Channel. The main Pacific Herring spawning area for this section is the vicinity of Namu on the mainland coast. The spawning records span the period from 1938 to 2020 and are patchy but mostly continuous since 1971. The earliest spawning reported at Sunny Island was on March 5 (DOY 64). The average date for the beginning of spawning is March 30 (DOY 89) and the end of spawning has occurred as late as April 27 (DOY 117) in Harlequin Basin. The longest duration of spawning observed in the section was 9 days in Mustang Bay. Intermittent reduction fishery landings are reported from 1952 to 1968, five sporadic food or bait landings from 1951 to 1973, and five sporadic roe landings from 1972 to 1992, and no fishery landings are currently anticipated. The spawn-on-kelp fishery has operated in the area sporadically from 1993 to 2017. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Table 9 Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 08, Central Coast, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 082 Dean Channel, Cousins Inlet	46	238751	5190	March 19	February 19	April 11	18
Section 083 Bentinck Arms	230	561011	2439	March 14	February 24	April 24	19
Section 084 Burke Channel	213	464509	2181	May 31	March 8	July 2	15
Section 085 Kwakshua Ch	727	724054	996	March 30	March 1	April 27	32
Section 086 Fitzhugh Sound	118	106551	903	March 30	March 5	April 27	9

STATISTICAL AREA 09

Section 091 Fish Egg Inlet

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. It was previously included as part of Section 85. The main Pacific Herring spawning area is Fish Egg Inlet and the immediate vicinity. The spawning records span the period from 1933 to 1981 and 2019 and are intermittent throughout. The earliest spawning was reported in Fish Egg Inlet on February 25 (DOY 56). The average date for the beginning of spawning is March 28 (DOY 87) and the end of spawning has occurred as late as April 5 (DOY 95) in Fish Egg Inlet. The longest duration of spawning observed in the section was 11 days. Nearly annual reduction fishery landings are reported from 1954 to 1967, five seasons of food or bait landings between 1962 and 1972, and a single roe fishery landing in 1972, but no fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 092 Rivers Inlet Entrance

The main Pacific Herring spawning areas at the mouth of Rivers Inlet include Pierce and Goose Bays and Draney Inlet (Hay et al. 1989d). The spawning records span the period from 1933 to 2009 and are mostly continuous through 1983 but intermittent since. The earliest spawning was reported at Goose Bay on March 10 (DOY 69). The average date for the beginning of spawning is March 22 (DOY 95) and the end of spawning has occurred as late as May 5 (DOY 125) in Draney Inlet. The longest duration of spawning observed in the section was 20 days in Goose Bay. Annual reduction fishery landings are reported for 1955 to 1967, a single food landing in 1971, and three seasons of roe fishery landings between 1972 and 1975 and no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 093 Rivers Inlet Head

The main Pacific Herring spawning area is at the head of Rivers Inlet (Hay et al. 1989d). The spawn records span the period from 1931 to 2006 and are mostly continuous throughout. The earliest spawning was reported at Kilbella Bay on March 5 (DOY 64). The average date for the beginning of spawning is March 22 (DOY 81) and the end of spawning has occurred as late as April 26 (DOY 116) in McPhee Bay. The longest duration of spawning observed in the section was 24 days in Kilbella Bay. Annual reduction fishery landings are reported from 1951 to 1968, and roe fishery landings from 1972 to 1977, but no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Table 10. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 09, Central Coast, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 091 Fish Egg Inlet	37	50273	1359	March 28	February 25	April 5	11
Section 092 Rivers Inlet Entrance	129	126564	981	April 5	March 10	May 5	20
Section 093 Rivers Inlet Headl	393	787998	2005	March 22	March 5	April 26	24

STATISTICAL AREA 10

Section 102 Takush Harbour

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. It now includes portions of what was previously included in Section 101. The main Pacific Herring spawning area is Takush Harbour and the immediate vicinity. The spawning records span the period from 1934 to 2020 and are mostly continuous throughout. The earliest spawning was reported in McBride Bay on February 27 (DOY 58). The average date for the beginning of spawning is March 30 (DOY 89) and the end of spawning has occurred as late as July 4 (DOY 185) in various locations. The longest duration of spawning observed in the section was 22 days at Fly Basin. Fishery landings occurred rarely in this area during the reduction fishery (one landing in 1967) or roe fishery (1973 to 1975) and none are currently anticipated. The spawn-on-kelp fishery has operated in the area continuously from 1980 to 2008 and sporadically since. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 103 Smith Inlet

The main Pacific Herring spawning area is at the head of Smith Inlet centered in the vicinity of Burnt Island (Hay et al. 1989d). The spawn records span the period from 1931 to 2016 and are mostly continuous from 1970 to 1984 and sporadic otherwise. The earliest spawning was reported on March 14 (DOY 73). The average date for the beginning of spawning is April 8 (DOY 98) and spawning has occurred as late as May 18 (DOY 138). The longest duration of spawning observed in the section was 19 days in Burnt Cliff Harbour. Regular reduction fishery landings are reported from 1954 to 1968, food landings in 1971 and 1972, and roe landings during four seasons between 1972 and 1967, but no additional landings are currently anticipated. The spawn-on-kelp fishery has been largely restricted to adjacent Section 102. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Table 11. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 10, Central Coast, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 102 Takush Hbr	626	478351	764	March 30	February 27	July 4	22
Section 103 Smith Inlet	61	67697	1110	April 8	March 14	May 18	19

APPENDIX 4. JOHNSTONE STRAIT SUMMARY OF PACIFIC HERRING SPAWNING LOCATIONS, FREQUENCY, SIZE, AND TIMING BY SECTION WITHIN STATISTICAL AREAS

Information on Pacific Herring spawning locations has been collected in portions of Johnstone Strait since the 1930s. Summaries provided below are of all available records of spawning although any that are incomplete were excluded. The summaries and tables below provide a count of the number of spawning observations in each section, a tally of the total cumulative shoreline length of egg deposition from all available complete records as a proxy for relative abundance, an estimate of the average length of an egg bed along the shore, an estimate of the average date of beginning of spawning in the section, the reported earliest date of spawning at any location within the section, the latest date reported for the end of spawning activity in any location in the section, and the longest reported duration of spawning at any location in the section. Fishery landings are reported on a seasonal basis from July 1 in year one to June 30 in year two. In the narrative below fishery landings are referred to by the second year of the season, e.g. 1950-51 is noted as a 1951 landing.

STATISTICAL AREA 11

Section 111 Belize Inlet

The main Pacific Herring spawning area in this section is in the vicinity of Allison Harbour (Hay et al. 1989d). There have only been 8 spawning records for the area in these years: 1954, 1958, 1964, 1980, and 1993 and completeness is unknown. The earliest spawning was reported in Allison Harbour on April 2 (DOY 92). The average date for the beginning of spawning is April 25 (DOY 115) and spawning has occurred as late as May 12 (DOY 132). The longest duration of spawning observed in the section was just 2 days. Reduction fishery landings are reported for six seasons between 1956 and 1968 and no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 112 Seymour Inlet and Nugent Sound

The main Pacific Herring spawning areas for this section are in Schwartzenberg Lagoon and Wawatle Bay (Hay et al. 1989d). The record of spawning activity spans the period from 1950 to 1989 and is mostly continuous. The earliest spawning was reported on February 4 (DOY 35) in Seymour Inlet. The average date for the beginning of spawning is April 5 (DOY 95) and spawning has occurred as late as May 12 (DOY 132) in Nugent Sound. The longest duration of spawning observed in the section was 24 days in Schwartzenberg Lagoon. Intermittent reduction fishery landings are reported between 1955 and 1967, and two very small roe landings in 1975 and 1976, and no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in this section. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Table 12. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 11, Johnstone Strait, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 111 Belize Inlet	8	5405	676	April 25	April 2	May 12	2
Section 112 Seymour Inlet, Nugent Sound	103	134625	1307	April 5	February 4	May 12	24

STATISTICAL AREA 12

Section 121 Queen Charlotte Strait

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The section has a few disparate spawning locations on Vancouver Island and the mainland but only 14 total reports. The main Pacific Herring spawning locations are Shelter Bay, and in the vicinity of Alert Bay. The spawning reports span the period from 1938 to 2020 but are sparse. The earliest spawning was reported at Alert Bay on February 17 (DOY 48). The average date for the beginning of spawning is April 22 (DOY 112) and the end of spawning has occurred as late as June 1 (DOY 152) at Port McNeill. The longest duration of spawning observed in the section was 53 days at Alert Bay. Regular reduction fishery landings are reported from 1956 to 1968, intermittent bait or food landings from 1964 to 1979, and roe fishery landings in four seasons from 1972 to 1977, and no fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 122 Beaver Harbour

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The section has two main Pacific Herring spawning locations, Hardy Bay and Beaver Harbour. The report of spawning activity spans the period from 1932 to 2020 and is mostly continuous from 1939 to 2016. The earliest spawning was reported at Hardy Bay on March 3 (DOY 62). The average date for the beginning of spawning is April 1 (DOY 91) and spawning has occurred as late as May 4 (DOY 124) at Hardy Bay. The longest duration of spawning observed in the section was just 15 days at Daphne Point. Three reduction fishery landings are reported from 1965 to 1967, a single bait landing in 1977, and roe fishery landings in four seasons from 1972 to 1975, but no fishery landings are currently anticipated. The spawn-on-kelp fishery has operated in the area almost annually from 1992 to 2018. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 123 West Cracroft Island

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The section has two main Pacific Herring spawning locations, Beware Passage and Clio Channel. The report of spawning activity spans the period from 1929 to 2004 and is mostly continuous from 1937 to 1982 but patchy since. The earliest spawning was reported in Beware Passage on February 17 (DOY 48). The average date for the beginning of spawning is March 23 (DOY 83) and the end of spawning has occurred as late as May 17 (DOY 137) at Bend Island. The longest duration of spawning observed in the section was 38 days at Baronet Passage. Frequent reduction fishery landings are reported from 1951 to 1967, intermittent bait or food landings from 1972 to 1992, and seven seasons of roe landings from 1972 to 1978, but no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 124 Wells Passage

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The section has one main Pacific Herring spawning location in the vicinity of Watson Island. The report of spawning activity spans the period from 1941 to 2019 and is mostly continuous from 1947 to 1977 and sporadic thereafter. The earliest spawning was reported in Grappler Sound on March 12 (DOY 71). The average date for the beginning of spawning is April 13 (DOY 103) and the end of spawning has occurred as late as May 18 (DOY 138) in Kenneth Passage. The longest duration of spawning observed in the section was 16 days also at Kenneth Passage. Intermittent reduction fishery landings are reported between 1951 and 1966, and four seasons of roe fishery landings between 1974 and 1977, but no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 125 Gilford Island

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The section has three main Pacific Herring spawning locations: Monday Anchorage, Retreat Passage-Health Lagoon, and Cramer Passage-Viner Sound. The report of spawning activity spans the period from 1929 to 2014 and is mostly continuous from 1929 to 1981, and 1989 to 2006 and then absent except in 2009 and 2014. The earliest spawning was reported in the area on February 20 (DOY 51). The average date for the beginning of spawning is March 25 (DOY 84) and spawning has occurred as late as May 11 (DOY 131) in Bond Sound. The longest duration of spawning observed in the section was 19 days in Viner Sound. Intermittent reduction fishery landings are reported from 1951 to 1968, a single bait landing in 1964, and roe landings in five seasons from 1972 to 1976. No additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 126 Kingcome Inlet

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The main Pacific Herring spawning location is at the head of Wakeman Sound with minor sites along Kingcome Inlet. The report of spawning activity spans the period from 1929 to 2019 and is mostly continuous from 1937 to present. The earliest spawning was reported in Belleisle Sound on February 24 (DOY 55). The average date for the beginning of spawning is March 22 (DOY 81) and the end of spawning has occurred as late as May 22 (DOY 142) in Wakeman Sound. The longest duration of spawning observed in the section was 41 days also in Wakeman Sound. Regular reduction fishery landings are reported from 1951 to 1967, a single food landing in 1951, and annual roe fishery landings from 1972 to 1978. No additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 127 Knight Inlet

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The main Pacific Herring spawning location is at the head of Knight Inlet with additional sites at Glacier Bay-Ahnuhati Point. The report of spawning activity spans the period from 1929 to 2019 and is mostly continuous from 1947 to 2005 and absent since except for 2017 and 2019. The earliest spawning was reported at Glendale Cove on January 29 (DOY 29). The average date for the beginning of spawning is March 20 (DOY 79) and the end of spawning has occurred as late as May 1 (DOY 121) at Shawl Bay. The longest duration of spawning observed in the section was 42 days. Regular reduction fishery landings are reported for 1951 to 1967, and annual roe fishery landings from 1973 to 1978. No additional fishery landings are currently anticipated. The spawn-on-kelp fishery has operated in the area from 1983 to 1985. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Table 13. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 12, Johnstone Strait, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 121 Queen Charlotte Strait	14	5418	387	April 22	February 17	June 1	53
Section 122 Beaver Hbr	245	152043	621	April 1	March 3	May 4	15
Section 123 West Cracroft Island	194	159340	821	March 23	February 17	May 17	38
Section 124 Wells Passage	79	100112	1267	April 13	March 12	May 18	16
Section 125 Gilford Island	469	214995	458	March 25	February 20	May 11	19
Section 126	865	1252881	1448	March 22	February 24	May 22	41

Kingcome Inlet							
Section 127 Knight Inlet	1016	1035841	1020	March 20	January 29	May 5	42

STATISTICAL AREA 13

Section 132 Deepwater Bay

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The section has two main Pacific Herring spawning locations, Deepwater Bay and Kanish Bay. The spawning reports span the period from 1931 to 2004 and are relatively continuous from 1934 to 1987 but sparse thereafter. The earliest spawning was reported in Plumper Bay on January 7 (DOY 7). The average date for the beginning of spawning is April 11 (DOY 101) and the end of spawning has occurred as late as April 30 (DOY 120) in Kanish Bay. The longest duration of spawning observed in the section was just 8 days at Deepwater Bay. Annual reduction fishery landings are reported from 1951 to 1968, regular food or bait landings from 1951 to 1997, and roe fishery landings from 1972 to 1976 and 1981, and future fishery landings may be expected. The spawn-on-kelp fishery has operated in the area in 1978 and between 1981 and 1985. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 133 Loughborough Inlet

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The section has one main Pacific Herring spawning location at the head of Loughborough Inlet. The spawning reports span the period from 1938 to 2005 and are mostly continuous from 1949 to 1964, 1969 to 1981, and 1990 to 2005. The earliest spawning was reported in Frazer Bay on March 2 (DOY 61). The average date for the beginning of spawning is March 19 (DOY 78) and the end of spawning has occurred as late as May 1 (DOY 121). The longest duration of spawning observed in the section was 33 days. Three seasons of reduction fishery landings are reported in 1962, 1964, and 1966, and roe fishery landings in 1972 and 1973. No additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 134 Bute Inlet

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989d) summarizing spawning records for this area. The section has one main Pacific Herring spawning location at the head of Bute Inlet (Waddington Harbour-Bear Bay). The spawning reports span the period from 1930 to 2020 and are mostly continuous from 1950 to 1983 and 1990 to 2005 but sparse before and after. The earliest spawning was reported at Ward Point on February 25 (DOY 56). The average date for the beginning of spawning is March 14 (DOY 73) and the end of spawning has occurred as late as April 30 (DOY 120). The longest duration of spawning observed in the section was 24 days. Reduction fishery landings are reported in 1956, 1961, and 1964 to 1967, two roe fishery landings in 1972 and 1975, and no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989d).

Section 135 Cape Mudge

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989e) summarizing spawning activity for this area and it was referred to as Section 137 and now also includes Section 138. The section has two main Pacific Herring spawning locations, one in the vicinity of Heriot Bay (Quadra Island) and the other in Whaletown and Smelt Bays (Cortes Island) and Marina Island. The spawning reports span the period from 1930 to 2020 and are mostly continuous from 1930 to 1944 and 1959 to 1983 but sparse afterwards. The earliest spawning was reported at Francisco Point on February 10 (DOY 41). The average date for the beginning of spawning is March 28 (DOY 87) and the end of spawning has occurred as late as April 26 (DOY 116) at Hyacinthe Bay. The longest duration of spawning observed in the section was just 12 days. Reduction fishery landings are reported in 1954, 1960, and 1965, ponding of herring to provide bait for recreational salmon fishing occurred from 1980 to 1994, and roe fishery landings in 1972 to 1974 and 1982. No landings are currently anticipated outside of bait for the recreational salmon fishery. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 136 Read Island

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989e) summarizing spawning records for this area. The section has one main Pacific Herring spawning location in the vicinity of Von Donop Inlet-Carrington Bay. The spawning reports span the period from 1930 to 1967 and are reasonably continuous to 1960 but likely incomplete since. The earliest spawning was reported at Quartz Bay on February 28 (DOY 59). The average date for the beginning of spawning is March 27 (DOY 86) and the end of spawning has occurred as late as April 18 (DOY 108) in Von Donop Inlet. The longest duration of spawning observed in the section was 9 days in Von Donop Inlet. Reduction fishery landings are reported in 1962 and 1967. A minor fishery occurred in the area to provide bait for recreational salmon fishing from 1978 to 1996 and future landings may be anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Table 14. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 13, Johnstone Strait, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 132 Deepwater Bay	191	76209	399	April 11	January 7	April 30	8
Section 133 Loughborough Int	200	64794	324	March 19	March 2	May 1	33
Section 134 Bute Inlet	647	558314	863	March 14	February 25	April 30	24
Section 135 Cape Mudge	234	161508	690	March 28	February 10	April 26	12
Section 136 Read Island	40	13650	341	March 27	February 28	April 18	9

APPENDIX 5. STRAIT OF GEORGIA SUMMARY OF PACIFIC HERRING SPAWNING LOCATIONS, FREQUENCY, SIZE, AND TIMING BY SECTION WITHIN STATISTICAL AREAS

Information on Pacific Herring spawning locations has been collected in portions of the Strait of Georgia since the 1930s. Summaries provided below are of all available records of spawning although any that are incomplete were excluded. The summaries and tables below provide a count of the number of spawning observations in each section, a tally of the total cumulative shoreline length of egg deposition from all available complete records as a proxy for relative abundance, an estimate of the average length of an egg bed along the shore, an estimate of the average date of beginning of spawning in the section, the reported earliest date of spawning at any location within the section, the latest date reported for the end of spawning activity in any location in the section, and the longest reported duration of spawning at any location in the section. Fishery landings are reported on a seasonal basis from July 1 in year one to June 30 in year two. In the narrative below fishery landings are referred to by the second year of the season, e.g. 1950-51 is noted as a 1951 landing.

STATISTICAL AREA 14

Section 141 Oyster Bay

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989e) summarizing spawning records for this area. The section has one main Pacific Herring spawning location, centered in the area around Kye Bay and Cape Lazo. The spawning reports span the period from 1939 to 2020 but are sporadic prior to 1999 and are mostly continuous since. The earliest spawning was reported in Kye Bay on February 21 (DOY 52). The average date for the beginning of spawning is March 12 (DOY 71) and spawning has occurred as late as March 28 (DOY 87) at Boat Cove. The longest duration of spawning observed in the section was just 10 days at Kye Bay and Kitty Coleman Creek. A single reduction fishery landing was reported in 1954, and three roe fishery landings between 1989 and 1994. Additional fishery landings are currently not anticipated here but are probable in the adjacent Section 142. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 142 Baynes Sound

The section represents the largest aggregation of Pacific Herring spawning sites on the BC coast. There are four main Pacific Herring spawning areas in the section: Comox Bar-Baynes Sound, Mapleguard Point, Komass Bluff (Denman Island), and Phipps Point (Hornby Island) (Hay et al. 1989e). The spawning reports span the period from 1928 to 2020 and are continuous from 1937 except 1968-70 and 1973. The earliest spawning was reported in Buckley Bay on February 13 (DOY 44). The average date for the beginning of spawning is March 13 (DOY 72) and spawning has occurred as late as May 28 (DOY 148) at Willemar Bluff. The longest duration of spawning observed in the section was 19 days at Comox Harbour. Annual reduction fishery landings are reported from 1954 to 1967, bait or food landings sporadically 1951 to 1994, and roe fishery landings annually from 1978 to 2020, and future landings may be anticipated. The spawn-on-kelp fishery operated in the area in 1983. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 143 Qualicum

The boundary of this section has been updated to include Section 144 since the earlier report by Hay et al. (1989e) summarizing Pacific Herring spawning records for this area. The section encompasses a continuous spawning area extending from Mapleguard Point to Cottam Point. The spawning reports span the period from 1929 to 2020 and are mostly continuous from 1933 to 2010 except for 1965 to 1970 when the population was depleted. The earliest spawning was reported at Rathtrevor Beach on January 22 (DOY 22). The average date for the beginning of spawning is March 14 (DOY 73) and spawning has occurred as late as April 19 (DOY 109) in the vicinity of Bowser. The longest duration of spawning observed in the section was 13 days near Bowser. A total of five reduction fishery landings were reported for this area between 1955 and 1964, roe fishery landings have occurred almost annually since 1975 and are expected to continue in future years. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Table 15. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 14, Strait of Georgia, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 141 Oyster Bay	68	226699	3334	March 12	February 21	March 28	10
Section 142 Baynes Snd	1047	2608135	2491	March 13	February 13	May 28	19
Section 143 Qualicum	674	1618344	2401	March 14	January 22	April 19	13

STATISTICAL AREA 15

Section 151 Redonda Islands

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989e) summarizing spawning activity for this area. The section has two main Pacific Herring spawning locations, one centered in Squirrel Cove (Cortes Island) and the other in Toba Inlet. The spawning reports span the period from 1930 to 2016 but are spotty throughout this interval. The earliest spawning was reported in Toba Inlet on February 27 (DOY 58). The average date for the beginning of spawning is March 19 (DOY 78) and spawning has occurred as late as April 22 (DOY 112) at Squirrel Cove. The longest duration of spawning observed in the section was 32 days also at Squirrel Cove. Two reduction fishery landings are reported in 1964 and 1967, two roe landings in 1975 and 1976, three bait landings (1973, 1976, and 1986) and no future fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 152 Powell River

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989e) summarizing spawning activity for this area. The main Pacific Herring spawning location is centered in the vicinity of Atrevida Reef-Sliammon with adjacent sites at Sutil Point, Hernando, Savary and Harwood Islands. The spawning reports span the period from 1930 to 2020 and are mostly continuous from 1936 to 1990 but sporadic since. The earliest spawning was reported in Cortes Bay on January 3 (DOY 3). The average date for the beginning of spawning is March 20 (DOY 79) and the end of spawning has occurred as late as May 15 (DOY 136). The longest duration of spawning observed in the section was 39 days also at Scuttle Bay. Two reduction fishery landings are reported in 1964 and 1967, sporadic bait, food, and roe landings all between 1972 and 1987, and no future fishery landings are currently anticipated. The spawn-on-kelp fishery has operated in the area from 1977 to 1984. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Table 16. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 15, Strait of Georgia, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 151 Redonda Is	89	18597	209	March 19	February 27	April 22	32
Section 152 Powell River	403	366284	909	March 20	January 3	May 15	39

STATISTICAL AREA 16

Section 162 Hotham Sound

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989e) summarizing Pacific Herring spawning activity for this area. The section has three main spawning locations, Blind Bay, Thunder Bay, and St. Vincent Bay. The spawning reports span the period from 1930 to 2020 and are mostly continuous from 1938 to 1951 and 1959 to 1972 but sporadic since. The earliest spawning was reported in Blind Bay on January 30 (DOY 30). The average date for the beginning of spawning is March 18 (DOY 77) and the end of spawning has occurred as late as April 20 (DOY 110) in Thunder Bay. The longest duration of spawning observed in the section was 7 days in Green Cove. Three reduction fishery landings (1961, 1962, and 1964), bait landings from 1970 to 1981, and one roe landing in 1973 were reported for this area, but no future fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 163 Malaspina Strait

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989e) summarizing spawning activity for this area. The section has three main Pacific Herring spawning locations, Pender Harbour, Bargain Bay and Secret Cove. The spawning reports span the period from 1930 to 2020 and are mostly continuous from 1937 to 1977 and sporadic since. The earliest spawning was reported in Bargain Bay on January 17 (DOY 17). The average date for the beginning of spawning is March 18 (DOY 77) and the end of spawning has occurred as late as May 7 (DOY 127) in Bargain Bay. The longest duration of spawning observed in the section was 41 days in Pender Harbour. Intermittent reduction fishery landings are reported between 1954 and 1965, bait landings and ponding mostly between 1965 and 1992, and roe fishery landings (1972 and 1977), but no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 164 Jervis Inlet

The boundary of this section has been updated (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989e) summarizing spawning activity for this area. The section has three main Pacific Herring spawning locations, Vancouver Bay, Deserted Bay, and the head of Jervis Inlet. The spawning reports span the period from 1930 to 1978 and are mostly continuous from 1936 to 1978 except for 1950 to 1957. The earliest spawning was reported in Deserted Bay on March 9 (DOY 68). The average date for the beginning of spawning is April 3 (DOY 93) and the end of spawning has occurred as late as May 1 (DOY 121) in Deserted Bay. The longest duration of spawning observed in the section was 32 days also in Deserted Bay. Bait fishery landings and ponding is reported for the area between 1971 and 1979 and no additional fishery landings are currently anticipated. The spawn-on-kelp fishery operated in the area in 1975 to 1982 and then relocated to Area 10. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 165 Sechelt Inlet

The section has one main Pacific Herring spawning location, Porpoise Bay at the head of Sechelt Inlet (Hay et al. 1989e). The spawning reports span the period from 1930 to 2020 and are mostly continuous from 1930 to 1972 but infrequent since. The earliest spawning was reported in Porpoise Bay on February 10 (DOY 41). The average date for the beginning of spawning is March 26 (DOY 85) and the end of spawning has occurred as late as May 9 (DOY 129) in Sechelt Inlet. The longest duration of spawning observed in the section was 39 days in Porpoise Bay. Two reduction fishery landings (1956, 1965), regular bait landings and ponding from 1964 to 1994, and two roe fishery landings (1975, 1976) are reported for the area but no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Table 17. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 16, Strait of Georgia, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 162 Hotham Snd	51	31280	613	March 18	January 30	April 20	7
Section 163 Malaspina Str	229	105842	462	March 18	January 17	May 7	41
Section 164 Jervis Inlet	62	75328	1215	April 3	March 9	May 1	32
Section 165 Sechelt Inlet	137	93149	680	March 26	February 10	May 9	39

STATISTICAL AREA 17

Section 172 Nanoose Bay

The section has one main Pacific Herring spawning location concentrated in the Nanoose Bay-Lantzville area (Hay et al. 1989e). The spawning reports span the period from 1929 to 2020 and are mostly continuous from 1937 to 2020 except for 1985 to 1994. The earliest spawning was reported in Nanoose Bay on February 16 (DOY 47). The average date for the beginning of spawning is March 17 (DOY 76) and the end of spawning has occurred as late as May 3 (DOY 123) at Blunden Point. The longest duration of spawning observed in the section was 60 days in Nanoose Bay. Reduction fishery landings are reported annually from 1951 to 1970, food or bait landings or ponding is reported intermittently from 1951 to 1997, and roe fishery landings periodically from 1972 to 2018. Additional fishery landings may be anticipated in the future. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 173 Yellow Point

The boundary of this section has been updated to include some of Section 171 (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989e) summarizing spawning records for this area. The section has four main Pacific Herring spawning locations: Pylades Channel, Boat Harbour, Coffin Point, and Thetis-Kuper Islands. The spawning reports span the period from 1929 to 2020 and are continuous from 1934 to 2020 except for 2017 to 2019. The earliest spawning was reported in Ladysmith Harbour on January 29 (DOY 29). The average date for the beginning of spawning is March 20 (DOY 79) and the end of spawning has occurred as late as May 6 (DOY 126) at Kulleet Bay. The longest duration of spawning observed in the section was 33 days also in Kulleet Bay. Reduction fishery landings are reported from 1951 to 1968, bait landings or ponding intermittently from 1953 to 1997, food landings regularly from 1951 to 1993, and roe landings intermittently from 1974 to 2016. Additional fishery landings may be anticipated in the future. The spawn-on-kelp fishery has operated in the area from 1981 to 1985. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Table 18. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 17, Strait of Georgia, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 172 Nanoose Bay	750	1058992	1412	March 17	February 16	May 3	60
Section 173 Yellow Point	1128	1667213	1478	March 20	January 29	May 6	33

STATISTICAL AREA 18

Section 181 Swanson Channel

The boundary of this section has been updated to include Sections 182 and 184 (Haist and Rosenfeld 1988) since an earlier report by Hay et al. (1989e) summarizing spawning records for this area. The main Pacific Herring spawning locations in this section are concentrated around Ganges Harbour and Prevost Island with a minor area in Fulford Harbour. The spawning reports span the period from 1929 to 2013 and are generally continuous from 1931 to 1983 and intermittent since. The earliest spawning was reported in Long Harbour on January 15 (DOY 15). The average date for the beginning of spawning is March 3 (DOY 62) and the end of spawning has occurred as late as April 16 (DOY 106) at Fulford Harbour. The longest duration of spawning observed in the section was 55 days also in Fulford Harbour. Reduction fishery landings are reported from 1951 to 1968, bait or food landings intermittently from 1952 to 1994, and roe landings annually from 1972 to 1978. Additional fishery landings may be anticipated in the future. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 182 Plumper Sound

The section was previously reported as Section 183 by Hay et al. (1989e) summarizing spawning for this area. The Pacific Herring spawning locations in this section are concentrated in Plumper Sound centered in Lyall Harbour. The spawning reports span the period from 1947 to 1982 and are generally continuous from 1955 to 1982. The earliest spawning was reported in Boot Cove on February 10 (DOY 41). The average date for the beginning of spawning is March 9 (DOY 68) and the end of spawning has occurred as late as April 10 (DOY 100) in Ladysmith Harbour. The longest duration of spawning observed in the section was 24 days in Boot Cove. Annual reduction fishery landings are reported from 1954 to 1968, bait or food landings intermittently from 1965 to 1989, and four seasons of roe landings (1973, 1975 to 1977). The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Table 19. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 19, Strait of Georgia, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 181 Swanson Ch	966	400673	415	March 3	January 15	April 16	55
Section 182 Plumper Snd	188	60153	320	March 9	February 10	April 10	24

STATISTICAL AREA 19

Section 191 Saanich Inlet

The boundary of this section has been updated (Haist and Rosenfeld 1988) and was reported as Section 185 in an earlier report by Hay et al. (1989e) summarizing spawning records for this area. The main Pacific Herring spawning activity in this section is concentrated in two locations: Patricia Bay-Deep Cove and Tod Inlet-Finlayson Arm at the head of Saanich Inlet. The spawning reports span the period from 1931 to 2012 and are generally continuous from 1945 to 1972 and sporadic since. The earliest spawning was reported in Tod Inlet on February 26 (DOY 57). The average date for the beginning of spawning is March 29 (DOY 88) and the end of spawning has occurred as late as April 25 (DOY 115) in Tod Inlet. The longest duration of spawning observed in the section was 24 days at Goldstream Flats. Bait and food fishery landings are reported in 1981 and no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 192 Saanich Inlet

The boundary of this section has been updated (Haist and Rosenfeld 1988) from an earlier report by Hay et al. (1989e) where it was referred to as Section 191, and their Section 192 is now part of Section 181. There are only four records of Pacific Herring spawning in two locations for this section: Sidney Channel and Tsehum Harbour. The spawning reports are for 1932 in Sidney Channel and 1969, 1973, and 1974 in Tsehum Harbour. The earliest spawning was reported in Sidney Channel on February 14 (DOY 45). The average date for the beginning of spawning is March 14 (DOY 73) and the end of spawning has occurred as late as March 30 (DOY 89) in Tsehum Harbour. The longest duration of spawning observed in the section was 3 days also in Tsehum Harbour. A single bait fishery landing is reported in 1971, one season of roe landings in 1977, and no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 193 Victoria Harbour

The boundary of this section has been expanded to include part of Section 191 (Haist and Rosenfeld 1988) from an earlier report by Hay et al. (1989e) summarizing spawning records for this area. Pacific Herring spawning activity in this section is concentrated in Portage Inlet and Esquimalt Harbour. The spawning reports span the period from 1931 to 1995 and are generally continuous from 1931 to 1951 and 1989 to 1995 and otherwise sporadic. The earliest spawning was reported in Esquimalt Lagoon on February 1 (DOY 32). The average date for the beginning of spawning is March 17 (DOY 76) and the end of spawning has occurred as late as May 29 (DOY 149) in James Bay. The longest duration of spawning observed in the section was 71 days in Victoria Harbour. Regular reduction fishery landings are reported from 1954 to 1967, intermittent bait or food landings from 1954 to 1996, but no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Table 20. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 19, Strait of Georgia, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 191 Saanich Inlet	106	89525	845	March 29	February 26	April 25	24
Section 192 Cordova Bay	4	228	57	March 14	February 14	March 30	3
Section 193 Victoria Hbr	73	11757	161	March 17	February 1	May 29	71

STATISTICAL AREA 20

Section 202 Sooke Harbour

Pacific Herring spawning locations in this section are concentrated inside Sooke Harbour. The spawning reports span the period from 1951 to 1995 but consist of only 6 years of observations suggesting that it is ephemeral or not well reported. Spawning has occurred as early as March 5 (DOY 64) in Becher Bay. The average data for the beginning of spawning is April 2 (DOY 92) in Sooke Inlet. Spawning activity has been observed as late as April 26 (DOY 116) in Anderson Cove. Three years of reduction fishery landings (1955, 1957, and 1958) are reported, one food landing in 1963, and a single roe landing in 1974 but no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Table 21. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 20, Strait of Georgia, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 202 Sooke Inlet	8	1655	236	April 2	March 5	April 26	1

STATISTICAL AREA 28

Section 280 Howe Sound

Pacific Herring spawning locations in this section are concentrated in four sites: Squamish, Gibson's Landing, Port Graves (Gambier Island), and Eagle Harbour (Hay et al. 1989e). The spawning reports span the period from 1934, and 1958 to 2020 and are generally continuous from 1960 to 1971 and 2015 to 2020 and otherwise intermittent. The earliest spawning was reported in False Creek on January 15 (DOY 15). The average date for the beginning of spawning is March 17 (DOY 76) and the end of spawning has occurred as late as May 18 (DOY 139) in Indian Arm. The longest duration of spawning observed in the section was 73 days in Squamish. Small reduction fishery landings are reported in 1953 and 1966, five seasons of bait or food landings from 1952 to 1981, and one roe landing in 1974. No additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Table 22. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 28, Strait of Georgia, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 280 Howe Snd	48	42270	881	March 17	January 15	May 18	73

STATISTICAL AREA 29

Section 292 Sechelt

The boundary of this section has been updated (Haist and Rosenfeld 1988), previously being part of Section 163 in an earlier report by Hay et al. (1989e) summarizing spawning records for this area. The sole Pacific Herring spawning location is Sargeant Bay and the general vicinity of Sechelt. The spawning reports span the period from 1954 to 2016 and are generally continuous from 1962 to 1971 and sporadic otherwise. The earliest spawning was reported in Sargeant Bay on March 10 (DOY 69). The average date for the beginning of spawning is March 24 (DOY 83) and the end of spawning has occurred as late as April 17 (DOY 107) at Sechelt. The information on duration of spawning is incomplete. One record of a roe landing is reported in 1961, regular bait fishery landings from 1964 to 1975, but no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Section 293 Boundary Bay

The boundary of this section has been altered, previously being part of Section 290 in the earlier report by Hay et al. (1989e) summarizing spawning records for this area. The sole Pacific Herring spawning location is throughout Boundary Bay. The spawning reports span the period from 1955 to 2019 and are generally continuous from 1955 to 1980, 1984 to 1992, and from 2013 to 2019. The earliest spawning was reported in Boundary Bay on February 14 (DOY 45). The average date for the beginning of spawning is March 2 (DOY 61) and the end of spawning has occurred as late as May 7 (DOY 127). The longest duration of spawning observed in the section is 31 days. Two records of landings in the reduction fishery are reported in 1963 and1966 and no additional fishery landings are currently anticipated. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989e).

Table 23. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 29, Strait of Georgia, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 292 Sechelt	13	9048	696	March 24	March 10	April 17	1
Section 293 Boundary Bay	90	189303	2103	March 2	February 14	May 7	31

APPENDIX 6. WEST COAST OF VANCOUVER ISLAND SUMMARY OF PACIFIC HERRING SPAWNING LOCATIONS, FREQUENCY, SIZE, AND TIMING BY SECTION WITHIN STATISTICAL AREAS

Information on Pacific Herring spawning locations has been collected in portions of the west coast of Vancouver Island since the 1930s. Summaries provided below are of all available records of spawning although any that are incomplete were excluded. The summaries and tables below provide a count of the number of spawning observations in each section, a tally of the total cumulative shoreline length of egg deposition from all available complete records as a proxy for relative abundance, an estimate of the average length of an egg bed along the shore, an estimate of the average date of beginning of spawning in the section, the reported earliest date of spawning at any location within the section, the latest date reported for the end of spawning activity in any location in the section, and the longest reported duration of spawning at any location in the section. Fishery landings are reported on a seasonal basis from July 1 in year one to June 30 in year two. In the narrative below fishery landings are referred to by the second year of the season, e.g. 1950-51 is noted as a 1951 landing.

STATISTICAL AREA 23

Section 231 Trevor Channel

The boundary of this section has been altered from that in Hay et al. (1989f), including portions of what were Sections 231 and 235 (Haist and Rosenfeld 1988). The two key Pacific Herring spawning locations in the section are Bamfield Inlet and Roquefeuil Bay. The spawning reports span the period from 1930 to 1987 and are generally continuous from 1930 to 1979 with a couple of two year gaps. The earliest spawning was reported in Bamfield Inlet on February 3 (DOY 34). The average date for the beginning of spawning is March 11 (DOY 70) and the end of spawning has occurred as late as April 15 (DOY 105) in Rainy and Roquefeuil Bays. The longest duration of spawning observed in the section was 15 days in Bamfield Inlet. Intermittent reduction fishery landings are reported from 1951 to 1967, eleven bait or food landings from 1951 to 1986, and four years of roe fishery landings between 1972 and 1984, and additional future fishery landings are possible. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 232 West Barkley Sound

The boundary of this section has been altered from Hay et al. (1989f), now including portions of Sections 231, 232, and 233 (Haist and Rosenfeld 1988). The section has numerous Pacific Herring spawning sites including Ucluelet Harbour, Macoah Passage, Toquart Bay, and parts of the Broken Island Group. The spawning reports span the period from 1930 to 2020 and have been continuous throughout. The earliest spawning was reported at Maggie River on January 16 (DOY 16). The average date for the beginning of spawning is March 13 (DOY 72) and the end of spawning has occurred as late as April 16 (DOY 106) at Toquart Bay. The longest duration of spawning observed in the section was 31 days in Ucluelet Inlet. Intermittent reduction fishery landings are reported from 1951 to 1967, four bait landing between 1975 and 1981, and almost annual roe landings from 1972 through 2003. Additional fishery landings are possible in the future. The spawn-on-kelp fishery has operated in the area intermittently in 1981 and 1991 to 2004. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 233 Imperial Eagle Channel

The boundary of this section has been altered from Hay et al. (1989f), now including portions of Sections 231 and 234 (Haist and Rosenfeld 1988). The section has two main Pacific Herring spawning sites, Useless and Effingham Inlets. The spawning reports span the period from 1930 to 2015 and have been mostly continuous from 1930 to 1962 and sporadic since. The earliest spawning was reported at Useless Inlet on January 7 (DOY 7). The average date for the beginning of spawning is March 4 (DOY 63) and the end of spawning has occurred as late as April 20 (DOY 110) at Useless Inlet. The longest duration of spawning observed in the section was 17 days in Useless Inlet. Annual reduction fishery landings are reported from 1951 to 1966, bait or food landings in four seasons (1951, 1954, 1964, and 1978), a single roe landing in 1981, and future additional fishery landings are possible. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Table 24. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 23, West Coast of Vancouver Island, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 231 Trevor Ch	124	59023	476	March 11	February 3	April 15	15
Section 232 W Barkley Sound	1382	1275520	923	March 13	January 16	April 16	31
Section 233 Imperial Eagle Ch	89	47298	531	March 4	January 7	April 20	17

STATISTICAL AREA 24

Section 241 Tofino Inlet

The boundary of this section has been altered from that in Hay et al. (1989f) moving Bedwell Sound into Section 245 (Haist and Rosenfeld 1988). The main Pacific Herring spawning location in the section is in Mosquito Harbour. The spawning reports span the period from 1931 to 2013 and are generally continuous from 1931 to 1936 and 1949 to 1969 and rare since. The earliest spawning was reported in Mosquito Harbour on February 1 (DOY 32). The average date for the beginning of spawning is March 4 (DOY 63) and the end of spawning has occurred as late as April 30 (DOY 120) in Mosquito Harbour. The longest duration of spawning observed in the section was 17 days. Six years of reduction fishery landings were reported between 1956 and 1967, annual roe landings from 1972 to 1982 and in 1988, and additional future fishery landings are possible. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 242 Hesquiat Harbour

The main spawning location in the section is in Hesquiat Harbour (Hay et al. 1989f). The Pacific Herring spawning reports span the period from 1930 to 2020 and are generally continuous from 1936 to 1947, 1959 to 1981, 1985 to 2000, 2013 to 2020, and otherwise intermittent. The earliest spawning was reported at Leclair Point and Hesquiat Harbour on January 7 (DOY 7). The average date for the beginning of spawning is March 8 (DOY 67) and the end of spawning has occurred as late as April 12 (DOY 102) in Hesquiat Harbour. The longest duration of spawning observed in the section was 83 days in Hesquiat Harbour. Roe fishery landings were reported from 1973 to 1977, and additional future fishery landings are possible but unlikely. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 243 Sydney Inlet

The main Pacific Herring spawning locations in the section are Hot Springs Cove, Hootla Kootla-Steamer Cove, and Young Bay (Hay et al. 1989f). The spawning reports span the period from 1930 to 2014 and are generally continuous from 1930 to 1985, 1993 to 2014, and otherwise intermittent. The earliest spawning was reported in Hot Springs Cove on February 1 (DOY 32). The average date for the beginning of spawning is March 19 (DOY 78) and the end of spawning has occurred as late as April 20 (DOY 110) also in Hot Springs Cove. The longest duration of spawning observed in the section was 31 days in Shelter and Sydney Inlets. Frequent reduction fishery landings are reported from 1951 to 1967, annual roe landings from 1972 to 1977 and 1999, and additional future fishery landings are possible. The spawn-on-kelp fishery has operated in the area between 1997 to 2004. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 244 Miller Channel

The main Pacific Herring spawning locations in the section are Matilda Inlet, Whitepine Cove, and Bawden Bay (Hay et al. 1989f). The spawning reports span the period from 1930 to 2018 and are mostly continuous from 1943 to 1994 with some single year gaps after 1973, and intermittent since. The earliest spawning was reported in Whitepine Cove on February 18 (DOY 49). The average date for the beginning of spawning is March 20 (DOY 79) and the end of spawning has occurred as late as April 30 (DOY 120) at Matilda Inlet. The longest duration of spawning observed in the section was 31 days at Matilda Inlet, Bawden Bay, and Whitepine Cove. A single reduction fishery landing was reported in 1965, roe landings from 1973 to 1978 and 1985, and additional future fishery landings are possible. The spawn-on-kelp fishery operated in the area in four years between 1991 and 1998. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 245 Vargas Island

The boundary of this section has been updated slightly from that in Hay et al. (1989f) to include Bedwell Sound (Haist and Rosenfeld 1988). The main Pacific Herring spawning locations in the section are Hecate, Cypress, Ritchie, and McIntosh Bays as well as Bedwell Sound and Maurus Channel. The spawning reports span the period from 1930 to 2020 and are generally continuous from 1945 to 1999 with only four years since. The earliest spawning was reported in Cypress Bay on February 9 (DOY 40). The average date for the beginning of spawning is March 17 (DOY 76) and the end of spawning has occurred as late as May 1 (DOY 121) in Bedwell Sound. The longest duration of spawning observed in the section was 31 days in Cypress Bay. Reduction fishery landings are reported in four seasons (1956, 1965 to 1967), annual roe landings from 1973 to 1982, 1988, 1990, 1994, and 1996, with possible additional future fishery landings. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Table 25. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 24, West Coast of Vancouver Island, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 241 Tofino Inlet	55	26948	490	March 4	February 1	April 30	17
Section 242 Hesquiat Hbr	272	233674	859	March 8	January 7	April 12	83
Sectoin 243 Sydney Inlet	452	231135	511	March 19	February 1	April 20	31
Section 244 Miller Ch	346	199681	577	March 20	February 18	April 30	31
Section 245 Vargas Island	1134	312911	276	March 17	February 9	May 1	31

STATISTICAL AREA 25

Section 251 Tahsis Inlet

The boundary of this section has been updated from that in Hay et al. (1989f) to allow for expansion of Section 253 (Haist and Rosenfeld 1988). The main Pacific Herring spawning locations in the section are Tahsis Inlet, Zeballos Inlet, and Galiano Bay (Tlupana Inlet). The spawning reports span the period from 1930 to 1971 but include only 8 years of records over this expansive and remote area and so are incomplete. The earliest spawning was reported in Tahsis Inlet on March 7 (DOY 66). The average date for the beginning of spawning is March 23 (DOY 82) and the end of spawning has occurred as late as April 27 (DOY 117) in Galiano Bay. The longest duration of spawning observed in the section was 8 days also in Galiano Bay. Eight seasons of reduction fishery landings were reported between 1951 and 1967 and and additional future fishery landings are unlikely. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 252 Nootka Sound

The boundary of this section has been updated from that in Hay et al. (1989f) to include a portion of Section 251 (Haist and Rosenfeld 1988). The main Pacific Herring spawning locations in the section are McKay Passage-Marvinas Bay, Kendrick Inlet, and Ewin Inlet. The spawning reports span the period from 1930 to 2020 and are continuous from 1930 to 1977 with a number of one and two year gaps in subsequent years. The earliest spawning was reported on February 28 (DOY 59) in Ewin and Kendrick Inlets. The average date for the beginning of spawning is March 25 (DOY 84) and the end of spawning has occurred as late as June 15 (DOY 166) in Friendly Cove. The longest duration of spawning observed in the section was 41 days in Cook Channel. Reduction fishery landings are reported in 1951, 1952, 1954, and 1959 to 1967, roe fishery landings from 1974 to 1981 and 1991, and additional future fishery landings are possible. The spawn-on-kelp fishery operated in the area in 1991 and 1992. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 253 Esperanza Inlet

The boundary of this section has been expanded slightly from that reported in Hay et al. (1989f) to include a portion of Section 251 (Haist and Rosenfeld 1988). The main Pacific Herring spawning locations in the section are False Channel-Queen Cove, Owossitsa Creek, Rosa Harbour, Inner-Outer Nuchatlitz, Port Langford, and Mary Basin. The spawning reports span the period from 1929 to 2020 and generally continuous throughout this period. The earliest spawning was reported on January 19 (DOY 19) in Mary Basin. The average date for the beginning of spawning is March 10 (DOY 69) and the end of spawning has occurred as late as April 20 (DOY 110) in Saltery Bay. The longest duration of spawning observed in the section was 41 days at Nuchatlitz Village. Intermittent reduction fishery landings were reported between 1951 and 1960, roe fishery landings annually from 1972 to 1984 and intermittently from 1987 to 2005, with possible additional future fishery landings. The spawn-on-kelp fishery operated in the area between 1993 and 2005. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Table 26. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 25, West Coast of Vancouver Island, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 251 Tahsis Inlet	11	4062	369	March 23	March 7	April 27	8
Section 252 Nootka Snd	368	310848	845	March 25	February 28	Jun 15	41
Section 253 Esperanza Inlt	860	622773	724	March 10	January 19	April 20	41

STATISTICAL AREA 26

Section 261 Amai Inlet

The boundary of this section has been updated from that reported in Hay et al. (1989f) to allow for expansion of Section 262 (Haist and Rosenfeld 1988). The main Pacific Herring spawning locations in the section are within Amai Inlet. The spawning reports span the period from 1928 to 2015 and are mostly continuous from 1928 to 1962 with a recent record in 2015. The area is remote so the record of spawning is probably incomplete. The earliest spawning was reported in Amai Inlet on February 20 (DOY 51). The average date for the beginning of spawning is March 22 (DOY 81) and the end of spawning has occurred as late as April 21 (DOY 111) in Amai Inlet. The longest duration of spawning observed in the section was 5 days. Three reduction fishery landings are reported (1960, 1961, and 1963) and additional future fishery landings are unlikely. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 262 Clanninick Cove

The boundary of this section has been expanded southward along the coast (Haist and Rosenfeld 1988) from that reported in Hay et al. (1989f) summarizing the spawning activity. The main Pacific Herring spawning locations in the section are Amos Island, Clanninick Cove, and Union Island (Dutchies Cove). The spawning reports span the period from 1928 to 2015 and are mostly continuous from 1928 to 1979 and are rare since. The earliest spawning was reported at Clanninick Cove on February 7 (DOY 38). The average date for the beginning of spawning is March 12 (DOY 71) and the end of spawning has occurred as late as April 12 (DOY 102) at Amos Island. The longest duration of spawning observed in the section was 27 days in Clanninick Cove. Reduction fishery landings were reported in 1954, 1955, and from 1959 to 1967, with roe fishery landings in 1976 and 1977. Future additional fishery landings and unlikely. The spawn-on-kelp fishery has operated in the area in 1993. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 263 Checleset Bay

The boundary of this section has been expanded, to include the southern shore of Brooks Peninsula (Haist and Rosenfeld 1988), from that reported in Hay et al. (1989f) summarizing the spawning activity. The main Pacific Herring spawning locations in the section are Nasparti, Ououkinsh, and Malksope Inlets and the Bunsby Islands. The spawning reports span the period from 1928 to 2016 and are mostly continuous from 1928 to 1972 and rare since. The earliest spawning was reported at Malksope Inlet on January 26 (DOY 26). The average date for the beginning of spawning is March 6 (DOY 65) and the end of spawning has occurred as late as April 16 (DOY 106) also in Nasparti Inlet. The longest duration of spawning observed in the section was 7 days in Malksope Inlet. Annual reduction fishery landings are reported from1951 and 1967, one bait landing in 1957, one roe fishery landing in 1977, with additional future fishery landings unlikely. The spawn-on-kelp fishery has operated in the area in 1994. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Table 27. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 26, West Coast of Vancouver Island, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 261 Amai Inlet	58	14924	257	March 22	February 20	April 21	5
Section 262 Clanninick Cv	174	81859	470	March 12	February 7	April 12	27
Section 263 Checleset Bay	137	42915	313	March 6	January 26	April 16	7

STATISTICAL AREA 27

Section 271 Quatsino Sound

The main Pacific Herring spawning locations in the section are Koprino Harbour at the mouth of Quatsino Sound and Ildstad Islands (Hay et al. 1989f). The spawning reports span the period from 1931 to 2013 but they are sparse covering only 10 years of which 7 have complete information. The area is remote so the record of spawning activity is probably incomplete. The earliest spawning was reported on February 15 (DOY 46). The average date for the beginning of spawning is March 12 (DOY 71) and the end of spawning has occurred as late as May 15 (DOY 135) in Koprino Harbour. The longest duration of spawning observed in the section was 65 days also in Koprino Harbour. Reduction fishery landings are reported in 1954, 1955, from 1961 to 1966, and additional future fishery landings are unlikely. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 272 Brooks Bay

The two main Pacific Herring spawning locations in the section are Klaskish and Klaskino Inlets (Hay et al. 1989f). The spawning reports span the period from 1931 to 2018 and they are mostly continuous from 1934 to 1955, intermittent, then continuous from 1985 to 1999, and rare since. The area is remote so the record of spawning is probably incomplete. The earliest spawning was reported on February 12 (DOY 43) in Klaskish Inlet. The average date for the beginning of spawning is March 8 (DOY 67) and the end of spawning has occurred as late as April 10 (DOY 100) at Anchorage Island. The longest duration of spawning observed in the section was 14 days also in Klaskish Inlet. Five reduction fishery landings are reported in 1954, 1961, from 1965 to 1967 and additional future fishery landings are unlikely. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 273 Forward Inlet

The two main Pacific Herring spawning locations in the section are Browning Inlet and Winter Harbour (Hay et al. 1989f). The spawning reports span the period from 1929 to 2019 and they are mostly continuous throughout likely due to proximity to Winter Harbour. The earliest spawning was reported on February 1 (DOY 32) in Forward Inlet. The average date for the beginning of spawning is March 15 (DOY 74) and the end of spawning has occurred as late as May 15 (DOY 135) in Browning Inlet and Winter Harbour. The longest duration of spawning observed in the section was 65 days in both these locations. Four reduction fishery landings are reported in 1954, 1955, 1961 and 1964, roe fishery landings almost annually from 1974 to 1984 and 1993 to 1995, and additional future fishery landings are possible. The spawn-on-kelp fishery has operated in the area annually between 1983 and 2014. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Section 274 Holberg Inlet

The two main Pacific Herring spawning locations in the section are Apple Bay and Hathaway Creek near Coal Harbour (Hay et al. 1989f). The spawning reports span the period from 1953 to 2013 and are episodic between 1961 to 1978 and otherwise rare. The earliest spawning was reported on March 5 (DOY 64) in Apple Bay. The average date for the beginning of spawning is April 13 (DOY 103) and the end of spawning has occurred as late as May 11 (DOY 131) at Hathaway Creek. The longest duration of spawning observed in the section was 12 days also at Hathaway Creek. A single roe fishery landing was reported for 1982 and additional future fishery landings are unlikely. The spawn-on-kelp fishery has not operated in the area. Maps of the spawning locations and additional information are available in Hay et al. (1989f).

Table 28. Number of Pacific Herring spawning events, cumulative and average length of spawning beds, average date of first spawn, earliest and latest spawns observed, and maximum duration of spawning by Section for Statistical Area 27, West Coast of Vancouver Island, 1928 to 2020.

	Number of Spawning Events	Cumulative Length (m)	Average Length (m)	Average Start Spawning	Earliest Spawn Date	Latest Spawn Date	Duration of Spawn (Days)
Section 271 Quatsino Snd	7	1966	281	March 12	February 15	May 15	65
Section 272 Brooks Bay	152	134115	882	March 8	February 12	April 10	14
Section 273 Forward Inlet	636	532352	837	March 15	February 1	May 15	65
Section 274 Holberg Inlet	29	10639	367	April 13	March 5	May 11	12