Understanding the past to inform future conservation policy: Mapping traditional ecological knowledge of Pacific herring spawning areas through time

by

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Ethics Statement

Abstract

Pacific herring (*Clupea pallasii*) play a foundational role in human-ocean systems. While once abundant, herring have experienced declines and intermittent fisheries closures in British Columbia (BC) during the last century. I interviewed members of the Heiltsuk First Nation, and mapped their traditional ecological knowledge of the spatial distribution of observed herring spawns along the central coast of BC from the 1940s to the 2000s. The results show a marked contraction and aggregation in the distribution of spawns over time, with the total length of coastline with observed spawns declining at an average rate of 7.6% per decade. The concentration of spawns also shifted in space, with substantial declines on the exposed outer shores in the west of the region and the majority of recent spawns observed further inland to the east. In order to support resilient populations, fisheries management should account for such spatial characteristics and variation through time.

Keywords: Pacific herring; traditional ecological knowledge (TEK); resilience; spawning areas; spatial diversity; fisheries management

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Introduction

Growing recognition that ecological and social systems are inextricably linked and highly complex has catalyzed a fundamental transformation in thinking and a new approach to conservation policy, one that explicitly aims to manage for resilience; that is, the capacity of a complex system to resist, recover from, and adapt to disturbances (Holling 1973, Gunderson and Holling 2002). Simultaneously, emerging evidence suggests that population diversity within exploited species can contribute to their resilience and, therefore, should be incorporated into management and conservation strategies (Hughes et al. 1997, Schindler et al. 2010). For example, genetic, behavioural and geographic diversity can enable populations to adapt and persist despite perturbations such as harvest pressure and changing climatic conditions (Hilborn et al. 2003). Among spatially structured marine fish populations, spatial dynamics and diversity in spawn locations and timing can increase the probability that recruitment will be successful in some locations and times, thereby avoiding recruitment failure for the population as a whole (Stephenson 1999, Kerr et al. 2010, Ruzzante et al. 2006, Corten 2002, Secor 1999). Given the role this biocomplexity can play in conferring resilience (Hilborn et al. 2003), it is becoming increasingly apparent that conservation and management policies must account for the geographic components of marine fish populations and how these spatial characteristics change through time, in order to support resilient social-ecological systems.

Along the world's temperate coastlines, small pelagic forage fish are experiencing substantive declines, with profound ecological, economic and socio-cultural impacts to coupled human-ocean systems (Alder et al. 2008, Smith et al. 2011, Pinsky et al. 2011, Pikitch et al. 2012). Pacific herring (*Clupea pallasii*), for example, a once highly abundant forage fish in the northeastern Pacific ocean, have experienced declines in abundance and intermittent fisheries closures during the last century over much of their range, from Alaska, through British Columbia (BC), to Washington (Schweigert et al. 2010, Martell at al. 2012, McKechnie et al. 2014). Pacific herring play a foundational role as a primary conduit of energy from low to upper trophic-level consumers, such as piscivorous fish, birds, marine mammals and humans (Cury et al. 2000, Willson and

Womble 2006). For human communities along North America's Pacific coast, herring have long served as an important source of food, economic livelihood and well-being. Archaeological and ethnographic evidence suggests that coastal Indigenous people, including First Nations in BC, have harvested herring and herring roe for millennia (Boas 1932, Bouchard and Kennedy 1989, McKechnie et al. 2014). The legal rights of First Nations to harvest and use herring for food, social and ceremonial purposes have been recognized by Canadian courts, and several First Nations also have established rights to harvest and sell herring spawn-on-kelp (*R. v. Gladstone*, [1996] 2 S.C.R. 723; *Ahousaht Indian Band and Nation v. Canada (Attorney General)*, 2009 BCSC 1494).

A recent decision by Fisheries and Oceans Canada ("DFO") to re-open slowly recovering Pacific herring stocks to a commercial fishing industry dominated by non-First Nations' participants has triggered a political and legal melee, raising ethical, ecological and governance questions regarding indigenous rights and title, social justice and equity, the state of scientific knowledge about herring stocks, and the potential role of ecosystem-based fisheries management in arbitrating multidimensional solutions to this complex problem. Given that Pacific herring are known to form a series of spatially structured integrating populations (Stephenson 1954, Hourston 1982), and the importance of spatial variation in maintaining resilient fish populations (Schindler et al. 2010, Hilborn et al. 2003), high resolution information about their historical and current spatial characteristics could improve decisions about management and conservation. One underutilized but key source of information and innovation is the knowledge held by Indigenous people who have observed, harvested and depended on fish populations over time (Salomon et al. 2007, Thornton et al. 2010).

Here, I used a novel, interdisciplinary approach to document the spatial variation in Pacific herring spawns along approximately 2500 km of BC's central coast region through time. By interviewing resource users from the Heiltsuk First Nation, I collected spatially explicit observations of herring spawns over a period of 70 years on a decadal basis. I then mapped this regional information to quantify the rate of change in the total linear extent of observed herring spawns through time, as well as the change in the number and average length of spawn locations. Examining these data at the sub-regional scale allowed me to assess trends in the local distribution of spawn

observations as well as the overall regional trends. I discuss the utility of integrating different sources of knowledge in fisheries management, including traditional ecological knowledge (TEK) such as that collected in my interviews, as well as DFO's historical fisheries records of spawns (based on observations of fisheries officers and divers). I explain how TEK can inform the design of management policies to support resilient human-ocean systems, and I consider the implications of these results within the contemporary land/seascape of changing ocean conditions, fisheries governance, and indigenous self government in Canada.

Methods

Study Area and Participants

To investigate changes in the spatial distribution of herring spawn along the central coast of BC (Figure 1A, B & C), I conducted semi-directed interviews (Huntington 1998) in the spring of 2011 with 28 Heiltsuk First Nation marine resource users, including elders and hereditary chiefs, from the Heiltsuk coastal community of Bella Bella. Participant age ranged from 30 to 90 years old and all participants had taken part in the commercial and/or traditional harvest of Pacific herring or herring roe in the study area (Figure 1C). I constrained the spatial scope of my interviews to that part of the coastline known to each participant.

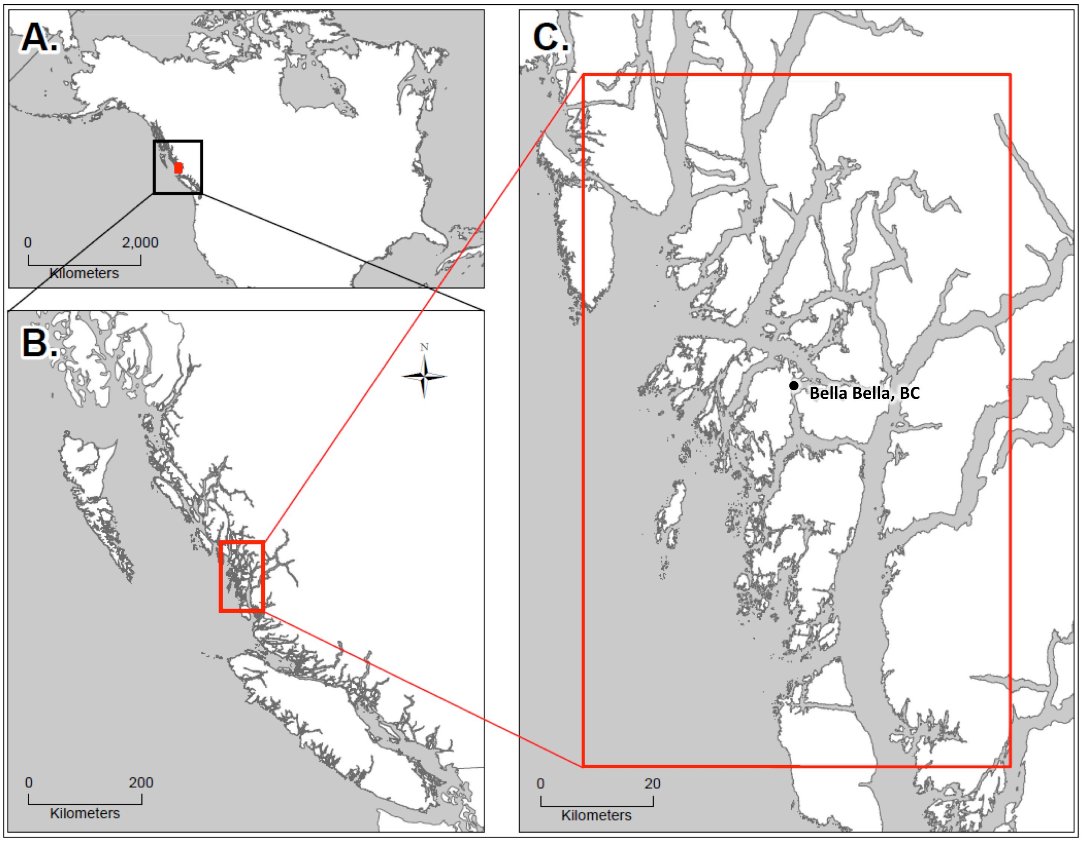

Figure 1 A, B&C. Location of the study area on the central coast of British Columbia, Canada.

Map Set-up

I created two base maps from digital Canadian Hydrographic Service marine charts using ArcGIS 10.0 geographic information system (GIS) software (ESRI, Redlands, CA, USA). I fitted each base map with a double matte mylar overlay and labelled each overlay with the map title, participant’s name, date of the interview, and four geographic registration marks.

Interviews

I used the map overlays to record traditional ecological knowledge of the spatial extent of Pacific herring spawns through time on a decadal basis. I began each interview by asking about the participant's experience with Pacific herring, including traditional and commercial herring harvest, as well as their general maritime experience in the study area. I then asked participants to delineate, by marking on the map overlays, coastline segments where they had observed herring spawns over the past 7 decades, from the 1940s through the 2000s. Participants distinguished their observations for each decade by using different coloured permanent markers. Participants delineated spawning locations for whichever decades they felt comfortable providing observations. I recorded 22 of 28 interviews using an audio recorder, and, at the request of individual participants, I documented the remainder of the interviews using only maps and hardcopy notes.

Map Translation

I digitally scanned the map overlays for each participant and digitized the delineated spawning locations by decade. I created a data set of amalgamated observations by decade by executing a union of all of the study participants’ delineated observations and then intersected these data with a 1:20,000 scale coastline, which matched the coastline of the charts used to make the base maps. Each coastline segment in the amalgamated data set was attributed with the length of the coastline segment and the number of coincident (shared) participant observations at the segment for each of the 7 decades. I created a second data set of individual observations by intersecting the observations of each individual with a 1:20,000 scale coastline. Each coastline segment in the individual data set was attributed with participant ID number, presence/absence for each of the 7 decades, length of coastline segment, and relevant notes.

Data Verification and Review

I convened a follow-up group workshop to verify and review the input data, present preliminary results, and receive feedback to inform my interpretation of the results. Nine study participants attended the workshop and three additional participants were met with individually. Each review participant was provided with a copy of their individual mapping results for personal review. Three participants added spawning areas to their maps, but no deletions or corrections were provided for previously identified spawning locations.

Data Analysis

To determine how the spatial distribution and extent of observed herring spawn has changed through time, I analysed the regional distribution of observations, the total linear extent of observed herring spawns, the number and average length of herring spawn locations, and the local distribution of observations.

Regional distribution of spawn observations. I used the maps of observed herring spawns by decade (described above) to assess the occurrence and spatial distribution of spawn observations across the study area through time.

Total linear extent. I calculated the total linear extent of herring spawn for each decade by measuring and summing all coastline segments with observed herring spawn based on the compiled observations of the 28 respondents. To estimate the rate and direction of change in the total kilometres (km) of observed herring spawn by decade and to account for the temporal autocorrelation in my data, I fit a linear regression to log transformed data (total kms of observed herring spawn), where:

$$\ln(N_t) = \ln(N_o) + \ln(\lambda)t$$

N_t = total linear extent of herring spawn in kilometres at time t, t = time and λ = rate of change.

Number and average length of spawning locations. The total extent of observed herring spawn is a function of both the number and the average length of observed herring spawns. I examined changes in these characteristics by decade to determine how changes in individual observed spawn locations contributed to regional trends.

Local distribution of spawn observations. To determine the local spatial variation in observed herring spawns by decade within the study area, I divided the study area into spatial subdivisions. I used subdivisions previously delineated by DFO based on the clustering of historical spawn sites (Hay et al. 2009). I used 19 of DFO's subdivisions for the region, capturing 94% of the spawned coastline in the study area. Subdivisions with <5 decades of observations or observations made by only 1 person over multiple decades (~6% of the spawned coastline) were excluded from the analyses due to insufficient data. To quantify rates and directions of change in local extent of herring spawn, I ran linear regressions on the log transformed data (as described above) for each of the 19 subdivisions.

Data strengths, limitations and assumptions

This data set has several important strengths, limitations and assumptions. Because Pacific herring spawn in shallow, near-shore coastal waters where the release of sperm results in a conspicuous milky quality in surrounding waters and the deposition of eggs is highly visible in the intertidal and shallow subtidal zones (Haegele and Schweigert 1985), herring spawns are highly visible and are therefore unlikely to have been misidentified by study participants. Furthermore, given the cultural significance of harvesting herring spawn (Brown and Brown 2009), many First Nations community members make repeated, high resolution observations of the coastline in their traditional territory during herring spawn season, and information about spawn sightings is often discussed and shared within the community. Consequently, I have high confidence in spawn detection.

Despite this high level of confidence in detection, there are also assumptions and limitations in the methods and data. First, the number of participants providing observations increased though time, as few respondents were old enough to recall events in the 1940s, 50s and 60s, and more respondents were involved in geographically dispersed commercial herring harvesting activities in the later part of the 20th century. Second, my data set does not include characteristics such as herring egg density, thickness of spawn layers, and width of spawn area, which could provide additional information about the quantity of spawned herring roe at the site of each observation. While some participants provided qualitative comments on layer thickness and spawn width, these characteristics were not reported for most spawn observations. Third, the spatial precision by which spawn observations were recorded on the maps varied by participant, with some tracing the coastline and others circling spawning areas. Furthermore, precision was constrained by the use of felt pens and the map scale used to capture respondent observations. Lastly, the reliability and other characteristics of traditional knowledge vary by individual (Close and Hall 2006, Drew 2005, Martin and Hall-Arber 2008) and each individual's knowledge is restricted in geographic range (Neis et al. 1999). Information provided by knowledge holders may contain inaccuracies due to observation error, lack of knowledge, or the provision of intentionaly biased information (Close and Hall 2006). Consequently, as with all data sources, traditional knowledge carries with it a degree of uncertainty and should be reviewed and verified (Huntington 2000, Ban et al. 2009, Gagnon and Berteaux 2009, Neis et al. 1999). As described above, I increased the accuracy and certainty of my data by conducting a follow-up group workshop and one-on-one meetings to review the data and preliminary results and inferences.

Results

Regional distribution of spawn observations

Participant observations revealed changes in the occurrence and spatial distribution of herring spawns across the central coast of BC from the 1940s to 2000s (Figure 2). Although the number of respondents able to provide observations of spawns increased by decade, by the 2000s the overall spatial extent of observed herring spawns had diminished by 48% and shifted in space, with fewer spawns observed on the exposed outer west coast and increased spawning activity observed further inland.

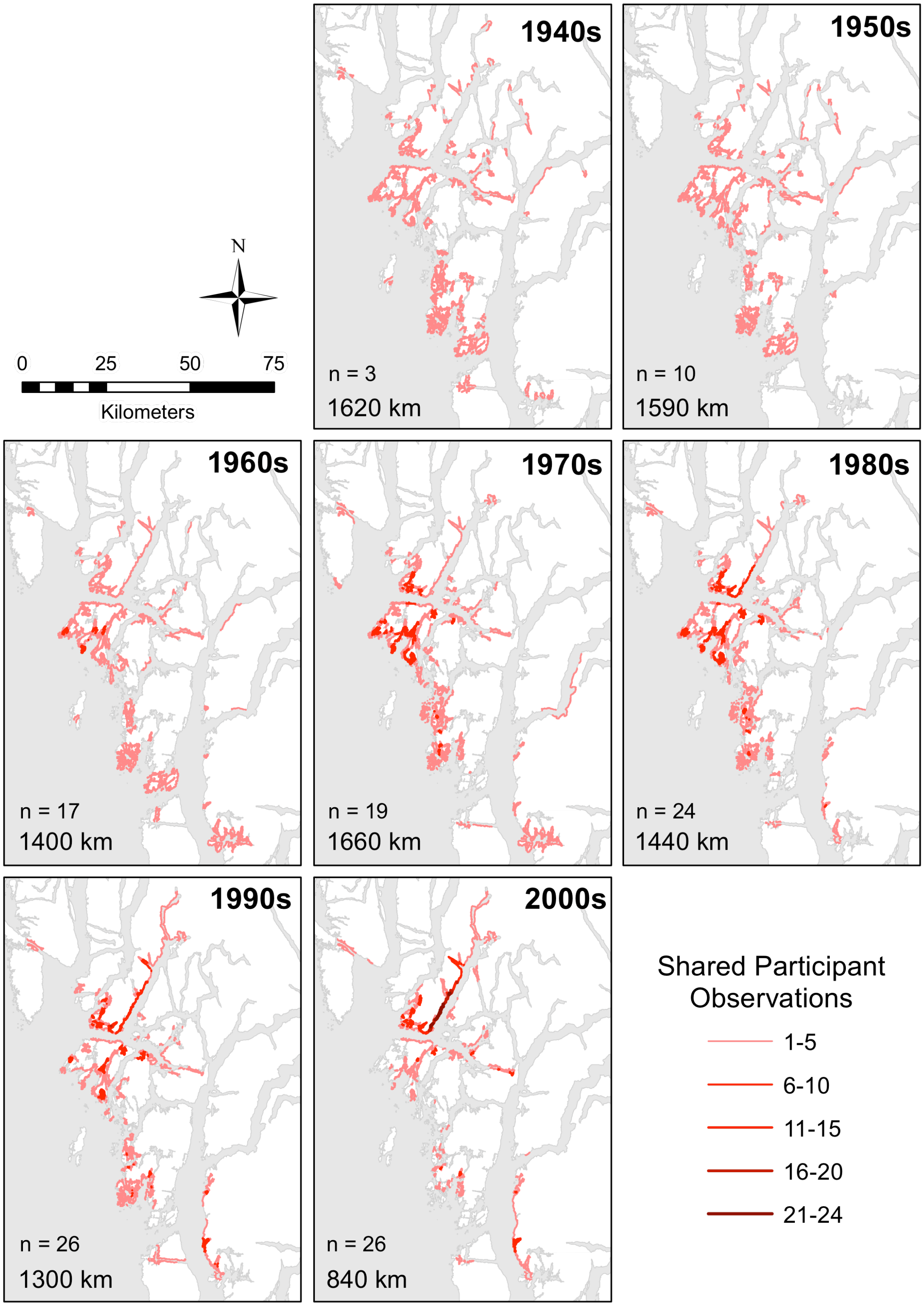

Figure 2. Spatial extent of observed herring spawn by decade (n = number of participants) along the central coast of British Columbia, Canada.

Total linear extent of spawn observations

Following an initial decline in the total kilometres of observed herring spawn from the 1940s to the 1950s, came an increase in the observed extent of spawn that, by the 1970s, reached similar levels to those reported in the 1940s (approximately 1600 km of spawned coastline). This was then followed by a steady decline in the total linear extent of observed herring spawn, from the 1970s to the 2000s, to a level of approximately half (800 km of spawned coastline) of that reported for the 1940s. Over the 70 year time series, the total length of coastline with observed herring spawn declined at an average rate of 7.6% per decade (Figure 3B).

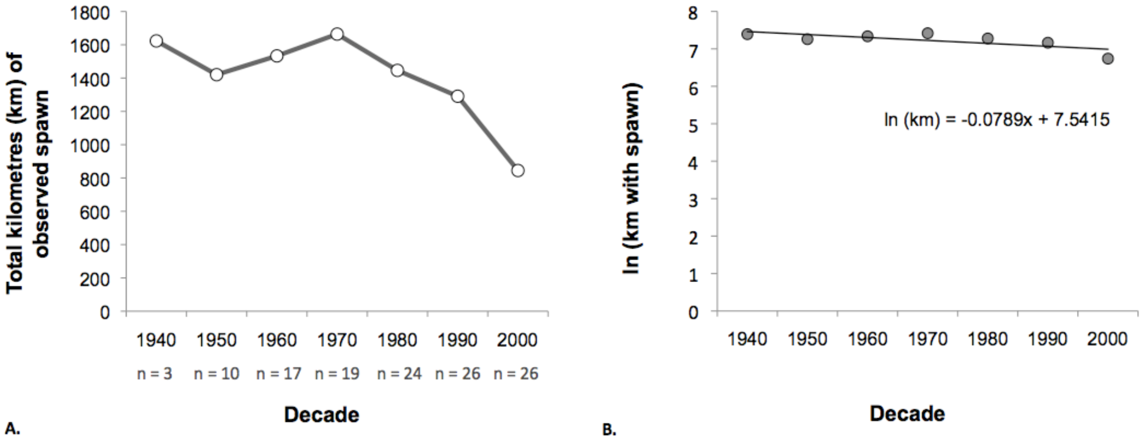

Figure 3. (A) Total kilometres of observed herring spawns by decade from the 1940s to 2000s. (B) Linear regression of the natural log-transformed observations of coastline with observed herring spawns.

Number and average length of spawn segments

Over the last 7 decades, from the 1940s to 2000s, the number of distinct coastline segments with observed spawn dropped at an average rate of approximately 8.7% per decade, from approximately 1800 spawn segments to 750 (Figure 4A). However, the average length of contiguous coastline segments with observed herring spawn remained relatively constant through time (Figure 4B).

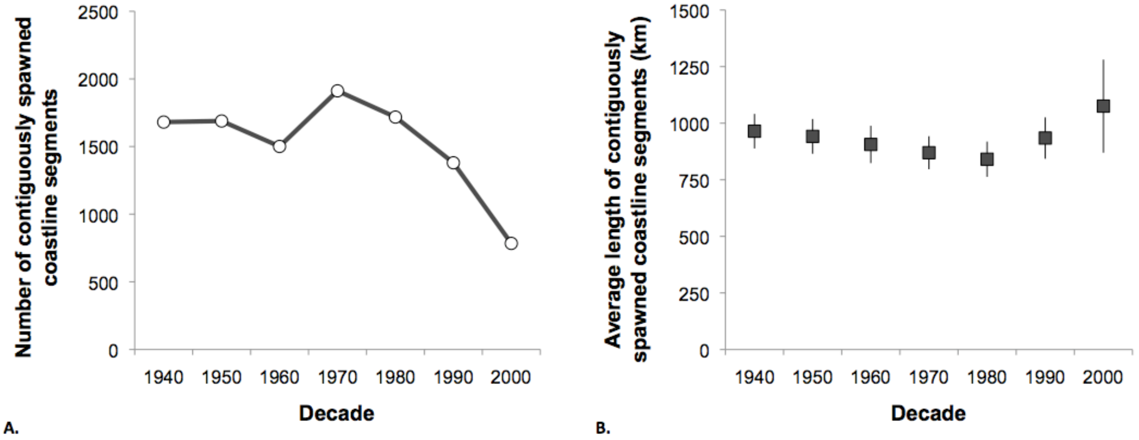

Figure 4. (A) Total number of contiguous coastline segments with observed spawning activity. (B) Average length of the contiguous coastline segments with observed spawning activity (+/- standard error) from the 1940s-2000s.

Local distribution of spawn observations

Over the past 7 decades, 13 of the 19 DFO subdivisions, representing 72% of the total coastline with reported observations, experienced declining trends in the total length of observed herring spawns. Six of the 19 subdivisions, representing 22% of the coastline with reported observations, experienced increasing trends in the total length of observed herring spawns (Figure 5). Subdivisions with declining trends tended to occur on the exposed western shores of the study region, while subdivisions with increasing trends tended to be located further inland (Figure 5B).

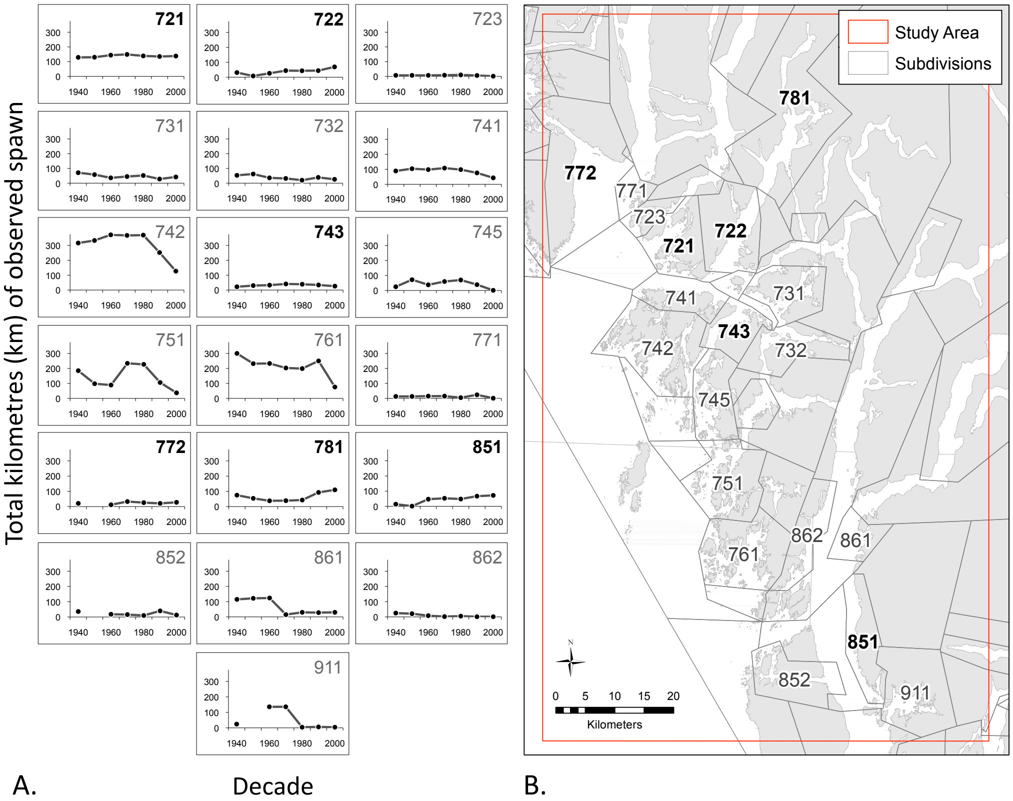

Figure 5. (A) Observed herring spawn (km) by decade and (B) DFO spatial subdivisions in the study area. Bold labels indicate subdivisions with increasing trends, and non-bold labels indicate subdivisions with decreasing trends.

Discussion

The changes in observed herring spawns did not follow uniform trends across the study area; while 13 of the DFO subdivisions experienced declining trends in observed herring spawns, 6 experienced increases (Figure 5). The concentration of spawning activity appears to have also shifted in space, with the majority of recent spawns observed around the more sheltered inner inlets and fjords to the east (Figure 2,5), and significant declines in observed spawns on the exposed outer shores in the west of the study region. Three of the subdivisions with increasing trends through time (including 722, 781 and 851) are located adjacent to areas described by several of the participants as herring massing areas. The massing areas were described as areas where herring gather together before heading out to their spawning grounds. Subdivisions with the most notable decreasing trends in observed herring spawns tended to be areas participants described as highly productive for both the traditional harvest of spawn on kelp and the commercial harvest of herring. In addition to the observations of herring spawns, participants also shared observations and hypotheses regarding declines in herring size, spawning duration, and roe thickness.

Hypotheses for spatial contraction of herring spawn

Multiple, non-mutually exclusive hypotheses can be invoked to explain the decline and spatial contraction of Pacific herring spawns evident in these results.

Recent and historic reduction in herring spawning stock biomass

The observed decline and aggregation in Pacific herring spawns may be due to recent declines in total spawning stock biomass. Over the past several decades, estimates of the herring population on the central coast of BC have exhibited declining overall trends, and spawning stock biomass estimates are at a fraction of their historical levels (Cleary et al. 2011, Martell et al. 2012, DFO 2014). Over this same time period, my results show substantial declines in the number and total extent of observed spawns (Figure 3A, 4A). Similar occurrences have been described for both Pacific herring and other species of exploited marine fish over the last century. After a steep population decline in the 1960s, near the end of the reduction fishery, an intensive commercial fishery on Pacific herring for oil and meal products, marked declines in spawn deposition were observed (Hourston 1980, Hay and Kronlund 1987). Atlantic Salmon (Parish et al. 1998), Atlantic Cod (Smedbol and Wroblewski 2002), and Atlantic Herring (Dragesund et al. 1997) have also experienced decreases in the number and distribution of spawning areas coincident with reductions in stock size.

Reduced social transfer of migration patterns as a result of truncated age structure

Strong empirical evidence suggests that the age and size of Pacific herring have decreased substantially along BC's west coast over the past several decades (Martell et al. 2012). The decline and aggregation in observed Pacific herring spawns evident in my results may be caused by this reduction in the proportion of larger, older herring in the population, as these older herring may be involved in the transfer of behaviour patterns, including spawning migration routes and locations, between year classes (Corten 2002). Petitgas et al. (2006) suggest that fish spawning migration patterns may be influenced by repeat spawners that retain and transfer the knowledge of migration routes. According to this "entrainment hypothesis", persistence of the spatial organization of a population is accomplished through juveniles adopting the behavioural patterns of the older group that entrains them. Within spatially structured fish populations, spawning groups develop, with members of each group having a specific memory of a learned life cycle (e.g., a migration route) and geographic spawning area (Petitgas et al. 2006). Herring spawning migrations tend to be stable despite environmental variability. Based on case studies of North Sea herring and Norwegian spring spawning herring, Corten (2002) suggests this stability is due in part to individual herring returning to the same spawning site in successive years, in combination with the social transfer of migration patterns from older year classes to recruit (first time) spawners. Hay and McCarter (2006) suggest that this "adopted-migrant" behaviour is consistent with the spawning distribution and behavioral patterns observed in Pacific herring. By removing the larger adults with established stock memory of spawning sites, entrainment potential decreases, which in turn increases the potential to disrupt established spatial patterns. Once disrupted, migration patterns are unlikely to resume, and consequently, suitable habitats may be left poorly occupied (Corten 2002). In my interviews, one Heiltsuk respondent commented on the transfer of spawning behaviour from older to younger herring: "They [central coast Pacific herring] have lost their big chiefs that told them where to go to spawn." (personal comment, Heiltsuk community member, 2010).

Changes in observation effort (spatial and temporal extent of participant observations)

The decline and aggregation in observed Pacific herring spawns may reflect changes in participant observation effort. Factors which may have affected observation effort over time include: the shift from the commercial reduction fishery to roe fisheries and the corresponding temporal and spatial shift of fishing efforts from herring migration routes to herring spawning grounds (Hourston 1980); changing practices for traditional roe-on-kelp harvest; increased presence on the water due to changing economics and the participation by Heiltsuk community members in the commercial sac roe gillnet and seine fisheries, and commercial roe on kelp fisheries; increased access to higher powered, more efficient vessels (Hourston 1980); introduction of area-based catch quotas; decreased presence on the water due to rising fuel costs, other changes in the economics of fishing, and fisheries closures; changes in presence on the water due to changes in the spatial distribution of spawns; and increased participation by Heiltsuk community members in formal and informal herring monitoring efforts by DFO or others (plane, dive and boat surveys).

While these factors may have affected the spatial and temporal effort of participants over time, the high commercial and cultural interest of the Heiltsuk people in herring and herring roe, the sharing of information on herring spawns within the community, and the increasing numbers of study participants providing observations each decade, suggest that it is unlikely that the decline in total extent and the increasing aggregation of observed herring spawns in my results is due to decreased observation effort.

Biocomplexity and resilience

Resilience is widely considered to be an important property of marine fish populations, as it represents the ability to adapt to and persist through perturbations (Hilborn et al. 2003). Population biocomplexity, such as diversity in spawn timing and distribution, can increase a population's resilience because of complementary productivity of various stock components under varying environmental conditions (Hilborn et al. 2003, Schindler et al. 2010, Corten 2002, Lambert 1990).

Pacific herring populations have evolved strategies that increase the spatial and temporal complexity of their spawning events, including spatially diverse spawning locations, repeated spawns within a spawning season, and variable timing of spawn seasons from year to year (Haegele and Schweigert 1985). Egg mortality, which occurs through predation, siltation, air exposure, storms, wave action, high egg density (Haegele and Schweigert 1985) and human harvest, varies by location, day and year. Predation by birds, for example, tends to be concentrated on larger spawns, and is unlikely to occur in areas with small or deep spawns (Haegele and Schweigert 1985). Annual temporal and spatial variation of spawns also decreases the predictability of spawn availability, which in turn decreases the effectiveness of predators (Wilson and Womble 2006, Therriault et al. 2009). The maintenance of spatial and temporal complexity in spawning sites also increases the probability that some larvae will meet suitable conditions during each spawning season (Corten 2002). Variability of hatch times both within and between sites ensures larvae are geographically dispersed and at different stages of development, which reduces competition for food resources and reduces the availability of larvae as prey at any particular location and time (Lambert 1990). Thus, by dispersing spawning events through space and time, Pacific herring reduce the vulnerability of eggs and larvae, while increasing the probability that some population components will encounter favourable conditions for successful recruitment (Berkeley et al. 2004, Corten 2002, Lambert 1990, Lambert and Ware 1984).

In the present research, I found a marked reduction in the number of observed spawns and a contraction in the spatial distribution of spawns in the study area over time (Figure 2, 3), indicating reduced spatial complexity. A similar reduction in the complexity of spawning behaviour has been observed in southern BC herring populations (Benson

2011). Loss of spatial diversity may erode a population's resilience to anthropogenic and environmental changes (Hutchings 2007). Consider the example of Atlantic cod, where failure to account for population structure and spatial processes contributed to stock collapse in the 1990s (Hutchings 1996). Conversely, managing for the maintenance of a population's diverse and complex life history characteristics can reduce variability in recruitment over time, contribute to the sustainability of populations, enhance ecosystem function, and support successful fisheries (Hilborn et al. 2003, Schindler et al. 2010).

Herring management and the Heiltsuk people

Pacific herring have suffered several severe population declines since they were first commercially exploited by non-Aboriginals in BC in the 1870s. The reduction fishery, which began in the 1930s, extracted high catches until herring populations collapsed in the late 1960s (Hourston 1980, DF0 2014). This collapse was foreshowed by several indicators, including: increased effort required to locate herring, a reduction in spawn deposition, and a shift in age structure of the population to a higher proportion of younger fish (Hourston 1980). Despite these indicators, harvest continued for several years before the population collapsed and the fishery was closed in 1967 (Hourston 1980, DF0 2014).

After the closure, herring populations in BC recovered over a period of 5 to 10 years, and a lucrative sac roe fishery commenced in the 1970s (Hourston 1980). The sac roe fishery shifted fishing pressure spatially and temporally, away from the major herring migratory routes that had been targeted by the reduction fishery, to herring spawning areas along the coast (Hourston 1980). Corresponding with this shift in fishing pressure, came a refinement in fisheries assessment and management methods with the recognition of a need to focus assessment at a more local scale or risk "the depletion or even elimination of runs to some spawning grounds" (Hourston 1982, p.1415, Schweigert 1993). Despite these changes in assessment and management, 3 of the 5 major BC herring populations have declined over the last several decades; the central coast commercial herring fishery closed in 2008, the Haida Gwaii fishery in 2005, and the west coast of Vancouver Island fishery closed from 2006 to 2011 and in 2013 (Schweigert et al. 2010, DFO 2014).

Industrial herring fisheries have only existed on the BC coast for about 130 years, but Pacific herring have been integral to the social, cultural and economic fabric of First Nations people on the coast for millennia (McKechnie et al. 2014, Bouchard and Kennedy 1989). The persistence and importance of this resource in the archeological record (McKechnie et al. 2014) and the evidence that the Heiltsuk harvested herring and herring roe long before Europeans arrived (Powell 2012) provide an indication of the longstanding close relationship between these coastal people and herring. Consequently, it is critically important to the Heiltsuk that governance of the harvest and allocation of Pacific herring in their territory be prudent and inclusive. The Supreme Court of Canada has recognized the Heiltsuk's unextinguished right to harvest, use and sell herring roe (R. v. Gladstone, [1996] 2 S.C.R. 723), but the declines in herring abundance and subsequent fisheries closures have denied the Helitsuk the economic and cultural benefits of exercising this right. Additionally, these declines continue to reduce the availability of herring roe for food, social, and ceremonial purposes. The courts have also indicated that First Nations are legally entitled to a greater say in resource decisions that affect their Aboriginal rights and title (*Tsilhqot'in Nation v. British Columbia*, 2014 SCC 44; *Delgamuukw v. British Columbia* [1997] 3 S.C.R. 1010). Yet current fisheries management regimes continue to exclude the Heiltsuk from controlling or even meaningfully participating in the governance of herring fisheries (Harris 2000). One key dimension of an increased role in governance would be to acknowledge the extensive knowledge of Heiltsuk community members about the movements and behaviours of Pacific herring and to incorporate this traditional ecological knowledge in the assessment and management of herring fisheries.

Integrating data types and knowledge systems

Although modern resource managers often favour Western scientific methodology, researchers and managers are beginning to rediscover the value of alternate knowledge systems such as local and traditional ecological knowledge (Close and Hall 2006, Hall et al. 2009, Drew 2005). As a result, traditional ecological knowledge is increasingly being used to inform research and resource management (Brook and McLachlan 2008). By comparing, contrasting, and integrating different knowledge systems, researchers and managers can increase insight and understanding, provide alternate perspectives, reveal blind spots, highlight areas for further exploration, and ultimately improve the knowledge base for more effective decision making (Ramstad et al. 2007, Salomon et al. 2007, Ban et al. 2009, Hall et al. 2009, Polfus et al. 2014).

Huntington (2000, p.1270) describes traditional ecological knowledge as “the knowledge and insights acquired through extensive observation of an area or a species”, which “may include knowledge passed down in an oral tradition, or shared among users of a resource.” In the present study, I systematically compiled a historical data set using traditional ecological knowledge to document the spatial distribution of herring spawns from the 1940s to 2000s. While this data set has some limitations (as described in the methods section), the standardized methodology for capturing observations by decade, the conspicuous nature of herring spawns, and the large extent of shared observations (Figure 2) increase the reliability of the collected data. Participants provided their direct observations of herring spawns, based on involvement with traditional, commercial and personal harvest of herring and herring roe over numerous years. For many of these individuals, their knowledge of where to find herring and herring spawns has been built on a lifetime of experience, coupled with the sharing of information across generations of family members and among other members of a coastal community that is closely connected with its marine setting.

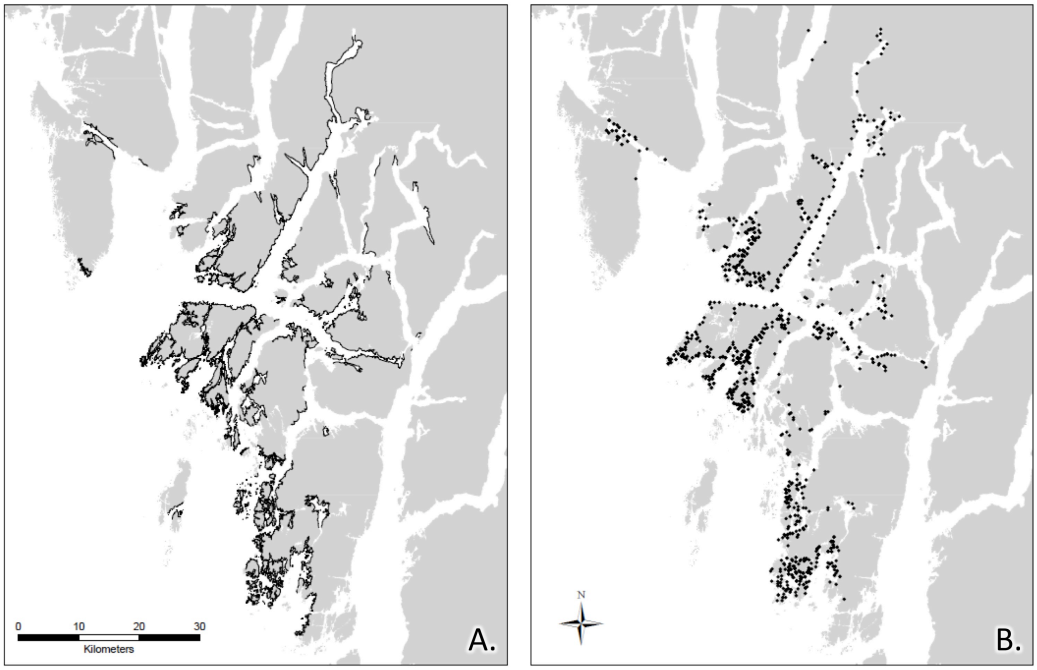

Figure 6. (A) Mapped participant observations from 1940 to 2010 for DFO Fisheries Management Area 07 - Pacific Region. (B) DFO recorded spawning events during the same time frame and area (Geographic Information Bulletin 1999).

Fisheries and Oceans Canada has also collected observations of herring spawns on the BC coast over roughly the same time period as that covered by my research. However, DFO's monitoring program was developed to monitor and inform spawning escapement rather than to provide a comprehensive inventory of herring spawning sites (Hay and Kronlund 1987). Also, there is substantial uncertainty in the DFO data set, arising from significant changes over time in the spawn survey methods used, incomplete records for remote locations and earlier years, and problems with the methods used for recording some of the data (Benson 2011, Hay and Kronlund 1987). (See Benson (2011) for a more complete description of the limitations of the DFO data set).

Traditional ecological knowledge can supplement and support the DFO data set on herring spawn locations, by filling gaps, helping to resolve inconsistencies, and highlighting areas where uncertainties remain. The traditional ecological knowledge documented in the present study not only offers spatial and temporal data that were previously unavailable, but also provides supplemental information which explicitly maps the extent of observed herring spawns through time.

While such traditional ecological knowledge can be a valuable source of ecological information, especially in data poor areas, abundance and distribution data are just a small subset of the potential benefits that may be realized from integrating traditional ecological knowledge and western science (Lertzman 2010, Thornton and Maciejewski Scheer 2012). For example, in addition to mapped spatial distribution of spawns, my interviews produced rich qualitative data, including insights on herring movement and behaviour, theories on observed changes, information about local commercial fishing pressure, and descriptions of traditional herring harvest and management. These qualitative data may be explored further in future research.

Policy and management implications

Managing for population resilience. The continued sustainability of a resource depends on many factors, including sound management, favourable environmental conditions, and resilience within a population (Hilborn et al. 2003). Management of exploited populations, therefore should aim to maintain or increase resilience. To manage for resilience, fisheries managers must understand the mechanisms and life history traits that support population persistence and stability (Kerr et al. 2010). Spatial and temporal diversity in spawning events (Lambert 1990, Secor 2000), complex internal age structure of populations (Murawski 2001, Lambert 1990), and the spatial dynamics of populations, such as migration routes, massing and spawning areas (Corten 2002), all likely contribute to population resilience in herring. Managers and biologists need to consider the implications of changing population dynamics and recognize the contribution of population diversity and stock complexity to long-term sustainability (Stephenson 1999, Schindler et al. 2010, Smedbol et al. 2002, Berkeley et al. 2004). Shifts and trends in these population characteristics, such as changes in spatial distribution or age structure, can provide early indicators of new or increased stressors in a system. As previously described, prior to the Pacific herring population collapse in the 1960s, for example, a reduction in spawn deposition and a shift in age structure occurred (Hourston 1980). By incorporating such population characteristics into management design, managers can more effectively support the strategies species have evolved to manage risk, and can help to ensure successful recruitment despite spatially and temporally variable environmental conditions (Berkeley et al. 2004, Secor 2000, Schindler et al. 2010, Corten 2002). Different management strategies may be required for different individual stock components within populations (Hutchison 2008). Also, care must be taken to collect and assess information at appropriate scales to inform these strategies (Hilborn et al. 2003, Hourston 1982, Kerr et al. 2010, Ruzzante et al. 2006).

Managing for resilient social-ecological systems. Forage fish, such as Pacific herring, play a foundational role in coastal ecosystems (Pinsky 2011, Willson, and Womble 2006, Varpe et al. 2005). Significant declines in populations of these fish or extensive changes to the spatial or temporal distribution of spawns have the potential to negatively impact ecosystem structure, function and stability (Pinsky et al. 2011, Therriault et al. 2009, Hutchison 2008). Declines in marine species and ecosystems can have profound and potentially cascading social, economic, and cultural implications for coastal First Nations communities in these coupled human-ocean systems. At the same time, such communities often have extensive knowledge about the marine species and ecosystems on which they depend. Meaningfully involving First Nations communities such as the Heiltsuk in herring management, by bridging cultures and integrating knowledge systems, offers an exciting (albeit tremendously challenging) opportunity to create innovative solutions to the complex problem of Pacific herring management on the BC coast (Lertzman 2010).

Conclusion

Repeated severe declines in herring abundance and associated fisheries closures over the last century (Hourston 1980, DFO 2014) suggest that there is an urgent need for new approaches to the assessment and management of Pacific herring on the BC coast. In order to support resilient herring populations and coastal communities, and to enhance understanding of the nature, magnitude and significance of historical changes, herring management should shift from a singular focus on biomass–based assessment (Benson 2011) to a more systems-oriented approach, acknowledging and accounting for the contributions of complexity and diversity within herring populations. Traditional ecological knowledge such as that documented in the present study can provide much-needed information as fisheries management shifts to a systems level. First Nations people and the traditional ecological knowledge that they hold have critical roles to play in ecosystem-based management of Pacific herring in BC.

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