

HERRING SPAWNING AREAS

OF

BRITISH COLUMBIA

A review, geographic analysis and classification

By

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ABSTRACT

The geographical distributions of Pacific herring (*Clupea pallasii*) spawning sites have been estimated each year since 1928. The analysis was based on approximately 29,000 spawning events recorded mostly by fishery officers and diver teams in six regions of the British Columbia (BC) coast. For each of about 100 geographical sections of BC, time series bubble plot maps were constructed to delineate annual herring spawn deposition along each kilometre of shoreline from 1930 to the year 2001. Cumulative spawn deposition (from 1928 to 2006) was also mapped using proportionately sized, multi-coloured, bubble plots which rank and classify each kilometre of herring spawning habitat according to the long-term frequency and magnitude of spawns over time. The analysis was conducted coast-wide, so that any kilometre on the BC coast could be compared with any other kilometre. Approximately 5,260 km (or 18 %) of British Columbia's extensive 29,500 km coastline have been ranked and classified as herring spawning habitat. An estimated 450 to 600 kilometres (or about 1.8 % of BC shoreline) is utilized by spawners in a typical year.

The approximate shapes of herring spawn depositions were also digitized over a 1:20,000 scale, Terrain Resource Information Management (TRIM) map for the years 1930 to 2002. Composite spawn maps for each section of BC were created by chronologically overlaying spawn polygons. In 2005, [Arcview© shapefiles](#) of each digitized spawning area and year were made available on the web. A series of plots and histograms summarize the magnitude, frequency and timing of spawning over all years and distinguish shoreline kilometres with highly repetitive spawning activity from those with less frequent activity. A statistical summary of herring spawn and catch records, including mean, minimum and maximum spawning dates and measured sea surface temperatures from nearest lighthouse stations are presented in a series of tables for each herring section, statistical area, region and for the entire British Columbia coast. The accuracy and completeness of records is discussed.

Key words: herring, spawning, British Columbia

INTRODUCTION

In recent years there has been increased awareness and concern by industry, government and the public about the environmental protection of Pacific herring spawning grounds. A number of nearshore developments, such as log booming activities and mariculture establishments could affect some intertidal and shallow, subtidal spawning areas used by herring. The impacts of oil spills, pollution, various inshore fisheries and ocean climate changes on herring spawning distributions is also a concern. A problem with the identification of nearshore areas as herring spawning habitat is that much of the British Columbia (BC) coast, perhaps 19% or more, has been used as a spawning site at least once during the last 75 years. However, much less of the coast (1-2%) is used for repetitive spawning over a number of years. The locations that support large and repetitive spawnings deserve the most attention and consideration from possible environmental impacts. This report provides the basis for identifying significant herring spawning areas and locations which support major herring fisheries.

HERRING SPAWNING RECORDS

Detailed records of herring spawns in British Columbia have been collected annually by fishery officers and diver teams (Hay and Kronlund 1987). Usually, an estimate of the location, length, width and density of the spawn deposition has been recorded. A total of approximately 29,000 spawning events at 1,368 locations have been recorded since 1928. These herring spawning locations were entered into a database using geographic names and numeric codes. Geographical areas represented by [location names](#), however, can vary from small islands or coves measuring only 100 m in length or breadth, to bays or inlets more than 50 km in length. Also, these herring spawning locations were frequently clustered, so that many geographical names were used to describe the same general vicinity (subsets of each other). In 1983, to resolve these database problems, we began to develop a **shoreline kilometre system** to represent herring spawning locations. This was the first step in a deviation from an earlier location naming and coding system developed by Issacson and Hourston (1972) and Hourston and Hamer, M. (1979). Additional location codes were subsequently compiled by Haist and Rosenfeld (1988) and Midgley (2003) as 'new' spawning locations were recorded and more permanent location boundaries established. Other Fisheries and Oceans Canada (DFO) report series that record spawning activity are listed by principle author as follows: (Humphreys, R.D. 1970-1973; Webb, L.A. 1974-1978; Chalmers, D.D. 1979-1992; Hamer, L. 1999-2002; Rusch, B. 2003-2004) and document details of the annual herring fishery and spawn abundance from a management perspective.

About 70% of spawn records have an accompanying map or chart showing the geographical locations of each spawning event. Records without charts consist of narratives or tables describing the location of each spawn deposition relative to a fixed reference point, such as a bay, inlet or island. To standardized and increase the number of fixed reference points, we plotted a series of kilometre positions on charts, at one kilometre intervals along shorelines using chart calipers. We then estimated, to the nearest 0.1 kilometre, the geographical start positions of each spawning event relative to these geo-referenced shorelines. Spawn depositions extended from a start position (x) to an end position (x+length) where length was the length (m) of the spawn deposition measured along the shoreline. This system was made to work in all sections of the BC coast where herring were known to have spawned. Herring sections or sub-areas within each statistical area (Haist and Rosenfeld 1988 or Midgley 2003) were utilized for mapping and data aggregation purposes as these convenient boundaries encompassed clusters of shoreline spawning beds. Most herring sections have a zero starting kilometre position which increases to a maximum of 400 km, so as to include all of the shorelines where herring spawning events have been reported. In several cases, spawning activity can overlap between adjacent sub-areas or sections. In these instances, the kilometre positions were made contiguous between sub-areas. The kilometre segments were not defined for the entire coastline but rather only for the general vicinity of herring spawning sites. Therefore, there are geographical gaps in the position numbers. Positions of spawning were defined in each sub-area on the BC coast that had a sufficient number of records for analysis. Consequently, they are a few recently recorded and peripheral spawning locations that do not have assigned kilometre positions.

Kilometre start positions were approximated for 30% of the records where only a location name was recorded (no charted positions). A median kilometre position was calculated for each of these spawning locations using the remaining 70% of records which did have charted positions. Most records where spawning positions had to be approximated, occurred prior to 1951. A few locations were never charted or there were insufficient records to make a reasonable approximation. In these relatively few instances we assigned a general kilometre position to some location names to facilitate computer mapping.

GEOGRAPHIC ORGANIZATION

The CD-ROM version of the "Herring Geographical Bulletin" web site is organized into 6 regions and about 101 herring sub-areas or "sections" compatible with the stock assessment regions and statistical areas defined by Fisheries and Oceans, Canada (Haist and Rosenfeld 1988 or Midgley 2003). There have been several changes in the boundaries and names used for regions, sections and locations since the spawn shoreline kilometre work began in 1983. These changes, however, do not interfere with the geographical analysis presented in this report as the herring spawn database has been updated and linked in 1994 to a geo-referenced data set with latitude and longitude coordinates of approximately 7,800 reference positions located approximately one kilometre apart. Computer mapping of herring spawns along shorelines and cumulative spawn analysis became feasible at one kilometre resolution after updating more than 28,000 spawn start positions (to the nearest 0.1 km). To display the details of these spawns, more than 100 sub-area or section maps were created from a single, seamless coastal map. We used [SYSTAT](#) and [MINITAB](#) to create spawn maps, plots, tables and image files suitable for electronic publication. The original seamless base map was prepared by digitizing and combining several 1:40,000 scale Canadian Hydrographic Service (CHS) charts. The chart digitization was done by Geo-Spatial Systems Ltd. over a period of several years during the early 1990s. Some section maps were geographically partitioned further and labelled: N=north, S=south, E=east and W=west due to their broad and expansive areas. This procedure was done only to permit the display of section maps at similar scales as some herring sections were considerably larger than others. All available spawn and catch data were summed and aggregated by **whole** sections, statistical areas and regions in the web site tables.

In the late 1990s the availability of geographical information systems (GIS) facilitated the digitization of the approximate **shapes** (polygons) of many previously recorded herring spawn depositions over a 1:20,000 scale, TRIM (Terrain Resource Information Management) digital map. Eventually more detailed, composite maps of major spawn depositions from 1930 to 2002 in each sub-area were compiled using [ARCVIEW](#) geographical information system. Region and section boundaries, originally defined on the basis of spawning bed clusters in the early 1970s (or during a period of stock rebuilding) were applied in this geographical analysis but these boundaries do not imply delineations of separate herring stocks. Currently, there are a total of 146 herring sections in BC. Only 101 of these sections, however, have a history of spawning within their boundaries. The remaining sections consist mostly of offshore areas and undefined spawning or fishing locations bounded within statistical areas. Herring catches have been recorded in 141 of the 146 herring sections and are summarized in the [web site tables](#) by catch season and gear type. The following table lists the 101 geographical sections and 6 regions examined in this herring spawn analysis and classification.

| | | | |
|---|------------|--|----------------|
| QUEEN CHARLOTTE ISLANDS | | PRINCE RUPERT DISTRICT | |
| Section 001 | Tasu Sound | Section 032 | Portland Inlet |
| Section 002 | Port Louis | Section 033 | Port Simpson |

| | | | |
|-----------------------------|------------------|-----------------------------|----------------------------------|
| Section 003 | Rennell Sound | Section 041 | Area 4 West (Dundas Island) |
| Section 004 | Cartwright Sound | Section 042 | Area 4 North (Prince Rupert) |
| Section 005 | Englefield Bay | Section 043 | Area 4 South (N. Porcher Island) |
| Section 006 | Louscoone Inlet | Section 051 | Other Area 5 (Banks Island) |
| Section 011 | Masset Inlet | Section 052 | Kitkatla Inlet |
| Section 012 | Naden Harbour | Section 053 | Principe Channel |
| Section 021 | Juan Perez Sound | | |
| Section 022 | Skidegate Inlet | | |
| Section 023 | Cumshewa Inlet | | |
| Section 024 | Laskeek Bay | | |
| Section 025 | Skincuttle Inlet | | |

| CENTRAL COAST | | JOHNSTONE STRAIT | |
|-------------------------------|-------------------|----------------------------------|------------------------|
| Section 061 | Caamano Sound | Section 111 | Belize Inlet |
| Section 062 | Gil Island | Section 112 | Seymour Inlet |
| Section 063 | Kitimat Arm | Section 121 | Queen Charlotte Strait |
| Section 064 | Gardner Canal | Section 122 | Beaver Harbour |
| Section 065 | Princes Royal Ch. | Section 123 | West Cracroft Island |
| Section 066 | Surf Inlet | Section 124 | Wells Passage |
| Section 067 | Laredo Sound | Section 125 | Gilford Island |

| | | | |
|-----------------------------------|--------------------|---|------------------------|
| Section 072 | Powell Anchorage | Section 126 | Kingcome Inlet |
| Section 073 | Bella Bella | Section 127 | Knight Inlet |
| Section 074 | Thompson Bay | Section 131 | Thurlow Islands |
| Section 075 | McNaughton Group | Section 132 | Deepwater Bay |
| Section 076 | Kildidt Sound | Section 133 | Loughborough Inlet |
| Section 077 | Milbanke Sound | Section 134 | Bute Inlet |
| Section 078 | Don Peninsula | Section 135 | Cape Mudge |
| Section 082 | Dean Channel | Section 136 | Reed Island |
| Section 083 | Bentinck Arms | | |
| Section 084 | Burke Channel | | |
| Section 085 | Kwakshua Channel | | |
| Section 086 | Fitzhugh Sound | | |
| Section 091 | Fish Egg Inlet | | |
| Section 092 | Rivers Inlet Mouth | | |
| Section 093 | Rivers Inlet Head | | |
| Section 102 | Takush Harbour | | |
| Section 103 | Smith Inlet | | |
| STRAIT OF GEORGIA | | WEST COAST VANCOUVER ISLAND | |
| Section 141 | Oyster Bay | Section 231 | Trevor Channel |
| Section 142 | Baynes Sound | Section 232 | West Barkley Sound |
| Section 143 | Qualicum | Section 233 | Imperial Eagle Channel |
| Section 151 | Redonda Islands | Section 241 | Tofino Inlet |
| Section 152 | Powell River | Section 242 | Hesquiat Harbour |
| Section 161 | Sabine Channel | Section 243 | Sydney Inlet |
| Section 162 | Hotham Sound | Section 244 | Millar Channel |

| | | | |
|-----------------------------|------------------|-----------------------------|-----------------|
| Section 163 | Malaspina Strait | Section 245 | Vargas Island |
| Section 164 | Jervis Inlet | Section 251 | Tahsis Inlet |
| Section 165 | Sechelt Inlet | Section 252 | Nootka Sound |
| Section 172 | Nanoose Bay | Section 253 | Esperanza Inlet |
| Section 173 | Yellow Point | Section 261 | Tahsish Inlet |
| Section 181 | Swanson Channel | Section 262 | Clannick Cove |
| Section 182 | Plumper Sound | Section 263 | Checleset Bay |
| Section 191 | Saanich Inlet | Section 271 | Quatsino Sound |
| Section 192 | Cordova Bay | Section 272 | Brooks Bay |
| Section 193 | Victoria Harbour | Section 273 | Forward Inlet |
| Section 202 | Sooke Harbour | Section 274 | Holberg Inlet |
| Section 220 | Nitinat Lake | | |
| Section 280 | Howe Sound | | |
| Section 291 | Fraser Foreshore | | |
| Section 292 | Sechelt | | |
| Section 293 | Boundary Bay | | |

A series of linkage maps, summary tables, plots and spawn maps for each sub-area (i.e. region, statistical area or herring section) can be explored with a web browser. Major features are described below:

MAP #1. A [British Columbia map](#) showing the locations of six regions. Any region map can be displayed by clicking a region name (hotspot or hyperlink) on the British Columbia map.

MAP #2. A [region map](#) showing the locations of statistical areas and sub-areas (herring sections) within each region. Summary tables, plots and maps of spawners and catches can be displayed by clicking a section number (hotspot or hyperlink) on a region map.

FIGURE 1. A [cumulative spawn map](#) (or spawn habitat map) of each herring section showing shoreline reference points or kilometre (km) positions. Long-term cumulative spawn (1928 to the present) is depicted at each km position by the proportional size of each dot. The dots are coloured to represent six classifications of cumulative spawn. Red indicates the top 5%, brown the next 10%, yellow the next 15%, green the next 20%, blue the next 25% and violet the last 25% of ranked shoreline kilometre segments.

| HERRING SPAWN CLASSIFICATION | COLOUR OF EACH MAP CIRCLE | PERCENTAGE OF RANKED KM | RANGE OF PERCENTAGES |
|------------------------------|---------------------------|-------------------------|----------------------|
| VITAL | Red | Top 5 % | 95-100 % |
| MAJOR | Brown | Next 10 % | 85-95 % |
| HIGH | Yellow | Next 15 % | 70-85 % |
| MEDIUM | Green | Next 20 % | 50-70 % |
| LOW | Blue | Next 25 % | 25-50 % |
| MINOR | Violet | Next 25 % | 0-25 % |

Cumulative spawn maps are based on indices calculated in [cumulative spawn tables](#) which are updated annually from data archived in DFO's *herring spawn database*. The cumulative **Spawn Habitat Index** (SHI) is used as a measure of habitat sensitivity as this index takes into account both the long-term frequency and magnitude of recorded spawns over time. The index is calculated by the sum of the product of each measured spawn "shoreline length" and the median of the product of spawn width and egg layers adjusted by percent cover and pooled geographically. This index (described more fully below) should not be confused with the "spawn index" used in the age-structured or escapement stock assessment models (Schweigert *et al.* 1993-2005 or Haist *et al.* 1984-1992). In addition to annual and cumulative spawn tables, spawn data records have also been imported from original records (documented since 1928) and can be viewed on this web site by clicking a numbered geographic "pool" (hotspot or hyperlink) on any [cumulative spawn habitat map](#).

FIGURE 2. A [location map](#) of each herring section showing the location names used by field surveyors to identify herring spawning sites. Some infrequently used, names were **not** plotted if they were eclipsed by more commonly used names. Names were plotted on maps by applying the mean latitude and longitude position of every spawner-utilized kilometre of shoreline aggregated within each location assignment.

FIGURE 3. A [catch and spawn plot](#) of each herring section showing herring catches during the spawning season (beginning of January to end of April catches only) and estimated spawner abundance (calculated using annual, [egg deposition survey data](#) and an [age-structure model](#)) for each calendar year from 1940 or 1950 to the present.

FIGURE 4. A [spawn magnitude plot](#) of each herring section indicating the magnitude of each spawning event based on the [spawn habitat index](#) at each kilometre centroid position (or reference point) during each of the previous 64 years.

FIGURE 5. A [spawn frequency plot](#) of each herring section showing the frequency of spawning events at each kilometre position (or reference point) over all years since 1928. Since herring can spawn in "waves" over the same kilometre of shoreline in the same year, the frequency of spawning events can

sometimes exceed the number of years in the time series.

FIGURE 6. A [spawn timing plot](#) of each herring section showing the date of each spawning event during the previous 64 years using a Day-Of-Year (DOY) or calendar designation.

TABLE 1. A collection of [spawn tables](#) summarize spawn records since 1940 by herring section, statistical area, region and the entire British Columbia coast. These tables can be viewed by selecting a region and choosing a section number (hotspot or hyperlink) on any of six region maps. The scroll bar can be used to scroll through values located beneath the table header. The header contains a Day-of-Year (DOY) to calendar date conversion table. Columns in the tables are described below.

| COLUMNS: | DESCRIPTION: |
|---------------------|--|
| Year | Survey year. |
| Total records | Total number of spawn records (spawning events). |
| Spawn Habitat Index | Sum of the product of each spawn length (m) and the median spawn width (m) and egg layers adjusted by percent cover and pooled geographically (see complete description below). |
| Total length | Total length (along shoreline) of the spawning area (m). |
| Mean width | Mean width (perpendicular to the shoreline) of the spawning area (m). |
| Mean layers | Mean number of egg layers (spawn thickness). |
| Wgt SST | Mean sea surface temperature (oC) weighted by the Spawn Habitat Index. Sea surface temperatures in this calculation were measured at daytime, high tide on the dates of each spawning event. Source: nearest lighthouse oceanographic stations . |
| Mean date | Mean spawn date (Day-Of-Year, DOY). |
| Wgt date | Mean spawn date (Day-Of-Year, DOY) – the spawn date is adjusted (or weighted) by the Spawn Habitat Index to incorporate differences in the magnitude of spawns at different sites within regions, statistical areas or herring sections. |
| Min date | Earliest spawn date (Day-Of-Year, DOY). |
| Max date | Latest spawn date (Day-Of-Year, DOY). |
| Diver Survey (%) | Percentage of recorded spawn deposition assessed by divers. |

DOY = Day of year (i.e. January 1 = 1, February 28 = 59, December 31 = 365)

TABLE 2. A collection of [catch tables](#) summarize catch records since 1888 by herring section, statistical area, region and the entire British Columbia coast. These tables can be viewed by selecting a region

and choosing a section number (hotspot or hyperlink) on any of six region maps. Herring catches (tonnes) are summed by season (Jan-Apr, May-Aug, Sep-Dec) and gear type (gillnet, seine, trawl and seine-caught spawn-on-kelp) for each year.

LIMITATIONS OF HERRING SPAWN RECORDS

The precise geographical limits of herring spawning probably are accurate to within a kilometre, more in some specific sites and less in others. The original records were made with varying degrees of precision and the degree of precision often depended on the area and time of the survey. Spawning areas characterized by many geographical landmarks such as the Gulf Islands in the southern Strait of Georgia, were probably more precisely plotted than other areas with fewer geographical details, such as the relatively straight shoreline between Parksville and Deep Bay. It is generally accepted that post-1987 diver surveys provide a more accurate measure of spawning bed widths and egg densities (where measurements from several diver transects are averaged) than standard surface surveys of the past. For example, surface survey, egg density measurements of extensive eelgrass beds (i.e. Boundary Bay sand flats) were frequently over-estimated because of difficulties in assessing patchiness (or percent cover). Similarly, spawning bed width measurements determined by grappling rakes on steeper shorelines were frequently under-estimated. In general however, the summaries presented here should be reasonable indicators of the locations of spawning activity to the nearest kilometre.

During the several years of preparatory work that has gone into this project, we often have heard the criticism that the herring spawning database has limited value because of alleged errors and omissions in the records. The most frequently cited error attributed to the records is that the data collected on the spawn dimensions were made in a sloppy way and "often by the cook on a patrol vessel". Alternately, we have heard that some fishery officers could not be bothered to go out and look for herring spawn rather, they simply noted the presence or absence of seabirds and assumed that herring spawn occurred whenever birds were reported. These stories undoubtedly could be correct, but probably for not more than a few of the nearly 29,000 records used in this analysis.

Based on detailed examination of the original records, it is clear that the overwhelming majority of the fishery officers and divers who report on herring spawns, have done it in a dedicated, professional and competent manner, often with detailed comments and charts accompanying the records. There are undoubtedly some errors in individual records, but usually the impact of such errors is diminished because of the relatively large number of records available for most locations. Furthermore, these records were gathered by hundreds of different individuals over a 75 year period. Within any single location, there were at least several different recorders, and often many more over the years. So it is unlikely to expect a continuous run of bad records.

There are, nevertheless, two kinds of systematic errors in these records which should be mentioned. The first appears to be a time-dependent trend for fishery officers to under-estimate spawn width. This occurred mainly in the earlier years, when it was generally believed that most of the spawn was confined to the intertidal zone. It has not been until relatively recent times that the significance of the subtidal fraction has been fully appreciated (Haegele *et al.* 1983). Also, there has been systematic changes (see Hay and Kronlund 1987) in the measurement of spawn density over the years, starting with a "1 to 5 intensity" scale from 1928 to 1950, a "1 to 9 intensity" scale from 1951 to 1982 and an egg layer measurement from 1977 to the present date. Each of these measurements has been converted to average egg layers in the database. In the recent past, a spawn coefficient (Hay and Kronlund 1987) was used to correct for time-dependent errors. This area-specific coefficient was calculated using the mean of the product of spawn width and intensity, pooled at the [herring section](#) geographic scale. Today, a similar correction is applied whereby the median of the product of spawn width and egg layer measurements are pooled by a range of discrete kilometre segments along the coastline. This coefficient is incorporated into a cumulative index described below.

Spawn Habitat Index We have computed a [cumulative spawn habitat index](#) (SHI) to represent the combined **long-term frequency and magnitude of spawns** along each kilometre of coastline over time. The index is simply a measure of shoreline utilization by spawning herring. This index should not

be confused with the "spawn index" used in the age-structured and escapement stock assessment models (Schweigert *et al.* 1993-2005 or Haist *et al.* 1984-1992). The cumulative Spawn Habitat Index is calculated by the sum of the product of each measured spawn length (m) and the median of the product of spawn width (m) and egg layers adjusted by percent cover and pooled geographically. Spawn width and egg layer measurements are pooled by a range of discrete, shoreline kilometre segments coast-wide, over all years (1928 to the present year) and reflect the bathymetric (depth and slope) and vegetative features (seaweed species composition) of the spawning sites (area-specific spawn coefficient). Spawn length is considered the most reliable of the three spawn measurements in terms of completeness and consistency and has the most influence on the Spawn Habitat Index (SHI = Length x Spawn Coefficient). Previously, the spawn coefficient was pooled either at a broader [herring section](#) level or at a more constricted [herring location](#) geographic scale (Hay and McCarter 1999). This latter practice, however, can sometimes maintain time-dependent errors because herring [location names](#) frequently cluster and overlap, and were inconsistently assigned during database development. Section pooling, on the broader side of the scale, does not always provide accurate representation as a great diversity of spawning habitats can exist within a single herring section. Intermediate pooling by **discrete** ranges of shoreline kilometre segments (or pools) provides the most accurate representation, reduces systematic error and has been implemented since the year 2000. A bootstrap procedure, adopted in 2003, is now used to determine spawn coefficients at the [geographical "pool" aggregation](#) level. If there are fewer than 10 years of spawn survey measurements in a "pool", a broader "section" spawn coefficient is applied.

The only other kind of error in the records which can severely affect conclusions presented in these analyses, is that of incompleteness. It is clear that for some locations, records were not collected systematically each year. Sometimes, problems with field communications, equipment and weather resulted in data deficiencies. It is also known that many small, but observable spawns, do not reach the database while others do. These spawns may be important from a habitat perspective but not from a stock assessment view where the survey priorities are set.

UTILITY OF HERRING SPAWN RECORDS

This geographical compilation and historical synopsis of herring spawns represents the culmination of several earlier but briefer versions. One of the earlier analyses, presented at the 1986 Herring Stock Assessment Meetings as PSARC Working Paper 86-5, had widespread distribution and was used for the examination and evaluation of ecologically sensitive areas relative to potential impacts from oil exploration activities and mariculture developments. A subsequent, detailed version (Hay *et al.* 1989) consisted of six volumes and was published in the Canadian Manuscript Series of Fisheries and Aquatic Sciences (No. 2019). Until recently, the herring spawn database has been used primarily for stock assessment purposes. Applications in habitat assessment have had to wait for the development and improvement of geographical information systems (GIS) and long-term distributional analysis software.

The data and analysis that are presented here have been available for several years, on request (or on the internet) to anyone with an interest in the historical distribution of herring spawning areas. These analyses have already been used many times for the examination of impacts of various nearshore developments and oil spill scenarios. It appears that one of the most useful aspects of this work is that some areas are clearly identified as important spawning locations while others, with a negligible history of herring spawning, are shown to be less important. There are many locations, however, which are intermediate in importance. These locations have a record of spawning which varies in time. These intermediate spawning locations are the most difficult to evaluate in terms of their role in maintaining the well-being of the herring resource. The habitat classification system proposed in this report should address the issue and prove useful in assessing the relative importance of each kilometre of British Columbia shoreline. A few core spawning locations stand out from the rest and are easily distinguished from the many peripheral locations that were frequently recorded during the early 1970s (a period of stock rebuilding). These peripheral spawning areas were utilized for about 10-15 years but have not been actively preferred since the early to mid-1980s. This spawning distribution and behavioural pattern supports the adopted-migrant hypothesis suggested in [Huse *et al.* \(2002\)](#) and is consistent with the observed [distributional contraction](#) (as oppose to area contraction) of herring spawning areas since 1985. As spawn surveying efforts shifted from surface or shore-based to diver-based assessments in

1988, it may be argued that this apparent distributional contraction may simply be a result of changes in survey methodology and priorities. Most of these peripheral spawning areas, however, were not recorded in years *before* the 1970 to 1985 expansion (only, *during* this period) and throughout a time when surface or shore-based surveys were actively employed before, during and after distributional changes. Furthermore, the duration of occurrence was *gradual* (10-15 years) as opposed to the more *sudden* changes from surface to diver survey methodology that occurred between 1986 and 1988. Since annual herring spawning events contribute immensely to local productivity (Hay and Fulton 1983), this analysis may also have important implications to the abundance and distribution of other shoreline inhabitants including invertebrates, seabirds, other fish and marine mammals that depend on herring and herring spawn for food.

In general, we suggest that it is essential to conserve the spawning areas that have a history of repetitive spawning over time. Also, areas immediately adjacent to spawning habitat must be protected. Ultimately however, each instance of a nearshore development that might impact herring spawning areas must be decided on its own merits and it should be kept in mind that we still do not understand why some sites are used as spawning areas and others are not. There is, as yet, no single, definitive explanation for the observed episodic utilizations of "inner" and "outer" spawning areas and apparent "spawn shifts". Heavily utilized spawning sites are often recorded on leeward sides of islands or along mainland shores, sheltered by islands or headlands as opposed to windward or more exposed shorelines. Overly sheltered and sometimes stagnant areas (i.e. heads of inlets) with only minimum estuarine circulation, are also utilized but to a much lesser degree. Spawning sites with intermediate or low ocean exposures that maintain significant water body circulation seem to be favoured. Protection from long fetch waves, *large vessel* traffic effects, transient lighting, prevailing winds, local temperature, salinity, dissolved oxygen and turbidity tolerances, siltation avoidance, dynamically variable distributions of predators (marine mammals, other fish, fishers and seabirds) and decadal-scale trends in sea surface temperatures have all been suggested as possible influences. Additionally, there are also many potential spawning locations which have never been documented as spawning areas but still appear to have all the appropriate vegetative substrates and local oceanographic conditions that are found in heavily utilized areas (Hay *et al.* 1984). Moreover, it should be realized that herring "enhancement" or "re-establishment" does not appear to be possible at the present time (Hay and Marliave 1988). Therefore, if herring spawning habitat is lost, we cannot necessarily expect the impacted stocks to spawn in other locations nor can we realistically expect that new spawning habitat can be created.

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