ICES Journal of
Marine Science

ICES Journal of Marine Science (2018), 75(1), 257–269. doi:10.1093/icesjms/fsx097

Original Article

A social–ecological study of stock structure and fleet dynamics in the Newfoundland herring fishery

Barbara Paterson[1,2,*], Barbara Neis[3], and Robert L. Stephenson[4,5]

[1]*School of the Environment, Department of Environmental Science, Saint Mary's University, NS, Canada, B3H 3C3*
[2]*Marine Research Institute, Department of Biological Sciences, University of Cape Town, Rondebosch 7701, South Africa*
[3]*Department of Sociology, Memorial University, St. John's, NL, Canada A1C 5S7*
[4]*Canadian Fisheries Research Network, University of New Brunswick, Fredericton, NB E3B 5A3, Canada*
[5]*Fisheries and Oceans, St. Andrews Biological Station, St. Andrews NB E5B 2L9, Canada*

Corresponding author: tel: + 1 902 491 6406; fax: + 1 902 491 6406; e-mail: barbara.paterson@smu.ca

Paterson, B., Neis, B., and Stephenson, R. L. 2017. A social–ecological study of stock structure and fleet dynamics in the Newfoundland herring fishery. – ICES Journal of Marine Science, 75: 257–269.

Received 20 June 2016; revised 29 March 2017; accepted 30 March 2017; advance access publication 1 June 2017.

Successful management of small pelagic fisheries is critical in integrated ecosystem based approaches and requires understanding of how the ecological dynamics of pelagic stocks mesh with the economic and social dynamics of commercial fisheries and the larger systems within which they operate. Combining insights from stock assessments with those from local fishers, scientists, and managers, can help identify knowledge gaps that could jeopardize stock resilience. This article presents results from a social-ecological, mixed-methods study that combines insights from science and from interviews with fishermen, scientists, and managers of small pelagic fisheries in western Newfoundland, Canada (NAFO division 4R) and in NAFO division 4X. Different approaches to herring management are used in the two areas. In area 4R fishing for herring (*Clupea harengus*) is part of a complex multi-species, multi-gear fishery; most harvesters who target herring also target Atlantic mackerel (*Scomber scombrus*). Harvester interviews indicate herring in 4R, like herring in 4X and elsewhere, have substantial within-species stock structure, but that it is not well-documented in science and not well protected under the current management system. Further, fishing strategies in the competitive mackerel fishery in which the herring vessels are involved may contribute to the risk of over-fishing on some herring populations.

Keywords: Atlantic herring (*Clupea harengus*), fishermen's ecological knowledge, social-ecological analysis, stock structure.

Introduction

Small pelagic fish species play a key role in marine ecosystems as forage for marine mammals, birds, and other fish; they are also important contributors to the economies and food security of coastal nations. Small pelagic species account for up to 50% of global annual landings (Fréon *et al.*, 2005). The combined effects of high fishing mortalities, past overfishing and the impacts of climate change are exerting pressure on small pelagic stocks in many parts of the world (Naylor *et al.*, 2000; Barange *et al.*, 2008; Melvin *et al.*, 2009). Successful management of small pelagic fisheries is critical because of the ecological, social, and economic importance of small pelagic fish and because of their vulnerability to environmental factors and to overfishing.

In line with commitments to ecosystem-based management, fisheries management objectives in Canada and elsewhere have broadened in recent years to include productivity, biodiversity and habitat considerations (Gavaris, 2009). Within the biodiversity category, increasing attention is being given to within-species diversity, i.e. stock structure. Herring stocks have a complex population structure; they are made up of several distinct spawning units, which may mix at various times during their life history (Stephenson *et al.*, 2009). Herring stock structure has been discussed for more than a century (Iles and Sinclair, 1982; Sinclair and Solemdal, 1988; Stephenson and Clark, 2002; Sinclair, 2009). The biological basis for the notion of herring stock-complexes is well documented and based *inter alia* on observations that

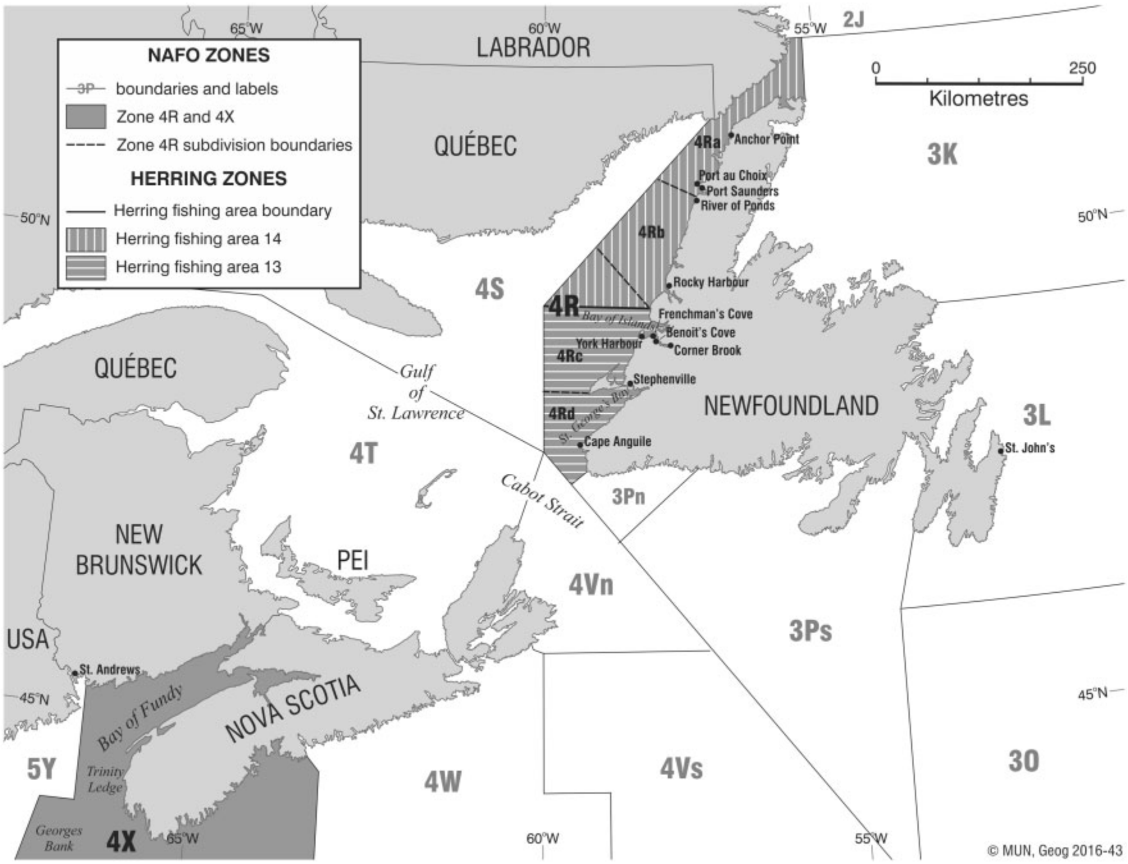

Figure 1. Study area.

herring spawn in multiple, discreet locations within a stock distribution area, that herring return to the same spawning grounds from which they originated ("homing"), and that different subpopulations show different trends in abundance and growth (Stephenson *et al.*, 2009; Payne, 2010). Management based on preserving this complex population structure has the potential to reduce the vulnerability of herring stocks to overfishing and ecosystem change. There is ongoing debate, however, whether it is practical to manage at the scale of individual spawning aggregations (Stephenson, 2002; Kell *et al.*, 2009).

This article reports findings from a study of the herring fishery in area 4R on the west coast of Newfoundland, Canada. In Canadian waters, the distribution of Atlantic herring extends from Georges Bank and the Nova Scotia coast to Newfoundland and Labrador (DFO, 2010a) (Figure 1). In eastern Canada, a great deal of attention has been paid to the collapse of multiple groundfish stocks in the early 1990s and to their limited recovery more than 20 years later (Frank *et al.*, 2005). The collapse of Atlantic herring (*Clupea harengus harengus*) on Georges Bank in the 1960s (Melvin and Stephenson, 2007) and the current weak status of the Atlantic herring and capelin (*Mallotus villosus*) stocks in the region (DFO, 2012a) have received less attention. These species are the prey for cod and other groundfish (FRCC, 2009).

Like all small pelagic fish, Atlantic herring populations are highly vulnerable to ecosystem changes and prone to rapid changes in abundance and collapse (Stephenson, 1997). Herring stocks in 4R are considered to be in trouble (DFO, 2014). A multidisciplinary research programme (www.curra.ca) took place on the west coast of Newfoundland between 2007 and 2014. Participating researchers observed intensive herring and mackerel purse seine fisheries each fall in the region and heard local people express concerns about the effect of these intensive, localized fisheries on the herring stocks in the region. We designed a study with the following objectives: (i) to gain a clearer picture of herring management in the region by interviewing fishermen, processors, scientists and managers and comparing the management in 4R with the more collaborative approach in the Bay of Fundy (Stephenson *et al.*, 1999; Power *et al.*, 2011), NAFO area 4X (Figure 1); and, (ii) to identify potential gaps in scientific knowledge and management that could jeopardize stock resilience by comparing available scientific information, such as landings data and assessment reports for area 4R (e.g. Beaulieu *et al.*, 2010, DFO, 2016) with data from fishermen's ecological knowledge (FEK). The research looked at both herring and mackerel fisheries in the region. Here we focus mainly on the herring-related parts of the research, but draw, where relevant, on information about the mackerel fishery.

Conceptual framework

Fisheries are complex social–ecological systems. The disciplinary boundaries between the social and natural sciences that often lead to natural scientists studying fish and social scientists studying social and economic dynamics of fisheries can contribute to knowledge gaps with consequences for stock resilience (Neis and Kean,

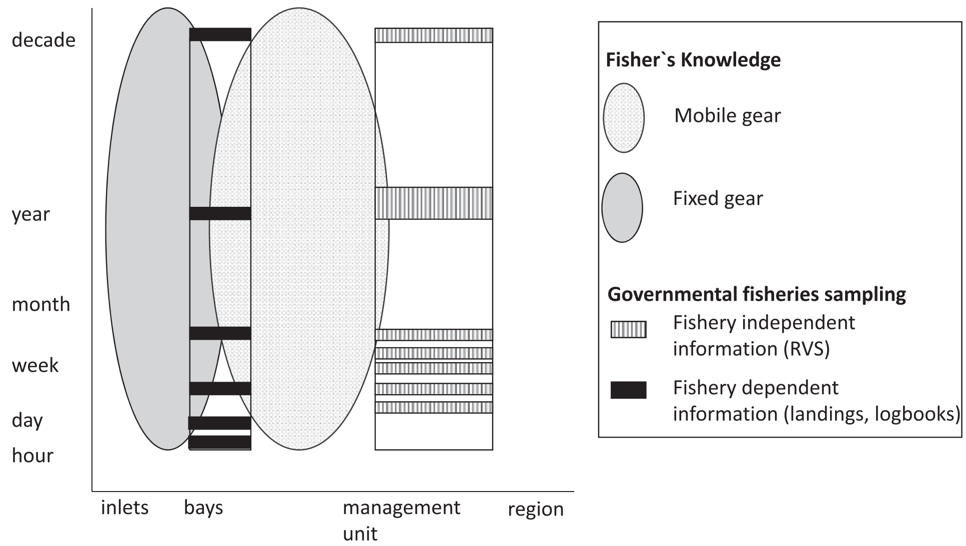

Figure 2. Conceptual representation of the relative spatial and temporal scales of information that may be derived from (existing) governmental fisheries sampling and the potential fishers knowledge from mobile and fixed gear fleets.

2003; Neis, 2011). One reason for these knowledge gaps is differences in the spatial and temporal scales of different kinds of fisheries and between commercial fisheries and research vessel surveys (Figure 2). The knowledge about fish and fisheries of fixed gear harvesters (traps, gillnets) tends to be highly localized and based on often longstanding and intensive observation within those areas. The knowledge of mobile gear harvesters, such as purse seine operators, is based on observations over larger spatial scales with a coarser temporal grain that are based on locating and following aggregations of fish with the efficiency of this improving overtime with improvements in fish finding equipment and potential knowledge sharing across the fleet. Research vessel surveys provide fishery independent information about fish stocks at a large spatial scale (often covering multiple management units) but at a very coarse temporal and spatial grain in that they are conducted only once annually, each area sampled only once and representing a small fraction of the survey area. Fishery dependent information is sampled from landings and logbook data but these are not always available and can be difficult to interpret in the absence of information about fishery dynamics.

One way to deepen understanding of fisheries and stock complexes is by bringing together information from different sources including from science, management and fishers' FEK (Murray *et al.*, 2008; Hind 2015; Stephenson *et al.*, 2016). The systematic collection and aggregation of local spatial scale information from fishermen and an examination of consistencies and inconsistencies between governmental assessment/management and FEK can contribute to understanding of such key processes as fish migration patterns and stock structure (Murray *et al.*, 2008). Interviews with fishers can also elicit valuable information about changes in fishing practices and how these may affect efficiency and the health of stock complexes. Stock assessment calculations are sometimes based on assumptions that are implicit, such as the premise that fishing practices remain constant, which is rarely the case (Paterson *et al.*, 2014; Neis and Kean, 2003). Interviews with scientists and managers can add observations that are not made explicit in reports and scientific papers. The combination of insights from these sources with those that can be derived from an analysis of historical sources, contemporary documents and quantitative data can help understand the history of and potential management consequences of particular fisheries (Ommer, 2007; Stephenson *et al.*, 2016) as well as potential gaps in knowledge and management that could jeopardize stock resilience (Neis *et al.*, 1999; Neis and Felt, 2000; Paterson and Kainge, 2014). The likelihood of successful and sustained collection and integration of insights from these disparate sources into science and management is influenced by the organization and operation of science and management regimes and power and other dynamics within particular fisheries. It is perhaps most likely to happen in the context of collaborative co-management regimes (Stephenson *et al.*, 2016; Mathew, 2011).

Background: the 4R herring fishery

Herring fishing has a long tradition on the west coast of Newfoundland. For most of the 19th century local fishers targeted so-called "shore herring" in St George's Bay for both bait and export (Korneski, 2016). The 4R herring fishery remained primarily a gillnet fishery until 1960 when, following the collapse of the purse-seine herring fishery in British Columbia (Mowat, 2004, p. 162), some purse seine vessels were transferred to the East coast of Canada. As a result, Herring landings in 4R shot up from <4000 to 25 000 tonnes in 1972. A Total Allowable Catch (TAC) was first set in 1977 at 12 000 tonnes, peaked in 1989 at 37 000 tonnes, and was reduced first to 22 000 tonnes in the late 1990s and then to 13 000 tonnes in 1999. Since 2003 the TAC has been set at 20 000 metric tonnes (Figure 3).

At the time of the study, in 2011, there were five large, corporate-owned purse seiners licensed to fish in 4R. These large seiners were allocated 55% (11 000 tonnes) of the herring quota in the form of Individual Transferrable Quotas (ITQs) with the other 45% split between 15 owner and operator <65 foot purse seiners (22% (4,400) in the form of Individual (non-transferable) Quotas (IQs). The remaining 4600 tonnes (23%) has been allocated to the fixed gear sector, which includes 20–24 vessels rigged with a modified bar seine, known as tuck seiners, and

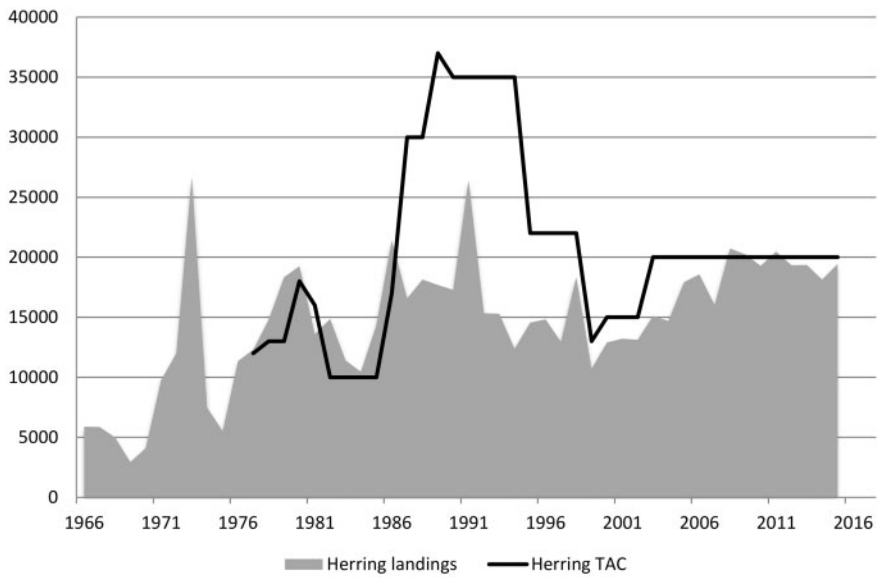

Figure 3. Herring commercial landings (t) and TAC (t) for unit areas of NAFO division 4R, 1966–2015. Source: DFO.

Table 1. Number of harvesters who participated in 4R Herring fishery in 2011 by license type, gear type, vessel category, and quota allocation.

DFO Category	**Fixed gear**		**Mobile gear**	
Vessel class	**Fixed gear**	**Tuck seiner**	**Small seiner (<65′)**	**Large seiner (>65′)**
Number of vessels per class	100–160	20–24	15	5
Length (ft)	25–27′	45–65′	45–65′	113′
Capacity (pounds)	8000	40 000–110 000	120 000–250 000	815 000
Engwine (hp)	130	200–380	430–620	1000
Gear	Gillnet, trap, handline, mechanical reel;	Tuck seine; power block, winch.	Purse-seine; power block, winch.	Purse-seine; power block, winch.
Herring quota (t) and percent of TAC	4600 (23%)		4400 (22%)	11 000 (55%)
Quota type	Open		Individual nontransferable (IQ)	Individual transferable (ITQ)

many more licensed trap and gillnet fishermen. In the fixed gear sector there are 680 licenses, but only 120–180 were in active use in 2011 including the 20–24 tuck seiners (Table 1). There are no individual quotas in the so-called fixed gear sector; the fishery remains open until the sector allocation has been caught and in recent years most of the quota has been caught by the tuck seiners. Thus, over the past several decades the herring fishery has moved from an inshore trap and gillnet fishery to a fishery heavily dominated by a relatively small number of large and smaller mobile purse and tuck seine vessels (DFO, 2010a; McQuinn and Lefebvre, 1996; Table 1).

The different fleet sectors have different fishing areas. Large corporate seiners are allowed to fish anywhere in 4RST; small purse seiners are allowed to fish anywhere in 4R; and tuck seiners and trap and gillnet harvesters are limited to fishing either in area 13 or 14 depending on their homeport (DFO, 2010b; Figure 1).

In 4R the two purse seiner fleets and many of the fixed gear harvesters including particularly the tuck seiners fish not only herring but also Atlantic mackerel. An Atlantic wide TAC for mackerel is divided between the United States and Canada. In 2012, the Canadian TAC was 36 000 tonnes (DFO, 2012b). No individual quotas are set for the Canadian fishery, which remains open until the TAC is reached.

Methods

We applied a social–ecological, mixed methods approach that allows the combining of diverse qualitative and quantitative fisheries data (Murray *et al* 2008). A key component of this methodology is the collection of spatial information, such as catch locations and spawning areas during interviews with fishermen. This approach was developed for the fixed gear cod fishery in western Newfoundland (Murray *et al* 2008) and later adapted to the Canadian Atlantic pelagic fisheries (Carruthers and Neis 2011) and the Namibian demersal trawl and longline fisheries (Paterson and Kainge, 2014). DFO documents, fisheries statistics and semi-structured interviews with scientists, managers and others (see Table 2) were used to document the history of the fishery, the basis for science advice and the management of the fishery. Landings data for 4R were retrieved from the NAFO Annual Fisheries Statistics Database (STATLANT 21), fisheries statistics Canada, DFO regional fisheries statistics (http://www.

Table 2. Research participants.

Affiliation		Count
Fish harvester		18
Large seiner (1 retired)	3	
Small seiner (2 retired)	8	
Tuck seiners	5	
Fixed Gear (Trap/Gillnet)	2	
DFO scientists		5
DFO economists, managers, and compliance officers		5
Industry stakeholders other than harvesters		3
Other		5
Total participants		**36**

dfo-mpo.gc.ca/stats/stats-eng.htm), DFO reports and from peer-reviewed literature.

Interviews

We conducted career history interviews (Murray *et al*., 2008) with 18 herring harvesters in 4R (15 active and three retired), during the period from 16 July to 14 October 2011, in several communities along the west coast of Newfoundland (Figure 1). In addition key informant interviews were conducted with DFO scientists responsible for herring science in areas 4R and 4X, as well as with industry representatives and other stakeholders (Table 2). Since the time of this field research the science and management approach in 4R have remained unchanged.

Initial recommendations for participants were sought from researchers who had previously worked in the area and from representatives of the Fish Food and Allied Workers Union, which represents fishermen in this region. Following a snowball sampling method (Biernacki and Waldorf, 1981), participants were asked during the interviews to recommend further participants. Potential participants were approached either directly or through initial telephone calls. Fulfilling the obligation to consider risks and benefits deriving from participating in this research (Maurstad, 2002; Carruthers and Neis, 2011), we explained the research process in writing to allow participants to give free and informed consent. A consent form was signed by both the participant and the researcher assuring confidentiality and outlining how the data could be used. In order to maintain the anonymity of research participants we use arbitrary codes instead of names to refer to individual interviews. The research was given full ethics clearance in accordance with the Canadian Tri- Council Policy Statement on Ethical Conduct for Research involving Humans by the Interdisciplinary Committee on Ethics in Human Research of Memorial University of Newfoundland.

Most of the interviews with fishermen took place on board fishing vessels. All harvesters we interviewed targeted capelin, mackerel and herring, with the exception of a gillnetter/handliner who did not fish for capelin. All fixed gear harvesters and some of the < 65 foot seiners targeted other species besides capelin, herring, and mackerel.

Interviews with fishermen were semi-structured and guided by an interview schedule (Supplementary material) starting with demographic questions, followed by questions regarding vessel history and finally asked about fishing areas and observations regarding the spawning and migration of herring and mackerel. This order allowed us to use vessel history information to elicit information about changes over time in fishing locations. Nautical charts were used to tie observations to places. The interview schedules for scientists and other key informants differed depending on the participant's expertise (Supplementary material).

Where consent was given, interviews were audio recorded and then transcribed. Otherwise, notes were taken during the interviews. In order to aggregate the information from individual interviews and to allow comparison with information from other sources the content of the interviews was arranged into different formats. Quantitative information, including demographic data, vessel characteristics and catch data were organized into spreadsheets. Qualitative data from interviews, notes and documents were coded and categories and themes were constructed (Henning, 2004) using TAMS Analyzer (Weinstein, 2006). We selected representative quotes from those themes for presentation in this article.

Spatial information captured on nautical charts was organized and analysed using QGIS (http://www.qgis.org), an open source geographic information system application.

Interviews and secondary data were synthesized around the following themes that emerged from the analysis:

(i) 4R Herring stock complexity.
(ii) The spatial and temporal dynamics of the 4R herring fleet.
(iii) Industry collaboration and participation in management.

Results

4R herring spawning areas and stock structure

Eight interviewees (one trap fisherman, four small seiner captains, two large seiner captains, and one marine biologist from the area) provided specific information on location and timing of spring and fall herring spawning (Figure 4). These participants described spawning events in particular bays, where they recognized spawning aggregations, either by observing the fish themselves or the cloudiness of milt in the water. Three harvesters who work in the southern part of the coast had observed spring spawning aggregations in St George's Bay and Port aux Port Bay. Four participants, who fish between Bonne Bay and Port aux Choix, reported spring spawning events further North in Bonne Bay and in St John Bay. Fall spawning aggregations were reported for the central part of the coast by three participants who live or fish in that area. There were no contradictions in the data. One older small purse-seine harvester who has fished along the entire coast during his career reported observations at all of these locations. This harvester described fishing on spawning aggregations in St George's Bay and selling his catch to Russian boats during the late 1980s:

> *I had a little boat and then, when you [took] the hatches off the boat the spawn would be running out, that much spawn all over the boat, you know, they spawned in the boat. I cried shame at the Fisheries for having her open at that time, at spawn time. ... It was two or three, or four factory freezer trawlers out there in the bay, anchored, and that's where we were selling it, to them ... there was no herring there after that* (NC 11).

Another small purse-seiner referred to the same events and the conservation measures that DFO put in place consequently in the form of area closures:

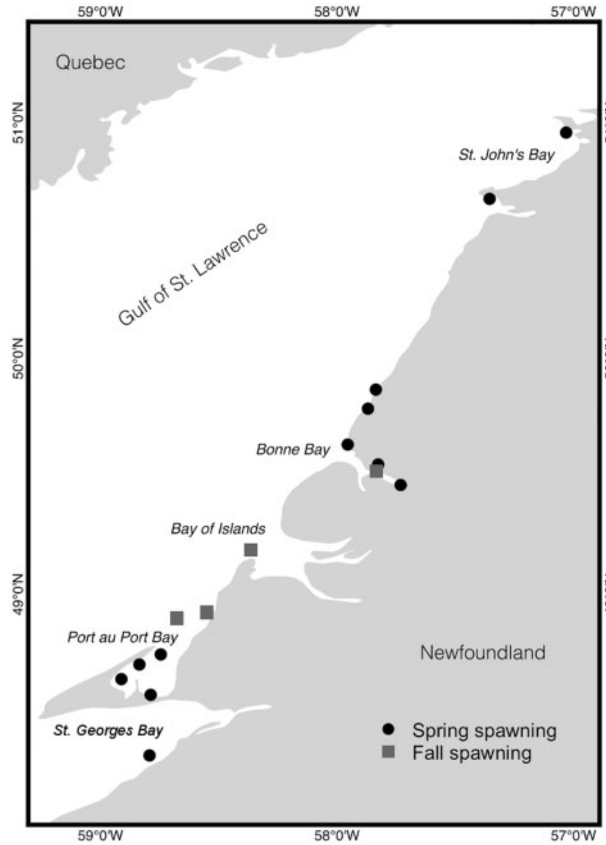

Figure 4. Localities where harvesters and a local resident have observed herring spawning in NAFO Division 4R.

> *Years ago, when the spawners used to come in Bay of St. George, I guess we fished them pretty hard there for a few years, and now they got the area closed where they spawn, so we can't go there in the spring* (NC 12).

DFO reports distinguish between two stock components for 4R, based on spawning time (DFO, 2010a). The distinction is based on otolith and gonad analysis of catch samples from various landing sites. Fish from the samples that show signs of spawning before 15 July are labelled spring spawners; those with signs of spawning after that date are labelled fall spawners (NC 29). According to DFO reports, the main spawning areas associated with the fall spawning stock are north of Port au Choix (e.g. DFO, 1997, 1999, 2010a,b).

Although "several other spawning sites are known along the coast towards the north" (DFO, 1997) DFO reports give explicit attention to only two main spawning areas for the spring spawning stock, i.e. St George's Bay and Port au Port Bay (Figure 4).

Stock status

None of the purse-seine harvesters we interviewed expressed concern about herring abundance. One small seiner captain suggested, however, that the seasonal abundance of herring has changed:

> *Researcher: So you say you have to look for the herring much less than you used to?*
> *Harvester: Oh yeah (...) now, it's end of spring, it's hard to find, they're really scarce in the spring here, but in the fall of the year that's when they come in, November, plenty of it in November. But the spring time is [when] they're scarce, I must say. Used to be the other way around years ago.*
> *Researcher: When was that?*
> *Harvester: Oh I guess twenty years ago, maybe* (NC13).

In contrast, the trap fisher stated that the stock was not in good shape (NC3). A DFO scientist reported that fixed gear harvesters have expressed concern about the status of the 4R herring stocks, because they were unable to catch herring at the locations where they used to catch it in the past (NC29).

Current catches consist overwhelmingly of fish that are considered to be fall spawning herring (DFO, 2016). Acoustic survey data indicate a continuous decline in spring spawner biomass since 1999 (DFO, 1999, 2016). Recent survey results indicate an almost complete disappearance of spring spawning herring and a possible decline in the fall spawning stock (DFO, 2016). The 2011, 2013, and 2015 assessments state clearly that current catches of herring cannot be sustained (DFO, 2012a, 2014, 2016).

Acoustic surveys were conducted every 2 years from 1989 until 2002. Since then surveys took place in 2009–2011, 2013, and 2015. No survey was conducted in 2012 and 2014 (DFO, 2014, 2016). The surveys are conducted in the fall, between mid-October and early November. The survey area extends from Cape Anguille in the South to Anchor point in the North (Figure 8 in DFO, 2014).

In addition to the acoustic survey data a second index of abundance used to be derived (from 1985 until 2006) from gillnet catch rates of some fixed gear harvesters, but was discontinued due to lack of resources at DFO and a lack of participation by harvesters (NC 29). Fishery dependent data on landings are still collected by DFO resource management, and made available to the stock assessment scientists. All landings by purse-seiners are weighed in the presence of a dockside monitor. In the case of fixed gear harvesters (i.e. trap, gillnet and tuck seine fishers) who sell their landings to a processor or buyer, landings data are calculated from purchase slips.

To protect the spring spawning stock a year round closure of Port aux port Bay and St George's Bay was introduced in 1995, but was lifted in 1997 (DFO, 2003, 2004, 2005, 2010b, a). Since 1999 both bays are closed during the spring (no fishing before 1 July) but remain open to herring fishing the rest of the year, except for a closed area inside St George's Bay (Figure 5). In 2001, a catch limit of 1000 metric tonnes was implemented and then increased to 2000 tonnes in 2002. In 2004, the year-round closure at the bottom of St. George's Bay was changed to a spring closure and the northern boundary of the closed area in Port au Port Bay was moved slightly southward following requests from the industry and, "based upon the view that catches in the more northern area were primarily autumn spawners" (DFO, 2010a). Recent DFO assessment reports recommend that the closures in Port au Port Bay and St Georges's bay, which changed from a large year-round closed area to a small area closed only during spring, remain in place to protect the reproduction of the spring spawning stock (DFO, 2015, 2016). The information about spawning locations provided by fishers suggests the possible existence of several subpopulations that spawn in 4R at different times and at locations other than Port au Port Bay and St. George's Bay. There are no management initiatives in place to try to protect these aggregations.

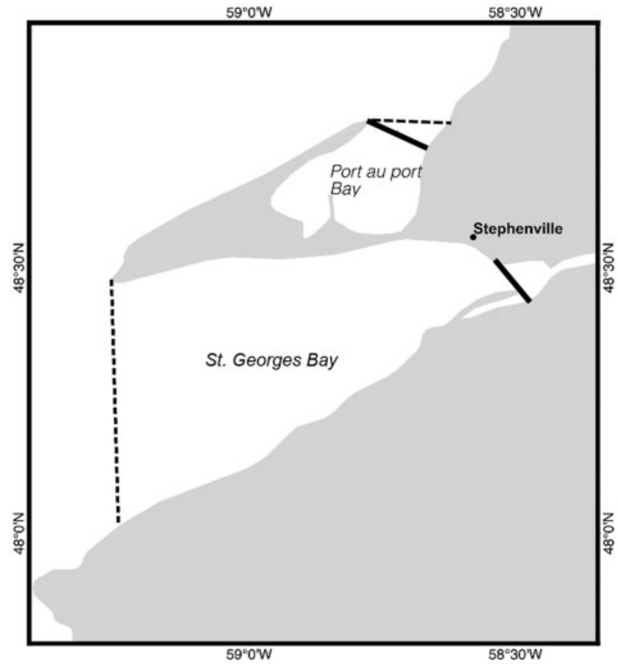

Figure 5. Closed areas in Port aux Port Bay and St Georges Bay in NAFO Division 4R. The striped lines indicate the boundaries of the closures in 1995, the solid lines indicate the changes that were made in 2004: the year-round closure at the bottom of St. George's Bay was changed to a spring closure and the northern boundary of the closed area in Port au Port Bay was moved slightly southward.

A DFO scientist suggested during the interview that the decline of the spring spawning stock may be due to changing environmental conditions, which caused herring to change their spawning behaviour resulting in more herring spawning in the fall than in the spring (NC 29). The scientific view regarding the fixed gear harvester's concern about herring not returning to previous fishing locations is that this change is likely a consequence of environmental conditions:

> *The fixed gear fishers think that when their catches are down one year that this indicates that the stock is low. It is a challenge to show them that the fish are there, they are just somewhere else and therefore not being caught in the traps. Water temperature is the reason for this* (NC29).

Some 200–300 fixed gear harvesters use their herring licenses to catch herring in the St George's Bay and Port au Port Bay to use as bait in the lobster directed fishery during the spring. The quota for the spring bait fishery is limited to 2000 metric tons. However, logbooks are the only potential source of data for this bait fishery because these catches are not sold and therefore not captured by purchase slips data. Although mandatory, logbooks are seldom submitted (NC 29). Thus it is impossible to enforce this quota. The amount is also not deducted from the overall TAC (DFO, 2005). A DFO scientist commented on this fishery:

> *(. . .) we have no idea about how much is caught in the spring fishery, which targets the spring spawners. Is it possible that they catch too much?* (NC 29).

Since the spring fishery is located in the same bays that are associated with the spring spawning stock and in the absence of catch data there seems to be a tendency to conflate this fishery with the spring spawner decline.

The spatial and temporal dynamics of the 4R herring fleet

We asked fishers where they had caught herring during the most recent season and in past years. The large and small seiner captains, including those whose homeports are in the Northern part of the coast, all reported catching most of their herring allocation in St George's Bay as well as Bay of Islands and Bonne Bay (Figure 4). None reported having caught herring north of Bonne Bay. Of the seven fixed gear harvesters who participated in our study, five are based in communities along the Northern part of the coast. Only one of them, a gillnetter, reported catching herring in that area. The remaining four fixed gear harvesters use a tuck seine and fish for herring in Bonne Bay. In fact, several of the small purse-seiners suggested that hardly any fish is caught in the northern part of the coast. A small seiner whose homeport is in the southern part of the fishing area explained:

> *Harvester: The bulk of the herring now, from everybody is taken in area 13 (. . .) the large seiners used to head [North] 20 years ago and took, say, one third of their quota, but the last 20 years they don't catch any down there. There's just no herring caught down there. Now the gillnetters did this year, the bait market was good and the price was good so the gillnetters went back at it and caught their share this year (. . .). So, like, the [Northern] part of Area 14, Like St. John's Bay, Port aux Choix, all [along] that coast, there's very little herring taken these last 20 years* (NC 20).

Another harvester from a Northern port confirmed that herring is available further north in that area from spring until fall, but that he catches his quota in the South. When asked why anyone would drive their boats from Port aux Choix all the way to St. George's Bay, harvesters explained that this is linked to the mackerel fishery.

One of the Port aux Choix-based purse-seiners explained:

> *Harvester: Herring [season] is however long you can squeeze it out (. . .). Usually, what I do, is catch my mackerel. When the mackerel season's over, on the way home, I catch my [herring] (. . .) The last few years my herring has been taken in Bonne Bay, and in the [South] even though there's lots here [Port aux Choix], but the buyers are on that end and coming here and setting up for just one or two boats, they'd have an excuse to try and trap you more (. . .)*
> *Researcher: Why do you catch the mackerel first?*
> *Harvester: It's global. Where my [herring] quota is individual.*
> *Researcher: So you save your quota [of herring]?*
> *Harvester: Sure, and go after the one that's there for what we call open season. It means that the more you can get the better for you* (NC 9).

A fishing strategy that prioritizes catching mackerel first is further encouraged by buyers, who want as many mackerel as possible because the value of mackerel per tonne of landings is far higher than the value of herring or capelin (Figure 6).

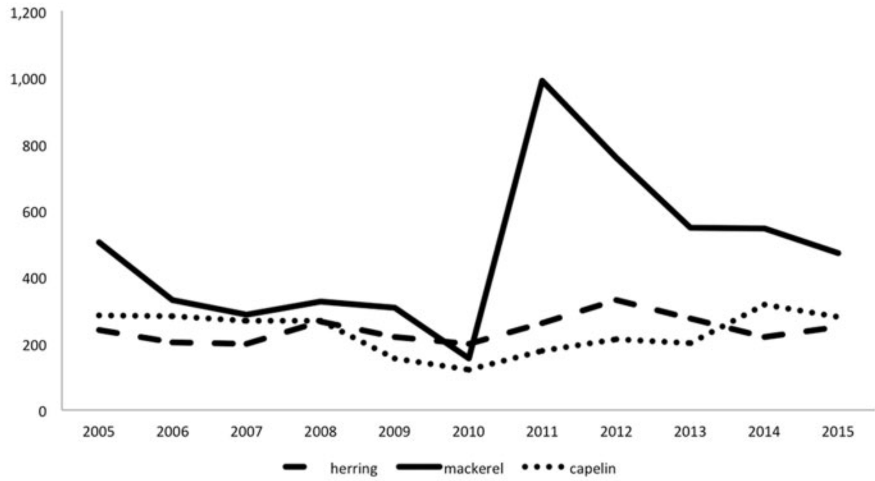

Figure 6. Annual value ($) herring, mackerel and capelin landings (t) in Newfoundland. Source: DFO.

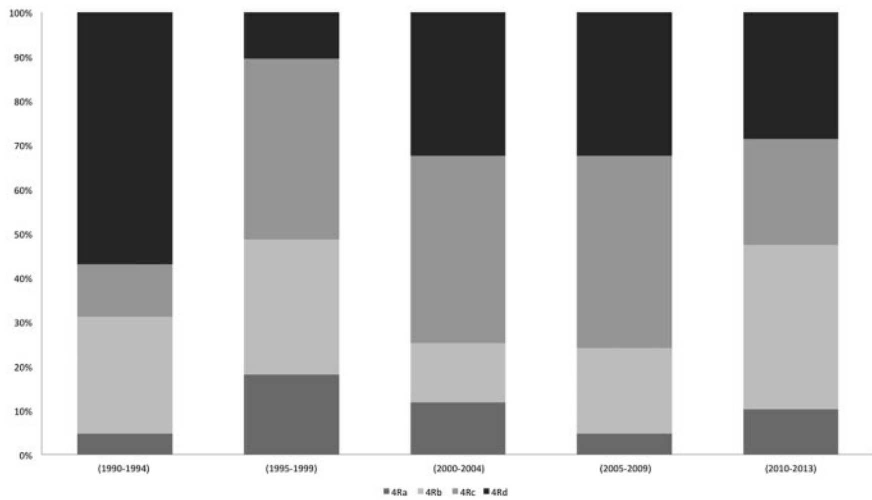

Figure 7. Distribution of average landings for each period across subareas. Sub area 4Rc includes Port au Port Bay, subarea 4Rd includes Bay St George. Source: DFO.

> *We spend all fall trying to avoid [herring] because [of] our buyers. The mackerel fishery is that lucrative to them that they don't want to put any herring in the cold storage until the mackerel fishery is finished* (NC10).

Thus, as mackerel schools are moving southwards during the fall migration and exit the Gulf of St Lawrence through the Cabot Strait, seiners aim to maximise catches as long as the fish are still within their fishing area. They follow the schools along the west coast of Newfoundland and part of the south coast to extend the time window for fishing. As a result, when the mackerel fishery ends and fishing effort shifts to herring the majority of seiners are concentrated in the southern part of the coast. In the absence of spatial management measures these harvesters catch their herring quotas in the southern bays rather than along the northern part of the coast.

The information provided by harvesters about the spatial distribution of fishing effort is consistent with DFO landings data which indicate that since 1990 the majority of herring landings were caught along the southern part of the west coast, i.e. in subareas 4Rc and 4Rd (Figure 7). Between 2000 and 2009 the two areas contributed to almost 80% of landings. This uneven effort is contrasted by scientific recommendations, which routinely state that there is a need to distribute fishing effort evenly along the coast to avoid disproportionate pressure on spring spawning herring (DFO, 2003, 2004, 2005, 2010b, 2012a).

During interviews we collected information about changes that harvesters have made over time to their vessels and fishing gear (Supplementary material—Protocol for career history interviews with fish harvesters—vessel history). We found that small-seiners have invested in larger boats, stronger engines and better fish finding technology to improve their ability to catch mackerel. As a result of these investments, harvesters have become highly dependent on the mackerel fishery but also more efficient:

> *You got people with million dollar boats, you got to have something to pay for it, right? If the mackerel fails, you know,*

we're finished. We'll never make a living. I'm okay because I own my boat, but the young guys starting out, with a million dollars in the hole, if the mackerel fails, we're finished. You can't even make a boat payment. The herring and capelin, there's no money in that, you might make yourself a hundred thousand dollars a year, a hundred and fifty thousand, but how in the hell are you going to live on that, with a bunch of men to pay and fuel, and the cost of fuel today (NC12).

Tuck seines

Although many of the fixed gear (primarily gillnet) licenses are inactive, the use of tuck seines is increasing in the sector. Tuck seine gear is operated from a vessel between 45 and 65 ft in length, which is equipped with a power block and fish pumps. Although tuck seines are not different from purse seines they are operated under fixed gear licenses. The fixed gear category always allowed the use of a bar seine to trap fish in a narrow inlet. A union representative explained how fixed gear harvesters have taken advantage of this loophole in the regulations:

There was a fisherman, this was back in the nineties, that basically went and set up a miniature purse-seine under the bar seine principle (. . .). And he went and he caught capelin with that miniature purse-seine that he rigged up and he was taken to court and the judge gave him the all clear (. . .), that's taken off since then, and most people that didn't ever fish, now, have geared up their vessels (. . .) and a lot of these boats geared up with tuck seine (. . .). And so it's allowed the fixed gear to become much more prolific at catching all three species, but particularly mackerel, which was very difficult to catch before (NC5).

Two younger harvesters described tuck seining as an opportunity for them to enter the small pelagic fishery by buying one of the many inactive fixed gear licenses and then gearing a vessel out as a small seiner.

In 2011 the only active fixed gear harvesters in area 13 (Figure 1) were 12–14 tuck seiners. In the same year there were 8–10 active tuck seine harvesters in area 14 and about 100 other fixed gear harvesters, 80% of whom used gillnets and 20% traps. To reduce competition, tuck seiners in each area have entered an informal agreement that divides the quota equally among them. In 2011 this amounted to 300 000 pounds per tuck seiner in area 13 and 130 000 pounds per tuck seiner in area 14.

Industry collaboration and participation in management

We asked DFO managers about the management of the 4R herring fishery and complemented what we learned in these interviews with information from DFO reports. The principal advisory body is the 4R herring co-management committee (DFO, 2010a); this committee includes harvesters, processors and DFO personnel from science, statistics, resource management, and conservation and protection. Committee meetings are held annually before the beginning of the season; additional meetings are seldom held (NC 26). These meetings are meant to provide a forum for stakeholders to raise issues and discuss problems; scientific data are presented to stakeholders, the previous years of the fishery are reviewed, and management measures are discussed before being put in place.

We did not explicitly ask harvesters about their participation in management but one tuck seiner mentioned that certain individuals dominate the committee meetings:

I've been going to the pelagic meetings the last few years, the meetings they've been having in Corner Brook in the spring [. . .] when we got all the fisheries [participants] sat down, (. . .), if they ask (. . .) if the fishery should get up and answer, [name of a processor] will get up and cut them off and answer for them (. . .) he's a smart man, can just shut them up or leave them speechless (NC22).

In 2010 and 2017 the committee included six seats representing fishers, two for the large seiner sector, two for the small seiners, and two fixed gear and six processor representatives (DFO, 2010a; NC2), thus seemingly providing an equal number of seats to harvesters from all three sectors and processors. The committee is co-chaired by a DFO resource manager, a representative of the small seiner fleet and a representative of the main processing company (DFO, 2010a; NC2). Moreover, all of the five large seiner vessels are owned or operated by two of the processors holding seats on the committee. Thus the interests of the processing sector are aligned with the large seiner fleet which have access to the majority of the TAC and are likely to outweigh the interests of the smaller operators and fixed gear harvesters on the committee.

Besides the annual committee meetings there have been two noteworthy collaborations between DFO and the fishing sector. First, information from fixed gear harvesters used to be collected by DFO through the index fishermen programme (NC29). However, this programme was discontinued due to a lack of resources at DFO. Although submission of logbooks is mandatory for fixed gear harvesters according to the management plan, none were submitted in 2004 (DFO, 2005) and the rate of return is generally very low, with only about 5 out of 200–300 fishermen submitting logbooks (NC 29). As a result, there is now no mechanism to collect fishers' knowledge from the fixed gear sector. Second, since 2004, annual larval surveys have been carried out by DFO in collaboration with the main processing company (NC 29; Barry, 2008). Thus, all current collaborations are with the large seiner fleet and the processing industry.

Management approach in 4X

In contrast to the herring fishery management approach in area 4R, herring management in the Bay of Fundy (NAFO division 4X) pays attention to individual spawning units based on spawning area and is based on a collaborative co-management approach. A DFO scientist explains:

These [spawning areas] form the basis for the divisions of where the herring are and where they spawn and that's really the basis for the management [in the Bay of Fundy]. That's, to collect information about these spawning groups, that we know about, and to try and maintain their integrity (. . .) We're doing multiple surveys up to two weeks apart on the same spawning area and the assumption is that herring are coming on to the grounds spawning and then leaving. But we need to verify that with the tagging evidence that they actually do leave the grounds and what the sort of depletion rate is through the season (NC 1).

Acoustic surveys of individual spawning aggregations and tagging operations are conducted with the help of the commercial fishing fleet. In some years, the TAC has been spread among spawning areas to prevent overfishing of individual subcomponents (Stephenson *et al.*, 1999).

The management of 4X herring is based on three management objectives (Power *et al.*, 2011):

(i) To maintain the reproductive capacity of herring in each management unit through persistence of all spawning components in the management unit; maintenance of biomass of each spawning component above a minimum threshold; maintenance of a broad age composition for each spawning component; and maintenance of a long spawning period for each spawning component.

(ii) To prevent growth overfishing by striving for fishing mortality at or below F0.1.

(iii) To maintain ecosystem integrity/ecological relationships ("ecosystem balance") through maintaining spatial and temporal diversity of spawning; and maintaining herring biomass at moderate to high levels.

The intensive management approach in the Bay of Fundy requires active support from the fishing industry. This support was gained in part through a shared experience in 1988 when fishermen and scientists were both able to see the effects of localized intensive fishing effort on a particular spawning area, Trinity Ledge (Figure 1).

> *The Trinity Ledge fishery, was a center of activity, a preferred area to fish, made up as much as 40% of the catch one year or two years and then collapsed. So that was the demonstration to the industry, that even staying within an overall quota, they were capable of eroding parts of the stock, if they applied the whole quota to that area (...). [They] saw themselves that they were eroding groups, 'families' they called them, and they helped us find a solution* (NC 2).

This realization led to an industry inclusive science and management structure that emulates co-management (Stephenson *et al.*, 1999).

Discussion

4R herring spawning areas and stock structure

Herring in the western Atlantic are managed as several stocks at the scale of relatively large NAFO management divisions (Figure 1). There is general agreement that all divisions contain complex populations, with several discrete subpopulations, but the attention paid to subpopulation integrity, especially at small spatial scales, varies between divisions and authorities (Stephenson *et al.*, 2009).

The simple division, in 4R management, into spring and fall spawners cannot account for the much finer temporal and spatial structure of herring populations. Spawning time is only a rough approximation of actual spawning behavior, which can happen from April until December. Most herring will spawn at a specific location and at about the same time within a few weeks each year (Iles and Sinclar, 1982). While it has been recognized that a change in environmental conditions may, over time, favour one spawning period over another (Melvin *et al* 2009), the concern expressed by fixed gear harvesters that herring are not observed in locations where they were previously caught, may indicate localized overfishing of a spawning group rather than environmental effects on fish movement. The assumption of single spring and single autumn stocks that underpins 4R herring management runs the risk of serial erosion of small spawning groups (Stephenson, 1999; Stephenson *et al.*, 2009).

Rejecting the existence of multiple spawning stocks and the possibility that some of them have been locally overfished implies that 4R herring are considered to be one single stock. This assumption would lead to the unlikely conclusion that the population dynamics of 4R herring are different from those of herring elsewhere in Atlantic Canada (Stephenson *et al.*, 2009) or in the northeast Atlantic (Kell *et al.*, 2009). The question remains whether the subunits can be adequately protected by a mixed stock management and whether more specific management is worth the effort (cf. Kell *et al.*, 2009).

The smallish nature of the spawning groups in 4R, combined with the observations of changes by harvesters, which may indicate the loss of small components, provide a rationale for addressing sub-components in management more explicitly (cf. Stephenson, 1999).

Acoustic surveys in 4R have been intermittent and fishery dependent information is patchy. Recent herring catches in 4R have been supported by a single year class (DFO, 2014). Maintaining a wide array of year classes is important for the sustainability of fish stocks and to reduce risk for the fishery (Rouyer *et al.*, 2011). Data gaps and the continuous decline of the spring spawning component highlight the precariousness of 4R herring management.

Considering past and present fishing effort in the bays that are considered the main spawning ground for spring spawners, it seems reasonable to suspect that this effort is linked to the continued decline of the spring spawning component.

The spatial and temporal dynamics of the 4R herring fleet

The information provided by harvesters regarding their fishing locations explains why fishing pressure has been spatially disproportionate, exerting pressure in the southern bays including St George's Bay in spite of scientific advice to disperse fishing effort to avoid intensive fishing in these areas (DFO, 1997). The information suggests that this disproportionate fishing effort is caused by interactions between the herring and mackerel fisheries. Harvesters reported during interviews that they usually target herring after the mackerel fishery. This is not due to availability because seiners from Port au Choix and Port Saunders report an abundance of herring close to their homeport. Rather, the harvesters provide a more complex rationale, i.e. that mackerel are more valuable than herring and sought after by buyers, and because there are no individual quotas, harvesters tend to concentrate on mackerel first as long as the fishery lasts. Indeed, since 2009 the minimum price for mackerel has increased by 50% (http://ffaw.nf.ca/en/fish-prices). Many of the harvesters have agreements with fish buyers, for whom cold storage space is a constraint.

Uneven fishing pressure can result in the local erosion of spawning components as has been observed for herring in 4X in the early 1990s (Stephenson *et al.*, 1997, for pollock (*Theragra chalcogramma*) in the western Gulf of Alaska and cod (*Gadus* *morhua*) resident on the eastern Scotian Shelf (Ciannelli *et al.*, 2013). Such depletions decrease the genetic and phenotypic diversity and thus the ability to protect against environmental or human-induced variability (Ciannelli *et al.*, 2013). Recovery after a local extinction may take longer than estimated (Murawski, 2010).

Our analysis not only highlights that the absence of quota regimes in the mackerel fishery influences when and where herring are caught, but also shows that the incentives towards overcapacity in one fishery can have consequences across other fisheries. Quota systems aim to curb trends toward efficiency increase and overcapacity in competitive fisheries (Copes, 1986). However, interactions between fisheries, if ignored, can lessen the effectiveness of such management regimes. In 4R, the small pelagic fisheries for herring and mackerel are managed separately under different management regimes, although the same participants are involved in each case. Both the large and small seiner fleets operate under individual quota management systems when targeting herring, but no individual quota systems are in place for mackerel. This "stovepipe" approach to fisheries management (Pinkerton, 2007) treats these fisheries as temporally and spatially distinct and ignores the fact that from the perspective of the fishers this distinction is much less clear. Consequently, high demand for mackerel combined with the absence of individual quotas has acted as incentives for increased efficiency in the seiner fleet. These investments in turn put pressure on harvesters to continue maximizing their returns from the mackerel fishery. In the fixed gear sector, the remaining traditional gillnet and trap fishing methods are increasingly being replaced by tuck seines, which are operating under fixed gear licenses and are catching the majority of the fixed gear allocation. As a result, the fixed gear sector is becoming increasingly mobile, fishing efficiency is intensifying in both sectors and with it the ability of mobile gears to catch herring aggregations wherever they may occur.

Industry collaboration and participation in management

The 4R herring sector is highly diverse; fishers are using different gear types and selling herring to different markets, both local and internationally. These differences in gear types and operations not only come with differing interests but also different knowledge about herring that is gained through fishing. Purse-seiners who are able to follow fish aggregations will gather information about fish movements at a larger scale than fixed gear harvesters who set their traps and gillnets often at the same place for several seasons. Fisheries science gathers information that is most relevant for stock assessment and thus also at a larger, population-wide scale. However, the only mechanism to bring these different kinds of information together is the annual co-management meeting in which representation is skewed in such a way that the interests of processors are likely to outweigh the interests of small fishing enterprises. In this light it is interesting that the explanations for the decline in spring spawners that were put forward by DFO representatives during the interviews are either focused on environmental factors or on the spring bait fishery but no mention is made of the possibility of overfishing by purse seiners. This line of argumentation is highly problematic for several reasons. Purse-seiners are capable of removing complete aggregations, which can quickly result in the removal of individual spawning components as observed in the Bay of Fundy. However, the current management assumption of a single spring and single autumn stock runs the risk of missing the erosion of small spawning groups. Associating the continued decline of the herring stocks with a localized fixed gear fishery ignores past high catches from mobile gears as well as the interactions between the herring and mackerel fisheries. The non-enforcement of logbook submissions from the fixed gear sector and the resulting non-reporting of bait catches means that it is impossible to verify how these catches are affecting the status of 4R herring stocks.

To improve understanding of herring stock structure in 4R and the causes for continued stock decline the knowledge of harvesters from all gear types needs to be integrated with scientific information. In order to determine who is fishing where and when, it will be necessary to map fishing locations by month and gear type. This could be achieved through further interviews with fish harvesters. The resulting information together with the reported landings will help determine the impact of each gear type on the fishery. Boonstra and Hentati-Sundberg (2016) demonstrate how qualitative interview data can be integrated with quantitative data from logbooks and other sources to analyse fishing behavior. Likewise, more detailed information about herring spawning locations from fish harvesters of all gear types is necessary to implement a management approach based on individual spawning grounds.

The benefits of an inclusive management approach have been demonstrated in the Bay of Fundy where collaboration with purse seiners allows explicit monitoring and consideration of individual spawning aggregations (Stephenson *et al.*, 1999). As in 4R a decline was also observed in 4X, but in contrast to the 4R fishery the erosion of individual spawning components could be shown and by giving attention to the smaller units management is attempting to prevent further erosion. The participatory and collaborative management regime in 4X was built on a long history of collaboration between the fishing industry, researchers and managers. The fishing industry now provides much of the sampling, surveys and information for assessment.

Conclusion

It is interesting that there are two quite different approaches used for herring fishery management in eastern Canada. It seems that in the case of the Bay of Fundy herring fishery scientists, managers and fish harvesters have been able to learn from past crises and to develop a collaborative management approach that allows them to pool resources and pay close attention to herring stock structure. Consideration of stock structure and protection of spawning components are important aspects of maintaining within-species diversity and thus should form part of an ecosystem based management approach for small pelagic fisheries. The integration of fishers' knowledge can help fill current knowledge gaps and thus forms an important part of "best available information" for fisheries science and management. It is part of the required information for integrated, ecosystem-based management approaches and constitutes a necessary element in the integration of ecological, economic, social, and institutional considerations of fisheries management decisions. It seems that the management of the 4X herring fishery in the Bay of Fundy has been more successful at recognizing and structuring management to maintaining multiple local spawning components.

It is important to look closely at how these developments were made possible: what factors support collaboration in the Bay of Fundy fishery and what factors prevent similar developments in 4R? These are important questions that need to be asked not only to improve the management of the 4R herring fishery but also for small pelagic fisheries in general. The fact that such different management approaches are possible in such close proximity clearly indicates that fisheries management systems are less determined by ecological conditions but rather are a product of those involved.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the article.

References

Barange, M. A., Bernal, M., Cergole, M. C., Cubillos, L. A., Cunningham, C. L., Daskalov, G. M., De Oliveira, J. A. A., Dickey-Collas, M., Gaughan, D. J., Hill, K., and Jacobson, L. D. 2008. Current trends in the assessment and management of stocks. *In* Climate Change and Small Pelagic Fish, chapter 9, pp. 191–255. Ed. by D. Checkley, C. Roy, Y. Oozeki, and J. Alheit. Cambridge University Press, Cambridge. 372 pp.

Barry, 2008. A sustainability framework for Atlantic herring. Presentation to the Fisheries Resource Conservation Council. Unpublished document. 6 pp.

Beaulieu, J.-L., McQuinn, I. H., and Gregoire, F. 2010. Atlantc herring (Clupea harengus harengus L.) on the West coast of newfoundland (NAFO Diviion 4R) in 29009. DFO Canadian Science Advisory Secretariat Research Document 2010/049, Vi: + 42. pp.

Biernacki, P., and Waldorf, D. 1981. Snowball sampling: problems and techniques of chain referral sampling. Sociological Methods and Research, 10: 141–163.

Boonstra, W. J., and Hentati-Sundberg, J. 2016. Classifying fishers' behaviour. An invitation to fishing styles. Fish and Fisheries, 17: 78–100.

Ciannelli, L., Fisher, J. A., Skern-Mauritzen, M., Hunsicker, M. E., Hidalgo, M., Frank, K. T., and Bailey, K. M. 2013. Theory, consequences and evidence of eroding population spatial structure in harvested marine fishes: a review. Marine Ecology Progress Series, 480: 227–243.

Carruthers, E. H., and Neis, B. 2011. Bycatch mitigation in context: using qualitative interview data to improve assessment and mitigation in a data-rich fishery. Biological Conservation, 144: 2289–2299.

Copes, P. 1986. A critical review of the individual quota as a device in fisheries management. Land Economics, 62: 278–291.

DFO. 1997. West Coast of Newfoundland Atlantic Herring (Division 4R). DFO Science Stock Status Report, 1997/B4-01. 10 pp.

DFO. 1999. West Coast of Newfoundland Atlantic Herring (Division 4R). DFO Science Stock Status Report, 1999/B4-01. 10 pp.

DFO. 2003. West Coast of Newfoundland Atlantic Herring (Division 4R) in 2002. DFO Science Stock Status Report, 2003/008. 11 pp.

DFO. 2004. West Coast of Newfoundland Atlantic Herring (Division 4R) in 2003. DFO Science Stock Status Report, 2004/017. 10 pp.

DFO, 2005. West Coast of Newfoundland Atlantic Herring (Division 4R) in 2004. DFO Science Stock Status Report, 2005/016. 9 pp.

DFO. 2010a. Integrated Fisheries Management Plan 4R herring (Clupea harengus). St John's, Fisheries and Oceans. 38 pp.

DFO. 2010b. Assessment of the West Coast of Newfoundland (Division 4R) Herring stocks in 2009. DFO Canadian Science Advisory Secretariat Science Advisory Report, 2010/032. 11 pp.

DFO. 2012a. Assessment of the West Coast of Newfoundland (Division 4R) Herring stocks in 2011. DFO Canadian Science Advisory Secretariat Science Advisory Report. 2012/024. 11 pp.

DFO. 2012b. Assessment of the Atlantic Mackerel stock for the Northwest Atlantic (subareas 3 and 4) in 2011. DFO Canadian Science Advisory Secretariat Science Advisory Report 2012/031. 17 pp.

DFO. 2014. Assessment of the West Coast of Newfoundland (Division 4R) Herring stocks in 2013. DFO Canadian Science Advisory Secretariat Science Advisory Report. 2014/056. 14 pp.

DFO. 2015. Assessment of 4VWX Herring. DFO Canadian Science Advisory Secretariat Science Advisory Report. 2015/040. 23pp.

DFO. 2016. Assessment of the West Coast of Newfoundland (Division 4R) Herring stocks in 2015. DFO Canadian Science Advisory Secretariat Science Advisory Report. 2016/024. 13 pp.

Frank, K. T., Petrie, B., Choi, J. S., and Leggett, W. C. 2005. Trophic Cascades in a formerly cod dominated ecosystem. Science, 308: 1621–1623.

Fréon, P., Cury, P., Shannon, L., and Roy, C. 2005. Sustainable exploitation of small pelagic fish stocks challenged by environmental and ecosystem changes: a review. Bulletin of Marine Science, 76: 385–462.

FRCC, 2009. Fishing into the future. The herring fishery in Eastern Canada. A report to the Minister of Fisheries and Oceans. Fisheries Resource Conservation Council, Report, Ottawa, ON. 41 pp. http://publications.gc.ca/collections/collection_2009/mpo-dfo/Fs158-3-2009E.pdf (last accessed 16 June 2016).

Gavaris, S. 2009. Fisheries management planning and support for strategic and tactical decisions in an ecosystem approach context. Fisheries Research, 100: 6–14.

Henning, E. 2004. Finding Your Way in Qualitative Research. Van Schaik, Pretoria, South Africa. 501 pp.

Hind, E. 2015. A review of the past, the present, and the future of fishers' knowledge research: A challenge to established fisheries science. ICES Journal of Marine Science, 72: 341–358.

Iles, T. D., and Sinclar, M. 1982. Atlantic herring: stock discreteness and abundance. Science, 215: 627–633.

Kell, L. T., Dickey-Collas, M., Nash, R. D. M., Pilling, G. M., and Roel, B. A. 2009. Lumpers or splitters? Evaluating recovery and management plans for metapopulations of herring. ICES Journal of Marine Science, 66: 1776–1783.

Korneski, K. 2016. Conflicted Colony: Critical Episodes in Nineteenth-Century Newfoundland and Labrador. McGill-Queen's Press-MQUP, Montreal and Kingston.

Mathew, S. 2011. Fishery-dependent information and the ecosystem approach: what role can fishers and their knowledge play in developing countries?. ICES Journal of Marine Science, 68: 1805–1808.

Maurstad, A. 2002. Fishing in murky waters: ethics and politics of research on fisher knowledge. Marine Policy, 26: 159–166.

McQuinn, I. H., and Lefebvre, L. 1996. An assessment of the west coast of Newfoundland (NAFO division 4R) herring fishery between 1973 and 1995. DFO Atlantic Fisheries Research Document. 96/57. 46 pp.

Melvin, G. D., and Stephenson, R. L. 2007. The dynamics of a recovering fish stock: Georges Bank herring. ICES Journal of Marine Science, 64: 69–82.

Melvin, G. D., Stephenson, R. L., and Power, M. J. 2009. Oscillating reproductive strategies of herring in the western Atlantic in response to changing environmental conditions. ICES Journal of Marine Science, 66: 1784–1792.

Mowat, F. 2004. Sea of Slaughter. Stackpole Books, Mechanicsburg,PA. 420 pp.

Murawski, S. A. 2010. Rebuilding depleted fish stocks: the good, the bad, and, mostly, the ugly. ICES Journal of Marine Science, 67: 1830–1840.

Murray, G., Neis, B., Schneider, D., Ings, D., Gosse, K., Whalen, J., and Palmer, C. T. 2008. Opening the Black Box: Methods, Procedures, and Challenges in the Historical Reconstruction of Marine Social-ecological Systems. *In* Making and Moving Knowledge, pp. 100–121. Ed. by J. S. Lutz, and B. Neis. McGill-Queen's University Press, Montreal. 360 pp.

Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C. M., Clay, J., Folke, C. *et al.* 2000. Effect of aquaculture on world fish supplies. Nature, 405: 1017–1024.

Neis, B., and Felt, L. 2000. Finding Our Sea Legs: Linking Fishery People and Their Knowledge with Science and Management. ISER Books, St. John's. 318 pp.

Neis, B., and Kean, R. 2003. Why fish stocks collapse: an interdisciplinary approach to the problem of 'fishing up'. *In* Retrenchment and Regeneration in Rural Newfoundland, pp. 65–102. Ed. By R. Bryon. University of Toronto Press, Toronto. 273 pp.

Neis, B., Schneider, D. C., Felt, L., Haedrich, R. L., Fischer, J., and Hutchings, J. A. 1999. Fisheries assessment: what can be learned from interviewing resource users? Canadian Journal of Fisheries and Aquatic Sciences, 56: 1949–1963.

Neis, B. 2011. Moving forward: social-ecological intractivity, global marine change and knowledge for the future. *In* World Fisheries: A Social-Ecological Analysis, pp. 182–199. Ed by R. E. Ommer, R. I. Perry, K. Cochrane, P. Cury. Wiley-Blackwell. 418 pp.

Ommer, R. E. 2007. Coasts under stress. Restructuring and Social-Ecological Health. McGill-Queen's University Press, Montreal. 592 pp.

Paterson, B., van Zyl, M., Jarre, A., and Green, L. 2014. Science, fishers' knowledge and Namibia's fishing industry. *In* Africa-Centred Knowledges: Crossing Fields and Worlds, pp. 111–125. Ed. by B. Cooper and R. Morrell. James Currey. 232 pp.

Paterson, B., and Kainge, P. 2014. Rebuilding the Namibian hake fishery: a case for collaboration between scientists and fishermen. Ecology and Society, 19: 49.

Payne, M. R. 2010. Mind the gaps: a state-space model for analysing the dynamics of North Sea herring spawning components. ICES Journal of Marine Science, 67: 1939–1947.

Pinkerton, E. 2007. Integrating holism and segmentalism: overcoming barriers to adaptive co-management between management agencies and multi-sector bodies. *In* Adaptive co-management: collaboration, learning and multi-level governance, pp. 151–171. Ed. By D. Armitage, F. Berkes, and N. Doubleday. UBC Press, Vancouver. 360 pp.

Power, M. J., Knox, D., and Melvin, G. D. 2011. 2010 Evaluation of 4VWX herring. DFO Can. Sci. Adv. Sec. Res. Doc. 2010/112 vi + 124 p.

Rouyer, T., Ottersen, G., Durant, J. M., Hidalgo, M., Hjiermann, D. Ø., Persson, J., Stige, L. C., and Stenseth, N. C. 2011. Shifting dynamic forces in fish stock fluctuations triggered by age truncation? Global Change Biology, 17: 3046–3057.

Sinclair, M. 2009. Herring and ICES: a historical sketch of a few ideas and their linkages. ICES Journal of Marine Science, 66: 1652–1661.

Sinclair, M., and Solemdal, P. 1988. The development of 'population thinking' in fisheries biology between 1878 and 1930. Aquatic Living Resources 1: 189–213.

Stephenson, R. L., Power, M. J., Fife, F. J., Melvin, G. D., Clark, K. J., and Gavaris, S. 1997. Evaluation of the Stock Status of 4WX Herring. DFO Atlantic Fisheries Research Document. St. Andrews, NB, Canada. 71 pp.

Stephenson, R. L. 1997. Successes and failures in the management of Atlantic Herring: do we know why some have collapsed and others survived? *In* Developing and sustaining world fisheries resources: The state of science and management. Proceedings of the Second World Fisheries Congress, Brisbane 1996, pp 49–54. Ed. by D. A. Hancock, D. C. Smith, A. Grant and J. P. Beumer, CSIRO Publishing. Melbourne. 797 pp.

Stephenson, R. L. 1999. Stock complexity in fisheries management: a perspective of emerging issues related to population subunits. Fisheries Research, 43: 247–249.

Stephenson, R. L. 2002. Stock structure and management structure: an ongoing challenge for ICES. ICES Marine Science Symposia, 215: 305–314.

Stephenson, R. L., Melvin, G. D., and Power, M. J. 2009. Population integrity and connectivity in Northwest Atlantic herring: a review of assumptions and evidence. ICES Journal of Marine Science, 66: 1733–1739.

Stephenson, R. L., Paul, S., Pastoors, M. A., Kraan, M., Holm, P., Wiber, M., Mackinson, S., Dankel, D. J., Brooks, K., and Benson, A. 2016. Integrating fishers' knowledge research in science and management. ICES Journal of Marine Science, 73: 1459–1465.

Stephenson, R. L., Rodman, K., Aldous, D. G., and Lane, D. E. 1999. An in-season approach to management under uncertainty: the case of the SW Nova Scotia herring fishery. ICES Journal of Marine Science, 56: 1005–1013.

Stephenson, R. L., and Clark, K. J. 2002. The role of ICES herring investigations in shaping fisheries science and management. ICES Marine Science Symposia, 215: 504–514.

Weinstein, M. 2006. TAMS analyzer: anthropology as cultural critique in a digital age. Social Science Computer Review 24: 68–77.

Handling editor: Sarah Kraak