HERRING SPAWNING AREAS

OF

BRITISH COLUMBIA

A review, geographic analysis and classification

By

D. E. Hay and P. B. McCarter

Fisheries and Oceans Canada
Pacific Biological Station
Nanaimo, British Columbia
V9T 6N7

Revised edition: 2006

© Her Majesty the Queen in Right of Canada 2006

Correct citation for this publication:
Hay, D.E., P.B. McCarter, 2006. Spawning areas of British Columbia herring: a review, geographical analysis and classification. Can. MS Rep. Fish. Aquat. Sci. 2019 rev. ed

Original edition: Hay, D.E., P.B. McCarter, R. Kronlund and C. Roy. 1989. Spawning areas of British Columbia herring: a review, geographical analysis and classification. Volumes 1-6. Can. MS Rep. Fish. Aquat. Sci. 2019.

ABSTRACT

The geographical distributions of Pacific herring (*Clupea pallasi*) 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 that 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 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 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 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

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.

ACKNOWLEDGEMENTS

The authors would like to thank the fishery officers, field personnel and diver teams for their efforts in contributing to this web site and CD-ROM. We also appreciate the efforts of Charles Fort, Lorena Hamer and former data custodians for helping to build and maintain the integrity of the herring spawn database. Students, Chris Oikawa, Alice Ortmann, Michael Luckach and Naomi Akune participated in kilometre positioning and geo-referencing tasks. Glen Langford, Geo-Spatial Systems Ltd., provided the original digitized CHS British Columbia map from which all SYSTAT© maps (time series and cumulative spawn maps) were derived. Cliff Robinson, Parks Canadian Heritage, was instrumental in the development of an earlier VISUAL BASIC© presentation of this data which has subsequently been developed further into the present, browser-based version. Andrew Thomson assisted in the initial conversion of multiple SYSTAT© maps to animation format and supervised and coordinated the initial digitization of herring spawns using SPANS© and ARCVIEW© GIS software. Kristen Daniel, GIS technician has done much of the recent digitization and GIS work. Tricia Boxwell assisted with the first HTML web pages in 1997 which have subsequently been standardized to Fisheries and Ocean's "Common Look and Feel" format in 2000 with the assistance of Megan Adam.

Over the years funding was provided from various sources, but we especially thank the Herring

Conservation and Research Society, Norm Sloan, Parks Canadian Heritage, Jim Bunch, DFO, Ottawa, Colin Levings, DFO, West Vancouver and Brad Mason, DFO, Vancouver. We would also like to thank Malaspina University-College for supporting the internship program.

REFERENCES

Chalmers, D. D. 1986. Review of the 1984-85 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 173: 65 p.

Chalmers, D. D. 1988. Review of the 1985-86 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 184: 64 p.

Chalmers, D. D. 1989. Review of the 1986-87 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 196: 91 p.

Chalmers, D. D. 1989. Review of the 1987-88 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 198: 83 p.

Chalmers, D. D. 1990. Review of the 1988-89 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 204: 108 p.

Chalmers, D. D. 1991. Review of the 1989-90 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 207: 121 p.

Chalmers, D. D. 1991. Review of the 1990-91 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 213: 128 p.

Chalmers, D. D. 1993. Review of the 1991-92 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 218: 133 p.

Chalmers, D. D., and D. Haase. 1985. Review of the 1983-84 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 163: 68 p.

Chalmers, D. D., and V. Miller. 1985. Review of the 1982-83 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 162: 59 p.

Chalmers, D. D., P. E. Sprout, A. Barber, and S. Benoit. 1982. Review of the 1980-81 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 134: 87 p.

Chalmers, D. D. and P.E. Sprout. 1981 Review of the 1978-1979 British Columbia herring fishery and spawn abundance. Can. Ind. Rep. Fish. Aquat. Sci. 120: 51 p.

Chalmers, D. D. and P. E. Sprout. 1982. Review of the 1979-80 British Columbia herring fishery and spawn abundance. Can. Ind. Rept. Fish. Aquat. Sci. 133: 64 p.

Haegele, C. W. and L. C. Fitzpatrick. 1983. The distribution of herring spawn and associated roe fisheries in British Columbia (1956 to 1980). Can. Data Rep. Fish. Aquat. Sci. 407: v +245 p.

Haist, V. and J. F. Schweigert. 1992. Stock assessments for British Columbia herring in 1991 and forecasts of the potential catch in 1992. Can. MS Rep. Fish. Aquat. Sci. 2146: 82 p.

Haist, V. and J. F. Schweigert. 1991. Stock assessments for British Columbia herring in 1990 and forecasts of the potential catch in 1991. Can. MS Rep. Fish. Aquat. Sci. 2119: 60 p.

Haist, V. and J. F. Schweigert. 1990. Stock assessments for British Columbia herring in 1989 and forecasts of the potential catch in 1990. Can. MS Rep. Fish. Aquat. Sci. 2049: 62 p.

Haist, V. and J. F. Schweigert. 1989. Stock assessments for British Columbia herring in 1988 and forecasts of the potential catch in 1989. Can. MS Rep. Fish. Aquat. Sci. 2028: 48 p.

Haist, V., J. F. Schweigert, and D. Fournier. 1988. Stock assessments for British Columbia herring in 1987 and forecasts of the potential catch in 1988. Can. MS Rep. Fish. Aquat. Sci. 1990: 63 p.

Haist, V., J. F. Schweigert, and D. Fournier. 1987. Stock assessments for British Columbia herring in 1986 and forecasts of the potential catch in 1987. Can. MS Rep. Fish. Aquat. Sci. 1929: 63 p.

Haist, V., J. F. Schweigert, and D. Fournier. 1986. Stock assessments for British Columbia herring in 1985 and forecasts of the potential catch in 1986. Can. MS Rep. Fish. Aquat. Sci. 1889: 48 p.

Haist, V. and M. Stocker. 1984. Stock assessments for British Columbia herring in 1983 and forecasts of the potential catch in 1984. Can. MS Rep. Fish. Aquat. Sci. 1751: 50 p.

Haist, V., Stocker, M. and J. F. Schweigert. 1985. Stock assessments for British Columbia herring in 1984 and forecasts of the potential catch in 1985. Can. Tech. Rep. Fish. Aquat. Sci. 1365: 53 p.

Haist, V. and L. Rosenfeld. 1988. Definitions and codings of localities, sections, and assessment regions for British Columbia herring data. Can. MS Rep. Fish. Aquat. Sci. 1994: 123 p.

Hamer, L. and J. Hepples. 2000. A Review of 1999/2000 British Columbia Herring Fisheries. Can. Ind. Rep. Fish. Aquat. Sci. 254: 51 p.

Hamer, L. and J. Hepples. 2001. A Review of 2000/2001 British Columbia Herring Fisheries. Can. Ind. Rep. Fish. Aquat. Sci. 263: 51 p.

Hamer, L., P. Midgley and B. Rusch. 2002. A Review of 2001/2002 British Columbia Herring Fisheries. Can. Ind. Rep. Fish. Aquat. Sci. 267: 52 p.

Hay, D. E. and J. Fulton. 1983. Potential secondary production from herring spawning in the Strait of Georgia. Can. J. Fish. Aquat. Sci. 40: 109-113 p.

Hay, D. E., C. D. Levings and M.J. Hamey. 1984. Distribution of a herring fishery relative to submerged vegetation, herring spawn distribution and oceanographic factors. Can. MS Rep. Fish. Aquat. Sci. 1760: 53 p.

Hay, D. E. 1985. Reproductive biology of Pacific herring. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1): 111-126.

Hay, D. E., Cooke, K. D., and Gissing. 1986. Experimental studies of Pacific herring gillnets. Fish. Res. 4: 191-211.

Hay, D. E. and A. R. Kronlund. 1987. Factors affecting the distribution, abundance, and measurement of Pacific herring (Clupea harengus pallasi) spawn. Can. J. Fish. Aquat. Sci. 44: 1181-1194 p.

Hay, D. E. and J. B. Marliave. 1988. Transplanting herring eggs in British Columbia - a stocking experiment. American Fisheries Society Symposium 4:

Hay, D. E., P. B. McCarter, R. Kronlund and C. Roy. 1989. Spawning Areas of British Columbia Herring: A Review, Geographical Analysis and Classification. Volumes I-VI Can. MS Rep. Fish. Aquat. Sci. 2019

Hay, D. E. and McCarter, P. B. 1999. Distribution and timing of herring spawning in British Columbia. Canadian Stock Assessment Secretariat Research Document 99/14 (Working Paper H98-5).

Hourston, A. S. and M. J. Hamer. 1979. Definitions and codings of localities, sections, management units and divisions for British Columbia herring data. Fish. Mar. Ser. MS Rep. 1533: 91 p.

Humphreys, R. D., and L. A. Webb. 1972. The abundance of herring spawn in the coastal waters of B.C. 1973. Fish. Mar. Serv. Tech. Rep. 1972-11: 31 p.

Humphreys, R. D., and L. A. Webb. 1973. The abundance of herring spawn in the coastal waters of British Columbia 1974. Fish. Mar. Serv. Tech. Rep. PAC/T-73-10: 36 p.

Huse, G., S. Railsback and A. Ferno. 2002. Modelling changes in migration pattern of herring: collective behaviour and numerical domination. Journal of Fish Biology 60: 571-582.

Isaacson, R. S. K., and A. S. Hourston. 1972. Area and locality codings for British Columbia herring biological data. Fish. Res. Board Can. MS Rep. 1174: 53 p.

Midgley P. 2003. Definitions and codings of localities, herring sections, and stock assessment regions for British Columbia herring data. Can. Manuscr. Rep. of Fish. and Aquat. Sci. 2634: 113 p.

Rusch, B., S. MacConnachie and L. Hamer. 2003. A Review of 2002/2003 British Columbia Herring Fisheries. Can. Ind. Rep. Fish. Aquat. Sci. 273: vi + 63 p.

Rusch, B. and L. Hamer. 2004. A Review of 2003/2004 British Columbia Herring Fisheries. Can. Ind. Rep. Fish. Aquat. Sci. 275: vi + 64 p.

Schweigert, J.F. 2005. Stock assessments for British Columbia herring in 2005 and forecasts of the potential catch in 2006. Canadian Science Advisory Secretariat Research Document 2005/xxx: xx p.

Schweigert, J.F. 2004. Stock assessments for British Columbia herring in 2004 and forecasts of the potential catch in 2005. Canadian Science Advisory Secretariat Research Document 2004/081: 95 p.

Schweigert, J.F. 2003. Stock assessments for British Columbia herring in 2003 and forecasts of the potential catch in 2004. Canadian Science Advisory Secretariat Research Document 2004/005: 102 p.

Schweigert, J.F. 2002. Stock assessments for British Columbia herring in 2002 and forecasts of the potential catch in 2003. Canadian Science Advisory Secretariat Research Document 2002/110: 91 p.

Schweigert, J.F. 2001. Stock assessments for British Columbia herring in 2001 and forecasts of the potential catch in 2002. Canadian Science Advisory Secretariat Research Document 2001/140: 84 p.

Schweigert, J.F. 2000. Stock assessments for British Columbia herring in 2000 and forecasts of the potential catch in 2001. Canadian Stock Assessment Secretariat Research Document 2000/165: 74 p.

Schweigert, J.F. and C. Fort. 1999. Stock assessments for British Columbia herring in 1999 and forecasts of the potential catch in 2000. Canadian Stock Assessment Secretariat Research Document 99/178: 96 p.

Schweigert, J.F. and C. Fort. 1994. Stock assessments for British Columbia herring in 1993 and forecasts of the potential catch in 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1971: 67 p.

Schweigert, J.F., C. Fort and L. Hamer. 1997. Stock assessments for British Columbia herring in 1996 and forecasts of the potential catch in 1997. Can. Tech. Rep. Fish. Aquat. Sci. 2173: 73 p.

Schweigert, J.F., C. Fort and L. Hamer. 1996. Stock assessments for British Columbia herring in 1995 and forecasts of the potential catch in 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2098: 66 p.

Schweigert, J.F., C. Fort and L. Hamer. 1995. Stock assessments for British Columbia herring in 1994 and forecasts of the potential catch in 1995. Can. Tech. Rep. Fish. Aquat. Sci. 2040: 70 p.

Schweigert, J.F., C. Fort and R. Tanasichuk. 1999. Stock assessments for British Columbia herring in 1998 and forecasts of the potential catch in 1999. Canadian Stock Assessment Secretariat Research Document 99/21: 96 p.

Schweigert, J.F., C. Fort and R. Tanasichuk. 1998. Stock assessments for British Columbia herring in 1997 and forecasts of the potential catch in 1998. Can. Tech. Rep. Fish. Aquat. Sci. 2217: 64 p.

Schweigert, J.F., V. Haist and C. Fort. 1993. Stock assessments for British Columbia herring in 1992 and forecasts of the potential catch in 1993. Can. Tech. Rep. Fish. Aquat. Sci. 1913: 111 p.

Webb, L. A. 1974. The abundance of herring spawn in the coastal waters of British Columbia 1974. Fish. Mar. Serv. Tech. Rep. PAC/T-74-17: 39 p.

Webb, L. A. 1975. The abundance of herring spawn in the coastal waters of British Columbia 1975. Fish. Mar. Serv. Tech. Rep. PAC/T-75-28: 50 p.

Webb, L. A. 1976. Review of the 1975-76 herring fishery and spawn abundance. Fish. Mar. Serv. Tech. Rep. PAC/T-76-19: 33 p.

Webb, L. A., and A. S. Hourston, 1979. Review of the 1976-77 British Columbia herring fishery and spawn abundance. Fish. Mar. Serv. Industry Rep. 110: 46 p.

Webb, L. A., A. S. Hourston, and B. G. Juvenile. 1980. Review of the 1977-78 British Columbia herring fishery and spawn abundance. Can. Ind. Rep. Fish. Aquat. Sci. 112: 43 p.