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ECONOMIC AND SOCIAL BENEFITS OF FISHERIES REBUILDING: SIX CANADIAN CASE STUDIES

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EXECUTIVE SUMMARY

Many fish populations in Canada are depleted and at risk of further decline. Fisheries loss jeopardizes the social, economic, and health well-being of thousands of Canadians and is therefore of national concern. However, of 56 fish stocks assessed as being in a Critical or Cautious state, only three have rebuilding plans developed for them. As such, there is an urgent need to intensify Canada's fisheries rebuilding efforts.

One of the challenges facing rebuilding fisheries is that it often necessitates an immediate and substantial reduction in fishing mortality. This invariably involves forgoing certain short-term benefits in order to gain the benefits of rebuilt fish stocks in the medium and long term. To investigate the economic and social implications of rebuilding Canada's fisheries, this study analyzes the socio-economic costs and benefits of rebuilding Canada's fisheries under six different scenarios of species' recovery rates and management strategies. We conduct the analysis for six fish stocks representing different biological life histories, geographic distribution, state of fisheries depletion, and socio-economic importance to coastal communities. These fish stocks include: i) Pacific herring Central Coast stock; ii) West Coast Vancouver Island chinook salmon — both aggregate abundance-based management (AABM) and individual stock-based management (ISBM) components; iii) yelloweye rockfish outside population; iv) Atlantic cod NAFO Division 2J3KL; v) Gulf of St. Lawrence Atlantic herring spring spawners NAFO Division 4T; and vi) Atlantic redfish Units 1 and 2.

Our results indicate that overall, for the time period studied, all fish stocks — except yelloweye rockfish, which is a long-lived species with a low natural growth rate — would likely experience economic gains from fisheries rebuilding relative to the status quo. Under the most optimistic scenario, northern cod (which has, among the fisheries studied, one of the largest current catch and number of fishers) and Pacific herring are projected to benefit the most by the end of the analysis period, with potential economic gains of seven and 11 times above the status quo, respectively. Under the least optimistic scenario, this gain drops to 0.85 and five times above the status quo, respectively. In most cases, a management strategy involving fishery closure results in higher potential economic gains compared to a low-fishing strategy, regardless of the rate of fish-stock recovery. Not surprisingly, slow recovery scenarios are projected to result in the fewest economic gains. An intergenerational discounting approach, which seeks to explicitly incorporate the interests of future generations in the analysis, increases projected economic benefits compared to conventional discounting, thereby emphasizing the importance of taking a long-term perspective to fisheries rebuilding.

Using fish stock assessments as a basis, we estimate that once fish stocks are rebuilt, they can support catches that range from 1.3 to 18 times above the status quo catch level. In terms of social impact, an estimated 5,100 fishers are currently involved in fisheries for the case study fish stocks, who can thus potentially benefit from this projected increase in fish catch in the future. The overall benefits of rebuilding are magnified if we consider the thousands more people in coastal communities who have food, cultural, and other social connections to fish stocks. While rebuilding may likely incur short-term costs for fishers and coastal communities, these need to be seen in light of the fact that without rebuilding and effective fisheries management, we have lost significant amounts of food, jobs, and incomes over the recent decades, and we could lose everything if and when the fish stocks collapse. Recall the cost to fishers and society when the cod stocks off Newfoundland collapsed in 1992.

Our results suggest that bearing this short-term cost can lead to economic benefits, which in the long term are an improvement over maintaining the status quo. This suggests that accounting for social impacts is crucial in developing rebuilding plans, especially in terms of access to and allocation of projected economic benefits from rebuilt fish stocks in the future.

This study further highlights that rebuilding plans have to be developed while bearing in mind that anticipated fish stock recovery can either be delayed or sped up by future changes in environmental conditions, which, although not modelled here, can change projected economic outcomes. While we show that fisheries rebuilding can improve the biological and economic state of Canadian fish stocks

overall, it is also important to emphasize the need for Canada to have strong precautionary fisheries management practices in place for species that are not currently depleted so that fish stocks are managed sustainably, avoiding the need for rebuilding.

INTRODUCTION

Canada's Pacific, Atlantic, and Arctic oceans support fisheries that provide important socio-economic and cultural benefits to coastal communities throughout Canada. However, a recent assessment of the state of Canada's fisheries found that many fish populations have been depleted (Baum and Fuller 2016). Currently, only 34 per cent of 194 assessed stocks are considered Healthy, while the status of 16 per cent are Cautious, 13 per cent are Critical, and 37 per cent are Uncertain (Archibald and Rangeley 2018). The overfished state of Canadian fisheries is exacerbated by management and policy actions that have largely failed to address ongoing anthropogenic pressures and climate risks (Favaro et al. 2012; Bailey et al. 2016). If Canada's fish stocks continue to follow the prevailing trend of decline, there is huge potential for fisheries loss that will jeopardize the food security, health, livelihood, employment, and cultural practices of thousands of Canadians (O'Donnell et al. 2013; Schrank and Roy 2013; Ecotrust and T Buck Suzuki 2018). Clearly, there is an urgent need to rebuild Canadian fish stocks so that fisheries can support ecological and societal well-being into the future.

Fisheries rebuilding plans aim to rebuild fish stocks to a level that can support sustainable fisheries and generate socio-economic benefits (OECD 2012). By sustainable fisheries, we mean catching fish in a way that meets present needs without compromising the ability to meet future needs.

In a global context, Sumaila et al. (2012) showed that rebuilding fisheries could increase global fisheries resource rent from an annual loss of US$13 billion to net gains of US$54 billion. In the European Union, it was estimated that fish stocks can be rebuilt if exploitation levels are set at 50–80 per cent of the maximum, and that once rebuilt, fish stocks could increase profits to fishers (Froese et al. 2018). A challenge of rebuilding fisheries is that it often necessitates an immediate and substantial reduction in fishing mortality (Murawski 2010), which invariably involves forgoing certain short-term economic benefits. Given the urgency to rebuild Canadian fish stocks, the objective of this study is to investigate the economic and social implications of rebuilding Canada's fisheries by analyzing the economic costs and benefits of rebuilding Canada's fisheries under different management scenarios.

This study is done against a backdrop of slow progress towards national fisheries rebuilding. Despite having 26 stocks assessed as being in the Critical zone in the 2018 Canadian Fisheries Audit (Archibald and Rangeley 2018), Fisheries and Oceans Canada (DFO) has only three rebuilding plans in place and has committed to develop fish stock rebuilding plans for only 18 more stocks[1] for 2018–2021. Therefore, results from this study provide timely and important insights about the economic and social impacts forthcoming rebuilding plans will have on the thousands of people across Canada who depend on these fisheries to support livelihoods, food security, health, and social-cultural well-being.

We focus on six fish stocks as case studies three on the Pacific coast and three on the Atlantic coast. Pacific stocks include: i) Pacific herring Central Coast stock (Pacific herring); ii) West Coast Vancouver Island Chinook salmon (WCVI Chinook), both AABM and ISBM components[2]; and iii) yelloweye rockfish outside population (yelloweye rockfish). Atlantic stocks include: i) Atlantic cod NAFO Division 2J3KL (northern cod); ii) Gulf of St. Lawrence Atlantic herring spring spawners NAFO Division 4T (Atlantic herring); and iii) Atlantic redfish Units 1 and 2 (redfish). We chose these fish stocks to present a range of life histories, levels of depletion, fishing pressures, socio-economic importance to First Nations and coastal communities, and susceptibility to different threats and drivers. For instance, yelloweye rockfish and redfish represent slow-growing, long-lived species as opposed to fast-growing Pacific and Atlantic

[1] Source: http://www.dfo-mpo.gc.ca/ae-ve/audits-verifications/16-17/work-plan-travail-eng.html

[2] Salmon are managed under two types of management regimes: 1) Aggregate abundance-based management (AABM) constrains catch or total mortality to a limit computed based on pre-season forecasts or in-season abundance estimates and a target harvest rate index (not stock specific); 2) Individual stock-based management (ISBM) is based upon the requirements of individual stocks. It places a limit on exploitation rate or mortality of naturally spawning chinook stock in all non-AABM fisheries.

herring. While yelloweye rockfish and northern cod represent stocks that have been in an extended depressed state, redfish presents a case where the stock is showing strong signs of growth.

According to the 2016 Sustainability Survey for Fisheries conducted by DFO, the majority of the selected fish stocks for this study are assessed to be in the Critical zone (Table 1). Except for Pacific herring, the stocks are among the 19 stocks that DFO has committed to develop rebuilding plans for. This study will therefore contribute timely insights to inform the development of these rebuilding plans, as well as draw and generalize insights for other Canadian fish stocks in need of rebuilding.

Stock trends

Stock status

A synopsis of the most recent stock assessment conducted by DFO for each of the case study fish stocks is provided in Appendix A. Synopsis of most recent DFO stock assessmentsThe majority of these are considered to be in the Critical zone as defined by DFO's precautionary approach framework. In addition, 2J3KL Atlantic cod (northern cod) and Units 1 and 2 *S. mentella* are assessed as Endangered under the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), while *S. fasciatus* is Threatened (Table 1). The DFO Sustainability Survey for Fisheries assessed redfish to be in the Critical zone. However, since the survey was completed in 2016, the redfish stock has shown improvements (DFO 2018d), as reflected in the "Healthy" and "Cautious" status reported by a more recent Fisheries Audit conducted by Archibald and Rangeley (2018).

Table 1. Status of case study fish stocks according to COSEWIC assessment, DFO Sustainability Survey for Fisheries, and Oceana Fisheries Audit

Stock	**COSEWIC status**[1]	**DFO status**[2]	**Oceana status**[3]
Gulf of St. Lawrence Atlantic herring 4T spring spawners	N/A	Critical	Critical
Atlantic cod 2J3KL	Endangered	Critical	Critical
Redfish *S. mentella* Units 1 & 2	Endangered	Critical	Healthy
Redfish *S. fasciatus* Units 1 & 2	Threatened	Critical	Cautious
Pacific herring Central Coast	N/A	Healthy	Cautious
Yelloweye rockfish outside population	Special Concern	Critical	Critical
WCVI Chinook	N/A	AABM stock is Uncertain; wild population is Stock of Concern[4]; listed as "red" under Wild Salmon Policy[5]	N/A

[1] Sources: COSEWIC (2008); COSEWIC (2010a; b)
[2] Source: 2016 Sustainability Survey for Fisheries, http://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/survey-sondage/index-en.html
[3] Source: Archibald and Rangeley (2018)
[4] Source: DFO (2018a)
[5] Source: DFO (2016a)

Catch trends

The main fishing gear and management approaches used for each stock are summarized in Table 2. Catches of northern cod, redfish, and Pacific herring[3] are currently at the lowest levels over the past 20 years (Figure A1, Figure A2,Figure A3). Northern cod was placed under moratorium from directed fishing in 1992. A limited commercial inshore fishery that was restricted to using fixed gear and vessels under 65 ft was allowed from 1998 to 2002 but was closed in 2003. In 2006, a recreational fishery was opened and the inshore fixed-gear fishery was reopened. Unit 1 redfish was placed under moratorium in 1995, but an index fishery has been allowed since 1998. Unit 2 redfish was never closed to commercial fishing. The Central Coast Pacific herring fishery was closed from 2008 to 2013. While catches of yelloweye rockfish and WCVI Chinook are not at all-time lows, catches are substantially lower than levels observed in the 1980s–1990s (Figure A4 and Figure A5). In particular, average landed catch of WCVI AABM troll fisheries for the period 2009–2016 was 70,080 fish, compared to 221,065 fish for the period 1985–1998 (DFO 2018b). Recent year landings of 4T spring spawning Atlantic herring are also close to 20-year lows (Figure A6).

Table 2. Main gears, fisheries, and management approaches associated with case study species

Case study fish stock	**Main gears/fishery (in parentheses)**	**Management approach**
Gulf of St. Lawrence Atlantic herring 4T spring spawners	Gillnet, purse seine	Total allowable catch (TAC)
Atlantic cod 2J3KL	Gillnet, hook and line, pots/traps, longline, rod and reel (recreational)	Individual weekly limits; maximum allowable harvest of 9,500 t (2017/2018)
Redfish *S. mentella* & *S. fasciatus* Units 1 & 2	Bottom trawl, gillnet and seine (Unit 2)	Competitive quota and enterprise allocations under a TAC with individual quotas in Unit 2
Pacific herring Central Coast	Seine roe, gillnet roe	TAC with individual quotas[1]
Yelloweye rockfish outside population	Troll, hook and line, longline, mid-water and bottom trawl, rod and reel (recreational)	Individual transferable quotas under a TAC
WCVI Chinook	Troll, rod and reel (recreational)	Competitive quota under a TAC

[1] Roe licences are notionally provided as individual quotas but are actually licensed as pools. Similarly, food and bait is managed as individual quotas, but licence holders also work co-operatively in the fishery.

METHODOLOGY

Figure 1 illustrates the analysis framework used to evaluate the economic impact of rebuilding, which is represented by the estimated net present value (NPV) derived from rebuilt fish stocks. The economic outcome (NPV) flows from scenarios of fish stock recovery and management strategies used in fisheries rebuilding (detailed in Section 1 below). A combination of biological and economic data is used to inform and generate the economic estimate.

[3] DFO catch data for Pacific herring used in this study are for commercial roe, food and bait, and special-use fisheries. First Nations food, social and ceremonial fisheries, and spawn on kelp fisheries are not included.

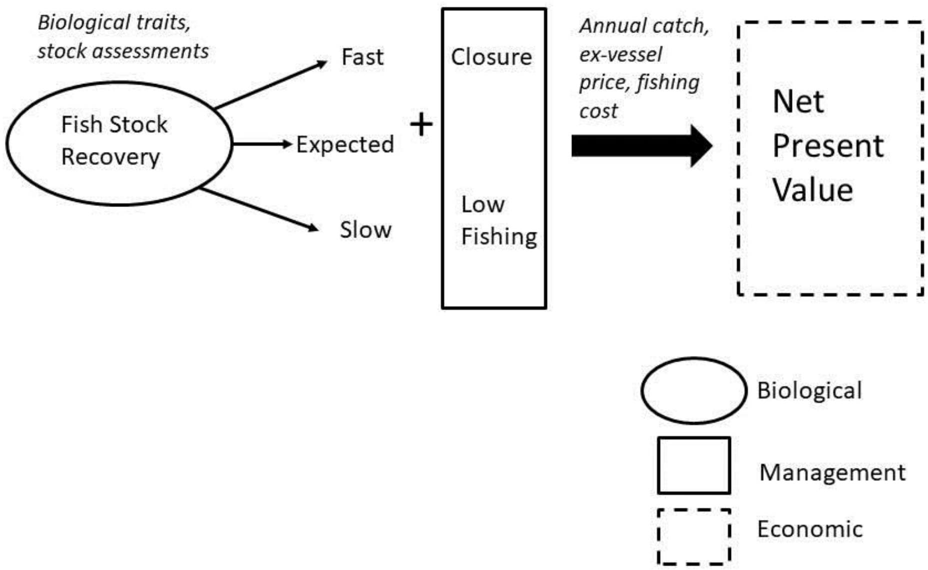


Figure 1. Analysis framework to estimate the economic net present value derived from rebuilt fish stocks. Text in italics represents data and information sources. Solid-line shapes represent scenarios (oval = biological, rectangle = management), and the broken-line rectangle represents the estimated economic outcome.

1. Description of scenarios

Scenario framework

In the rebuilding scenarios, each species' recovery is influenced by two main factors: the rebuilding strategy and the biological response of the species. It should be noted that the rapidly evolution of ecosystems arising from climate change is not explicitly modelled in this analysis, although it is implied in the species' biological responses (see below). In addition, this analysis assumes that First Nations fisheries for food, social, and ceremonial purposes continue during the rebuilding process. For Pacific herring, this means that traditional harvesting of spawn on kelp (a "no kill" fishery) is not affected during rebuilding.

Three types of rebuilding strategies have been chosen to represent trade-offs between management objectives: i) directed fishing closure represents a higher weighting to long-term conservation objectives; ii) low directed fishing represents a higher weighting to short-term socio-economic objectives; iii) status quo reflects the prevailing management and biological regime in place. The biological response of each stock represents the speed at which the fish stock rebuilds. We consider three rates of biological recovery response: fast, expected, and slow. Biological response is expressed in terms of each species' generation time. The scenarios are thus defined by a matrix of two rebuilding strategies and three biological responses, plus a single status quo scenario which assumes that both management and biological regimes stay unchanged from recent years (Table 3).

Table 3. Description of scenarios in terms of management strategy (closure, low fishing) and rate of biological response (fast, expected, slow)

Scenario	Description
FC	Fast Recovery + Closure
FL	Fast Recovery + Low Fishing
EC	Expected Recovery + Closure
EL	Expected Recovery + Low Fishing
SC	Slow Recovery + Closure
SL	Slow Recovery + Low Fishing
SQ	Status Quo

Rebuilding strategies and species' biological responses are themselves influenced by various socio-economic and environmental drivers. While we do not further elaborate on these drivers, they are implicit within each scenario. For instance, the type of management action chosen may reflect prevailing political, social, economic, or cultural concerns. At the same time, the type of biological response demonstrated by each fish stock is not only due to its biological traits but may also be influenced by wider environmental factors that either speed up or slow down the expected response.

Scenario time frame

The goal of fisheries rebuilding is to ensure a long-term, sustainable fishery that can support ecosystems and humans into the future. It is a long-term process, which may not yield positive benefits for many years (e.g., Sumaila et al. 2012), if at all. To reflect this, intergenerational aspect of rebuilding, the time frame for each scenario is 100 years, although we also report results in the following sections at 30- and 50-year intervals. The entire time frame of 100 years is split into two periods, as described below:

Period 1 (P1): Rebuilding process — During this period, there is no or reduced fishing activity (i.e., rebuilding strategies (i) and (ii), respectively) in order to promote stock growth to healthy levels.
Period 2 (P2): Rebuilt — During this period, stocks are assumed to be at a rebuilt level and can support higher catch rates than the catch rates supported by depleted stocks.

The duration of P1 and P2 varies under each of the scenarios because the number of years it takes for a stock to grow from a low biomass to a level that takes it out of the Critical zone (i.e., P1) differs based on species, type of management regime in place, environmental conditions, and other factors. The exception is the status quo scenario, where the current biological and management conditions are assumed to be maintained for the entire analysis time frame.

We define P1 for each scenario as follows:

According to DFO rebuilding plan guidelines, a reasonable length of time required to allow a high probability of the stock growing out of the Critical zone should correspond to 1.5 to two generations of the species. We use this range to represent the "expected" rate of recovery for the biological response dimension, with the faster rate (1.5 generations) corresponding to a more conservative management strategy (fishing closure) and two generations corresponding to low fishing pressure (Table 4).

Table 4. Generation times (G) associated with rebuilding scenarios

		Biological response		
		Fast	**Expected**	**Slow**
Rebuilding strategy	**Closure**	0.75 G	1.5 G	2.25 G
	Low fishing	1.00 G	2.0 G	3.00 G

We then define "fast" biological response as 0.5 times the expected rate and "slow" as 1.5 times the expected rate. Thus, the estimated rebuilding time required for each stock is expressed as:

$T_i = B \times M \times G_i$,

Where T_i is the number of years required for rebuilding stock *i*
B is the biological response (expected, fast or slow)
M is the management strategy (closure or low fishing)
G_i is the generation time for stock *i*

The rationale for including fast biological response is that some stocks (such as redfish and northern cod) have already been rebuilding for a number of years. It may also be possible that favourable environmental conditions allow a species to recover faster than expected. The opposite (unfavourable conditions) is assumed to result in a slow biological response. This can apply to species such as yelloweye rockfish, which have not shown signs of recovering despite conservation measures put in place (Haggarty et al. 2016). The length of P1 for each case study stock and scenario is summarized in Table 5.

Table 5. Length of Period 1 (no. of years) for case study fish stocks under each of the six scenarios. Note that the status quo scenario does not involve different periods and is not shown below.

Scenario	Atlantic herring	Northern cod	Pacific herring	Redfish	WCVI Chinook	Yelloweye rockfish
FC	4.5	8.25	3.75	13.5	3.75	24
FL	6	11	5	18	5	33
EC	9	16.5	7.5	27	7.5	49
EL	12	22	10	36	10	65
SC	13.5	24.75	11.25	40.5	11.25	73
SL	18	33	15	54	15	98

The generation time for each species is provided in Table 6. Details for selecting generation time are explained in Appendix B. Selection of species generation timeNote that the literature-based generation times in Table 6 are used in the ensuing economic analysis, while the generation times from Fish Base (Froese and Pauly 2018) are used for sensitivity analysis. This is because the approach for estimating species' generation time is not consistent across studies, whereas generation time estimated in FishBase follows a consistent method across all species.

Table 6. Generation time for each species (no. of years)

Species	Generation time (FishBase)[1]	Generation time (literature)	Literature source
Redfish	6.7[2]	18[3]	COSEWIC (2010b)
Atlantic herring	3.6	6	Lorance et al. (2015)
Northern cod	8.6	11	COSEWIC (2010a)
Pacific herring	2	5	Cleary et al. (2010)
WCVI Chinook	6.5	5	Riddell et al. (2013)
Yelloweye rockfish	17.2	33	Yamanaka et al. (2006)

[1] Froese and Pauly (2018)
[2] This is the average generation time for *S. mentella* (9.1 years) and *S. fasciatus* (4.3 years)
[3] This is the average generation time for Gulf of St. Lawrence *S. mentella* (18.4-18.6 years) and *S. fasciatus* (16-18 years)

P2 is equivalent to the analysis time frame (100 years) minus P1 for each species and scenario.

Projected catches under different scenarios

Projected catches for each scenario in P1 and P2 are based on information taken from stock assessments of the case study stocks.

Selection of Period 1 catch levels:

During P1, catch levels depend on the type of rebuilding strategy in place. Under a fishing closure rebuilding strategy (scenario FC, EC, or SC), P1 catch is zero. Under a low fishing rebuilding strategy (scenario FL, EL, or SL), the general approach we followed was to select an annual total allowable catch (TAC) level that is above zero but maximizes the opportunity for stocks to rebuild — i.e., catch levels associated with the lowest probability of decline or with the highest probability of exceeding LRPs.

This TAC level was based on decision tables provided in stock assessments conducted by DFO. Decision tables often show the predicted status of a stock given a range of constant catches relative to specified LRPs. However, stock assessments and the catch advice provided therein are not presented in a consistent format for all stocks. In addition, not all stocks have established LRPs (e.g., Pacific herring and WCVI Chinook). Further, since stock assessments are not published every year, the catch advice provided may not reflect the most recent events occurring in the fishery. In these circumstances, we modified the final P1 catch while attempting to follow the same intent as the above rationale for selecting P1 catch. Details are included below:

Yelloweye rockfish (outside population) — Catch advice provided in the most recent stock assessment conducted in 2014 was that total catches of more than the 2014 replacement yield of 162 t would have a higher probability of causing further population declines, whereas catches of 150 t or less in 2015 were not projected to create net population declines for the stock to 2029 (Yamanaka et al. 2018). According to the stock assessment, of the TACs >0 that were evaluated, the catch with highest probability of being above the LRP of 0.4 B_{MSY} (the biomass that allows a stock to deliver the maximum sustainable yield) was 50 t (Yamanaka et al. 2018). Following our P1 selection approach described above, 50 t was initially used as the low fishing catch. However, the low fishing catch level was subsequently revised to 100 t, since this is the catch associated with the yelloweye rockfish rebuilding plan in place since 2016 and already represents a substantial reduction from the estimated mortality cap of 287 t in 2014 (Appendix 9: Rebuilding Plans for Groundfish Species, Pacific Region Integrated Fisheries Management Plan for Groundfish).

Gulf of St. Lawrence Atlantic herring spring spawners — Catch advice from the most recent stock assessment conducted in 2018 was that spawning stock biomass (SSB) at the start of 2019 and 2020 would increase slightly at annual catches of less than 500 t, remain mainly stable at 1,000 t, and decline at catches above 1,500 t (DFO 2018c). As per our P1 selection approach, we set the low-level catch at 500 t to maximize the chances of getting this stock out of the Critical zone.

Northern cod — The most recent stock assessment in 2018 estimated that 2018 SSB is at 37 per cent of the conservation LRP (biomass limit [B_{lim}]) (DFO 2018d). At current levels of SSB, the stock is considered to have suffered serious harm, and fishing must be kept to the lowest level possible until the stock is out of the Critical zone (DFO 2018c). The stock assessment provided SSB projections for catch multipliers of 0 to 1.2 times the estimated 2017 catch of 15,054 t. The projected catch >0 with the lowest risk of SSB in 2019 declining below the 2018 value (<0.1 per cent) and highest SSB/B_{lim} ratio in 2019 (0.33) was equivalent to a catch multiplier of 0.8 — i.e., a catch of 12,043 t (0.8 x 15,054 t). As per our P1 selection approach, 12,043 t would represent P1 catch. However, this exceeds management measures for the 2018 stewardship fishery, which stipulated that 2018 catch levels were not to exceed 9,500 t.[4] To be consistent with this policy, and because the catch advice was to keep catches to the lowest level possible, we set P1 catch to 9,500 t.

[4] Source: http://www.dfo-mpo.gc.ca/decisions/fm-2018-gp/atl-17-eng.htm

Pacific herring (Central Coast stock) — The most recent stock assessment in 2018 indicated that the TAC >0 with the lowest probability of spawning stock biomass (SSB) in 2018 falling below the limit reference point of 0.3 SB_o was 3,000 t (DFO 2018e). While 3,000 t would be the P1 catch following our P1 selection approach, this does not seem realistic given that the average catch for the three most recent years (2014, 2015, and 2016) was 509 t. Prior to that, the Central Coast was closed to fishing for seven years, from 2008–2013. We therefore modified our selection approach, considering recent (2014–2016) catches to be reflective of a conservative fishing level, and set P1 catch to 500 t instead of 3,000 t.

Redfish (Units 1 & 2) — The most recent stock assessment indicated a positive outlook for redfish stocks due to large cohorts from 2011, 2012, and 2013. While it was expected that large numbers of these cohorts will recruit to the fishery from 2018 to 2020 (DFO 2018f), no quantified catch advice or decision tables were provided in the stock assessment. Consequently, we had to modify our P1 selection approach for redfish. A management strategy evaluation (MSE) approach was completed in 2018 to investigate the performance of candidate management procedures for redfish (DFO 2018g). The MSE assumed a status quo period of management prior to the implementation of simulated harvest control rules, during which catch was assumed to be 2,838 t (average retained catches from 2015–2017). Since this status quo catch level appears to have allowed the stock to grow, it is consistent with our P1 selection criteria of a catch level above zero that maximizes the opportunity for rebuilding the stock. As such, we used 2,838 t to represent the P1 low catch for redfish.

WCVI Chinook — Salmon stock assessments use approaches different from those for other stocks and do not provide decision tables. Due to the different scientific method, the basis for selecting a P1 catch level for WCVI Chinook used the number of forecasted returning fish in a given year. Specifically, we selected a catch level corresponding with a strong return year during a period of low productivity, as this is consistent with our P1 selection approach of choosing a catch level that maximizes the opportunity for the stock to grow. We therefore set the P1 catch level to the year with the highest forecasted returns within the time period 2000–2016. This time period was assumed to represent a low stock productivity period because spawner abundances of southern Chinook, inclusive of WCVI stocks, have generally declined since 2000 (Riddell et al. 2013). The number of forecasted returns was taken from Agency (DFO) forecasts reported by the Pacific Salmon Commission Joint Chinook Technical Committee (PSCCTC 2017a). For the period 2000–2016, Agency forecasts were highest in 2016, with 224,119 forecasted returns (PSCCTC 2017a). Total catch of WCVI Chinook (AABM and ISBM) in 2016 was 179,890 fish (PSCCTC 2017b), which we used to represent P1 catch.

Selection of Period 2 catch levels:

Except for the status quo scenario, stocks under the other six scenarios are assumed to be in a rebuilt state by P2, which we defined as reaching the maximum sustainable yield (MSY). P2 catch levels were therefore set to the MSY catch level in cases where a recent estimate of MSY was available (yelloweye rockfish, redfish, and Pacific herring). For cases where an MSY estimate was not available, rebuilt catch levels were based on catch levels during historical periods of high stock productivity, as detailed below.

Yelloweye rockfish (outside population) — Rebuilt catch was set to the most recent MSY estimate, provided in Yamanaka et al. (2018), of 276 t per year.

Gulf of St. Lawrence Atlantic herring spring spawners — In the past 30 years, estimated spawning stock biomass (SSB) of spring spawners at the beginning of the year was highest in the late 1980s, after building up from below the LRP of 22,000 t in the early 1980s (DFO 2016b). During this period, fishing mortality was also below or just at the reference level of F=0.35. We thus use the average catch for these years (1982–1988) to represent rebuilt P2 catch levels because: i) it did not exceed fishing mortality reference levels; and ii) at the same time, it allowed SSB to grow (Table 7).

Northern cod — A conservation limit reference point for northern cod was established in 2010 and defined as the average spawning stock biomass during the 1980s, as 1983–1989 was the last period over which reasonable recruitment occurred (DFO 2010a). Similar to the approach for Atlantic herring, we used the averaged total annual catch over the period 1983–1989 (209,177 t) to represent the rebuilt stock level in P2.

Pacific herring (Central Coast stock) — Rebuilt catch was set to an MSY of 9,104 t, as estimated by Martell et al. (2011).

Redfish (Units 1 & 2) —The rebuilt catch level is represented by the combined MSY for both redfish species. According to a professor of fisheries science at the University of British Columbia, MSY was estimated at 25,000 t and 34,000 t for *S. mentella* and *S. fasciatus*, respectively (M. McAllister, pers. comm.), providing a combined MSY of 59,000 t for both redfish species.

WCVI Chinook — TAC in P2 was based on catch levels corresponding to years with large returns of salmon, which occurred in the 1980s and early 1990s (DFO 2012a). Marine survival rates were also at high levels during the 1970s and 1980s, before declining to lows in the 1990s and 2000s (Riddell et al. 2013). As such, we used the averaged total annual catch from 1980–1992 (368,745 fish) to represent the "high returns" catch, as this period also showed good stock productivity (i.e., high marine survival) (Table 7).

Status quo catch

The status quo scenario assumes constant biological and management conditions, so catches were assumed to be constant for the entire time frame of the analysis. We used the averaged landings over the past five years to represent annual status quo catches. Landings data were based on DFO statistics. An exception was made for northern cod, for which status quo catch was set at 2016/2017 reported landings of 13,000 t (DFO 2018d).[5] This was chosen because the past five years' average of 7,146 t was considerably lower than the estimated P1 catch (9,500 t). Since it is unlikely that a conservation policy will set a catch level higher than the status quo, we found it reasonable to use 13,000 t to represent status quo catch instead. An important assumption about the status quo scenario is that the current catch level can be maintained into the future (i.e., the stocks are not experiencing overfishing).

Table 7. Catch levels (t) used for low fishing catch scenarios in Period 1, Period 2 (rebuilt catch), and status quo (SQ) scenario. Note that WCVI Chinook catch refers to the number of fish.

Fish stock	**Rebuilt catch (t)**	**Low fishing catch (t)**	**SQ catch (t)**	**Source for SQ catch**
Atlantic herring	8,603	500	2,185	McDermid et al. 2016
Northern cod	209,177	9,500	13,000	Brattey et al. 2018
Redfish	59,000	2,838	3,483	DFO Newfoundland and Labrador 2018
Pacific herring	9,104	500	509	Kronlund et al. 2018[1]
WCVI Chinook (no. of fish)	368,745	179,890	201,191	PSCCTC 2017b
Yelloweye rockfish	276	100	210	DFO 2018[2]

[1] DFO catch data are for roe herring and whole herring fisheries only, and do not include removals associated with spawn on kelp fisheries.
[2] Yelloweye rockfish landings data provided via DFO data request.

[5] Note this differs from the 15,054 t used in selecting P1 catch, which was a model-derived estimate, whereas 13,000 t is reported landings from Area 2J3KL.

2. Economic analysis

Net present value

In this study, the economic benefits from rebuilding are represented by the change in net present value (NPV) generated by the capture fisheries sector under the six rebuilding scenarios compared to the NPV under the status quo scenario. The approach for calculating NPV is detailed in Appendix C. Economic analysis method. NPV for each scenario is equivalent to the discounted flow of costs and benefits to the commercial and recreational fisheries sectors over the 100-year analysis time frame. In the case of yelloweye rockfish, which is a “choke” species, the costs associated with lost opportunities to pursue other Pacific groundfish in the Pacific mixed groundfish fishery are incorporated (Appendix C. Economic analysis method). This is because a reduction in yelloweye rockfish fishing quotas will prevent fishing on other groundfish species. We estimate NPV using conventional as well as an intergenerational discounting approach. Intergenerational discounting seeks to explicitly incorporate the interests of future generations in the NPV analysis (Sumaila and Walters 2005). For both approaches, a discount rate of 8 per cent, which is the recommended rate by the Treasury Board of Canada Secretariat (2007), is used. Table 8 summarizes the economic parameters used to calculate NPV for each fishery.

Table 8. Summary of economic parameters used to calculate NPV for each fish stock

Fishery[1]	Ex-vessel price ($/t)	Price year	Fishing cost (% of landed value)
Atlantic herring	450.26	2016	70
Northern cod	1,409	2017/2018	66
Pacific herring	692	2015	96
Redfish	1,739	2017/2018	64
WCVI Chinook ($/piece)	60.83	2015	78
Yelloweye rockfish	1,592	2015	87

[1] Sources for ex-vessel prices:
Pacific herring price is the weighted average of spawn on kelp, food and bait, and roe herring. Source: BC Ministry of Agriculture (2015)
Yelloweye rockfish and WCVI Chinook — DFO Pacific online statistics: http://www.pac.dfo-mpo.gc.ca/stats/comm/summ-somm/annsumm-sommann/2015/ANNUAL15_USER_three_party_groups-eng.htm
Atlantic herring — DFO Maritimes online statistics: http://www.dfo-mpo.gc.ca/stats/commercial/sea-maritimes-eng.htm
Northern cod and redfish — DFO Newfoundland online statistics: http://www.nfl.dfo-mpo.gc.ca/NL/Landings-Values

Economic impact

Economic multipliers reflect the impact that a change in fisheries output, as measured by fisheries landed value, will have on fisheries-related economic activities through secondary and tertiary activities (Dyck and Sumaila 2010). Note that economic multipliers do not capture intangible benefits (e.g., ecosystem services and cultural value). We estimate the economic impact associated with fisheries rebuilding as follows:

Economic output (E) is calculated as E = PV(LV_{sy}) x economic multiplier

Where PV(LV_{sy}) is the present value of the summed landed value for species *y* over T years = $\sum_{t=0}^{T} \frac{LV_y}{(1+r)^t}$

Note that economic impact is based on the value of fisheries production (landed value), without accounting for fishing costs. Economic multipliers for the Pacific and Atlantic regions were taken from two main sources:

Pacific — In a study of the economic impact of Pacific salmon fisheries, Gislason et al. (2017) developed multipliers for direct and indirect impacts, based on Statistics Canada input-output models and expenditure information from fishing industry income statements. Based on these multipliers, Gislason et al. (2017) estimated the economic output generated from commercial salmon fisheries in B.C. for the years 2012–2015. We averaged the multipliers across these four years (which equals 1.54) to use as the economic multiplier in this study. The simple multiplier for direct and indirect effects provided by Statistics Canada for the fishing, hunting and trapping industry was 1.48 in 2010. We chose to follow Gislason et al.'s (2017) multiplier since it was developed specifically for the fishing industry. As there was no comparable analysis available for herring or rockfish, we applied the same multiplier to all three fisheries, while acknowledging that the economic impact of each fishery is likely not identical due to the different value chains and consumers involved in each fishery.

Atlantic — We obtained provincial economic multipliers for direct and indirect effects on output for the fishing, hunting and trapping industry in 2010 from Statistics Canada (Table 9). The average of the five Atlantic provinces' multipliers was used to estimate total economic output supported by redfish and Atlantic herring, while the Newfoundland and Labrador multiplier was used for northern cod fisheries production.

Table 9. Provincial economic multipliers on output in the fishing, hunting and trapping industry in 2010

Province	**Direct & indirect**
New Brunswick	1.25
Newfoundland and Labrador	1.28
Nova Scotia	1.27
Prince Edward Island	1.20
Quebec	1.40
Average	*1.28*

Source: Statistics Canada Provincial Input-Output Multipliers, 2010, Catalogue no. 15F0046XDB.

3. Sensitivity analysis

Biological parameters

Generation time — We conducted a sensitivity analysis on species' generation time using values from FishBase (see Table 6 and Appendix B. Selection of species generation time).

Rebuilt catch in Period 2 — We reduced the level of P2 catch by 50 per cent to investigate the outcome of fish stocks being unable to recover and reach their anticipated level of productivity.

Economic parameters

We tested the sensitivity of NPV to two economic parameters: ex-vessel fish price and cost of fishing. A recent temporal analysis of global fish ex-vessel prices from 1950–2010 indicated that prices have generally increased over time (Tai et al. 2017). Over this period, prices of fish used for direct human consumption increased by around 54 per cent. It was therefore reasonable to assume that ex-vessel prices would tend to increase by the end of the analysis time frame. For each fish stock, we tested the effect of a 50 per cent, 75 per cent, and 100 per cent increase in ex-vessel prices by year 100, assuming that prices increased linearly through time.

We did not find a clear temporal trend in the cost of fishing. While improved management led to reduced operating costs in some Pacific coast fisheries (Jones 2003), increases in fuel and quota leasing costs has driven up the cost of fishing in other fisheries, both in Canada and internationally (Jones et al. 2015; Pinkerton et al. 2016). Current fishing costs are already very high for all case study fisheries (Table 8), with the lowest cost being 64 per cent of landed value. We therefore capped fishing cost increase at 50 per cent and tested the effect of a –25 per cent, 25 per cent and 50 per cent change in fishing costs by year 100, assuming costs changed linearly through time.

4. Social implications of fisheries rebuilding

We reviewed the literature (both published and grey) to compile information on the potential social impacts of fisheries rebuilding. Information collected covered the number of fishers, fish consumption and nutrition, coastal population trends, and others. These information sources formed the basis for a descriptive analysis of three main social impacts: 1) number of fishers participating in fisheries for the six stocks; 2) the number of indirect participants — fish processing workers and coastal communities — dependent on the fish stocks; and 3) access and allocation. A detailed methodology for each of these components are provided in Appendix E. .

ECONOMIC ANALYSIS RESULTS

NPV gains/loss relative to the status quo

The results reported in this section pertain to NPV generated using an 8 per cent discount rate, unless noted otherwise. Our analysis indicates that fisheries for all case study species except yelloweye rockfish may experience some economic gains from rebuilding, relative to the status quo (Table 10). In the short term (30 years), slow biological response scenarios (SC and SL) resulted in projected NPV losses for all assessed fish stocks except for Pacific herring. Projected losses eventually turned to gains by the end of the analysis time frame under the SL scenario (slow recovery + low fishing) but still resulted in NPV loss for redfish and WCVI Chinook under the SC scenario (slow recovery + closure).

Table 10. Projected gains/losses in NPV relative to the status quo scenario over the 100-year analysis time frame. "+" indicates gains and "–" indicates losses — (i.e., + indicates NPV is 0 to 1 times higher relative to SQ, ++ is 1 to 3 times higher, +++ is 3 to 5 times higher, ++++ is more than 5 times higher, and – is <0).

	Scenario					
	FC	**FL**	**EC**	**EL**	**SC**	**SL**
Atlantic herring	++	++	+	+	+	+
Atlantic redfish	+++	+++	+	+	–	+
Northern cod	++++	++++	+++	++	++	+
Pacific herring	++++	++++	++++	++++	++++	+++
WCVI Chinook	+	+	–	+	–	+
Yelloweye rockfish	–	–	–	–	–	–

Fisheries for Central Coast Pacific herring were estimated to benefit the most from rebuilding, showing NPV gains across all scenarios and time periods (Figure 2d). These projected gains were the highest among all stocks, exceeding the status quo by a factor of five for all scenarios except scenario SL (Figure 2d; Table A2, Table A3 Table A4). Atlantic herring saw NPV gains across all scenarios over the 50- and 100-year time periods (Figure 2a). Rebuilding resulted in estimated NPV losses for both Atlantic redfish and WCVI Chinook under the slow recovery + closure scenario (SC), with WCVI Chinook also showing a loss under the EC scenario (expected recovery + closure). Redfish NPV loss turned to gains between 30–50 years for expected recovery scenarios (EC and EL), but NPV was still negative relative to SQ under the SC scenario and just barely positive at 100 years under the SL scenario (Figures 2b).

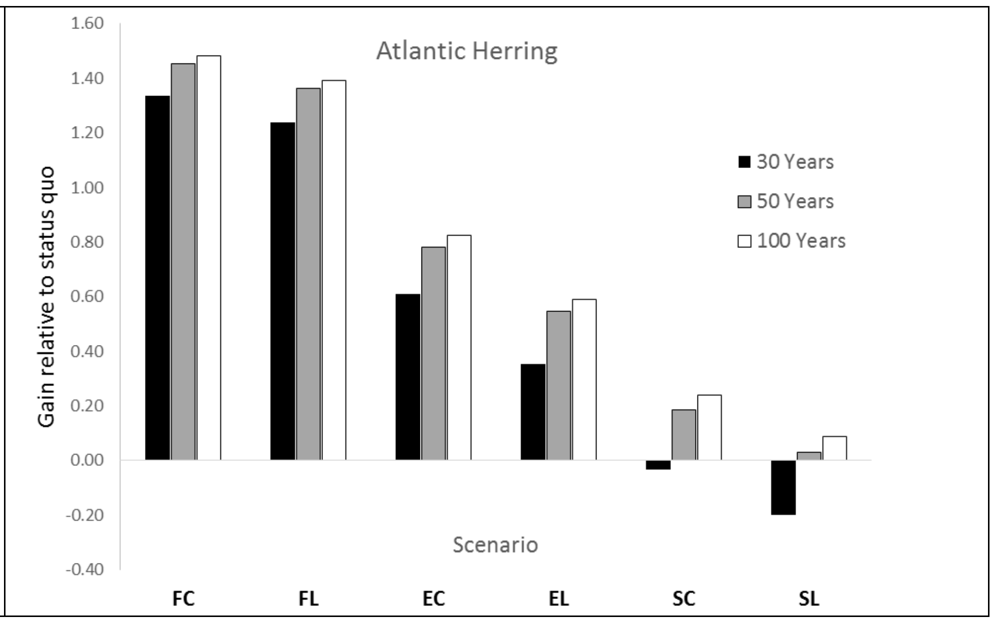
The yelloweye rockfish fishery does not appear to obtain economic benefits from rebuilding because of the species' long generation time and also because its role as a "choke" species means that a reduction in yelloweye rockfish fishing quotas will create a substantial economic impact on other groundfish species. If the cost of other groundfish fisheries were not accounted for, rebuilding would still result in

NPV loss across all scenarios but at much smaller magnitudes, ranging from a factor of 0.6 to 1, relative to the status quo (Table A2, Table A3,Table A4). Applying intergenerational discounting resulted in minimal improvement in NPV for yelloweye rockfish.

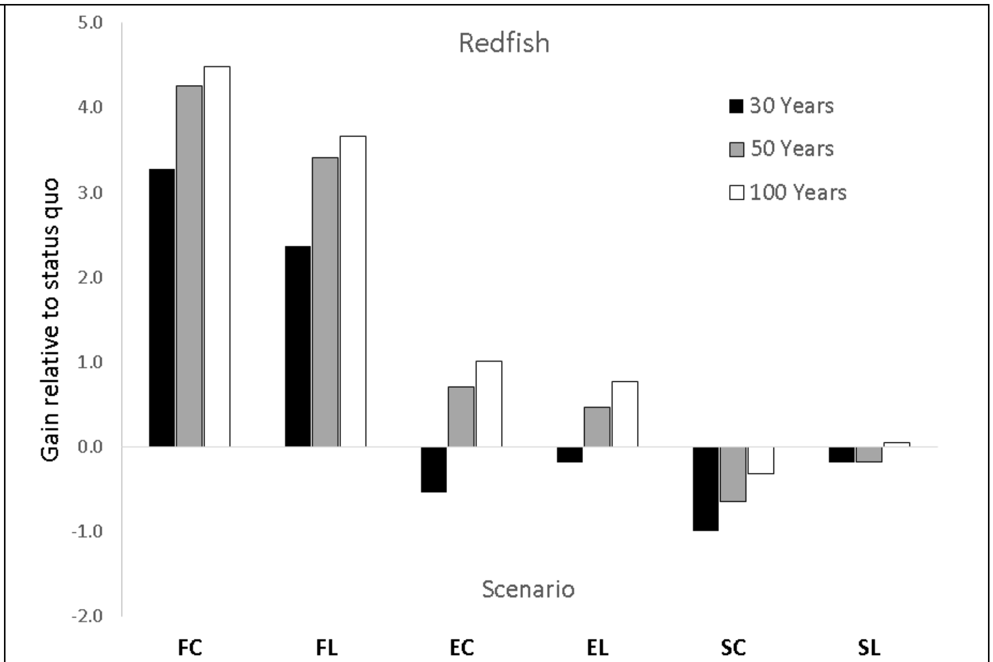
Across all stocks, the highest NPV gains occurred under the fast-biological response scenarios (FC and FL), while the largest NPV losses, which were experienced by redfish and WCVI Chinook, occurred under scenario SC (slow recovery + closure). Both scenarios involving slow recovery (SC and SL) resulted in the greatest number of stocks experiencing NPV losses. The highest gains were obtained by Pacific herring, for which estimated NPV exceeded the status quo NPV by a factor of five for all scenarios except scenario SL (Figures 2d; Table A2, Table A3, Table A4).

In most cases, a more conservation-oriented management strategy (the FC, EC, and SC scenarios) resulted in higher potential economic gains at 100 years when compared to a strategy allowing low levels of fishing. This was consistent across all scenarios of biological recovery. The exceptions were WCVI Chinook under expected and slow recovery and redfish under slow recovery, for which long-term NPV gains were projected under a low fishing strategy, whereas fishery closure resulted in NPV loss (Table A4). For redfish, this outcome was driven by its relatively long generation time of 18 years, which resulted in a long closure period of 41 years under a slow recovery + closure scenario. Consequently, even though the rebuilt catch was over 20 times higher than the low fishing catch (Table 7), it was not high enough to compensate for the long closure period. The closure period for WCVI Chinook was not as long (eight and 11 years under expected and slow recovery, respectively). Instead, the lower NPV projected under the closure scenarios was likely driven by its relatively low rebuilt catch level, which was only around twice as high as the low fishing catch and was the lowest among all case study stocks (Table 7).

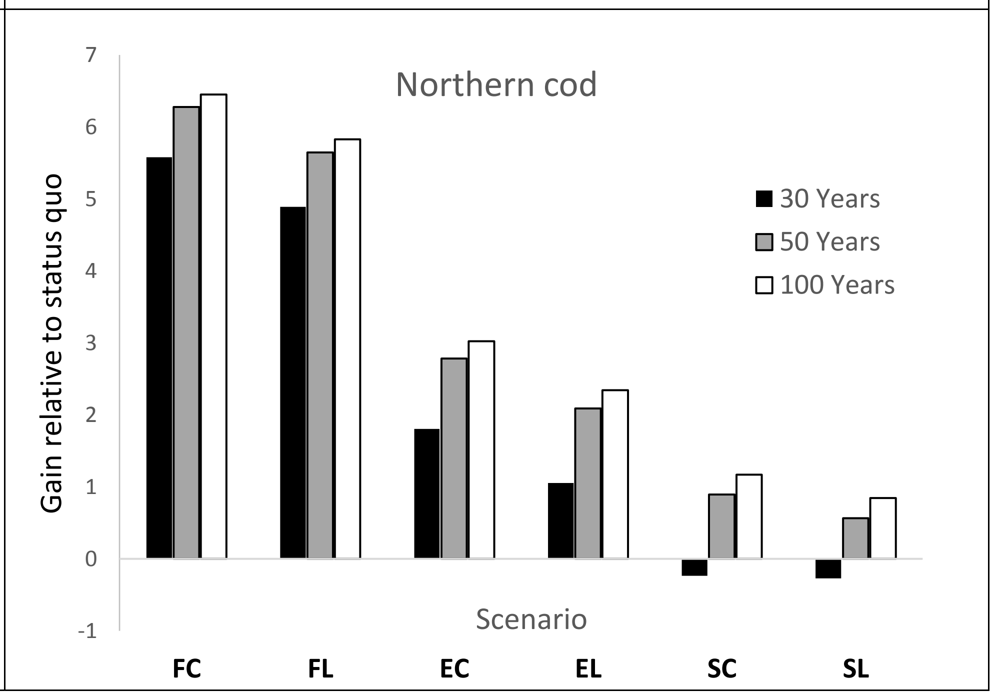
a)



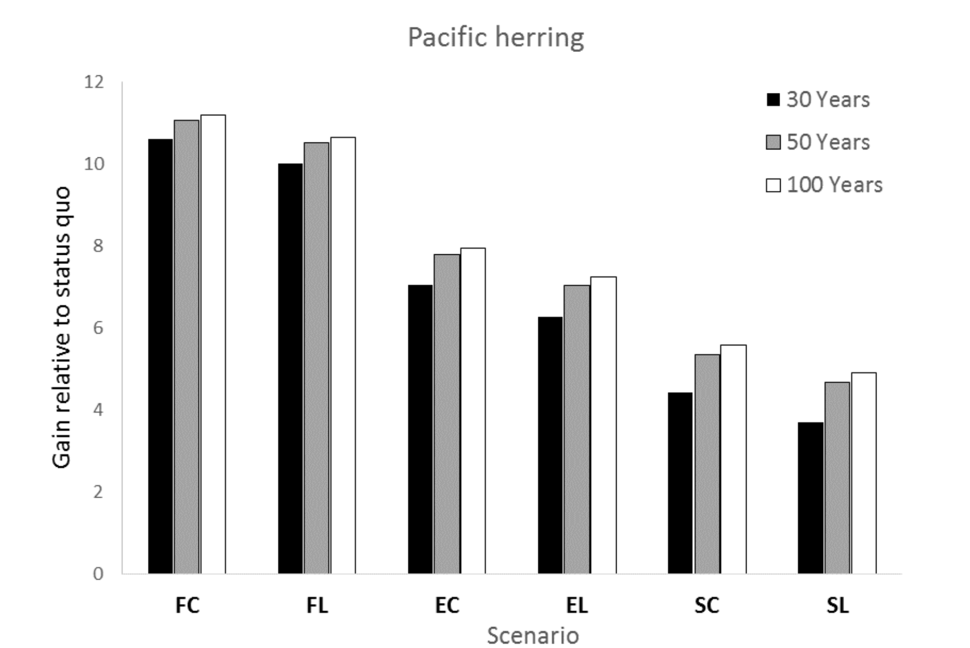
b)


Redfish
30 Years
50 Years
100 Years
Gain relative to status quo
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
Scenario
FC
FL
EC
EL
SC
SL

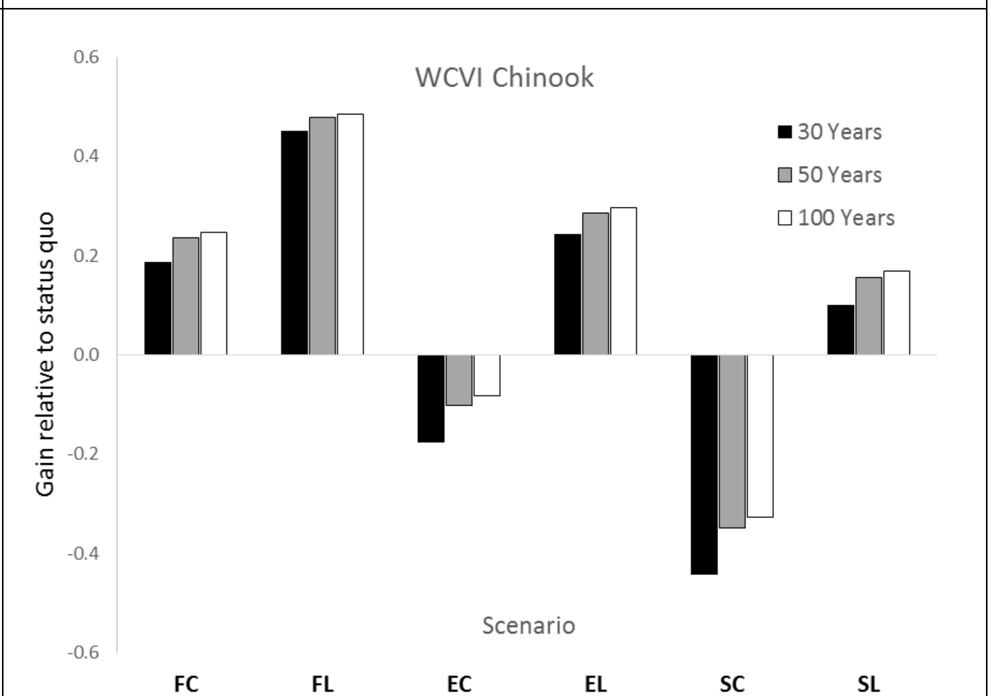
c)


Northern cod
30 Years
50 Years
100 Years
Gain relative to status quo
7
6
5
4
3
2
1
0
-1
Scenario
FC
FL
EC
EL
SC
SL

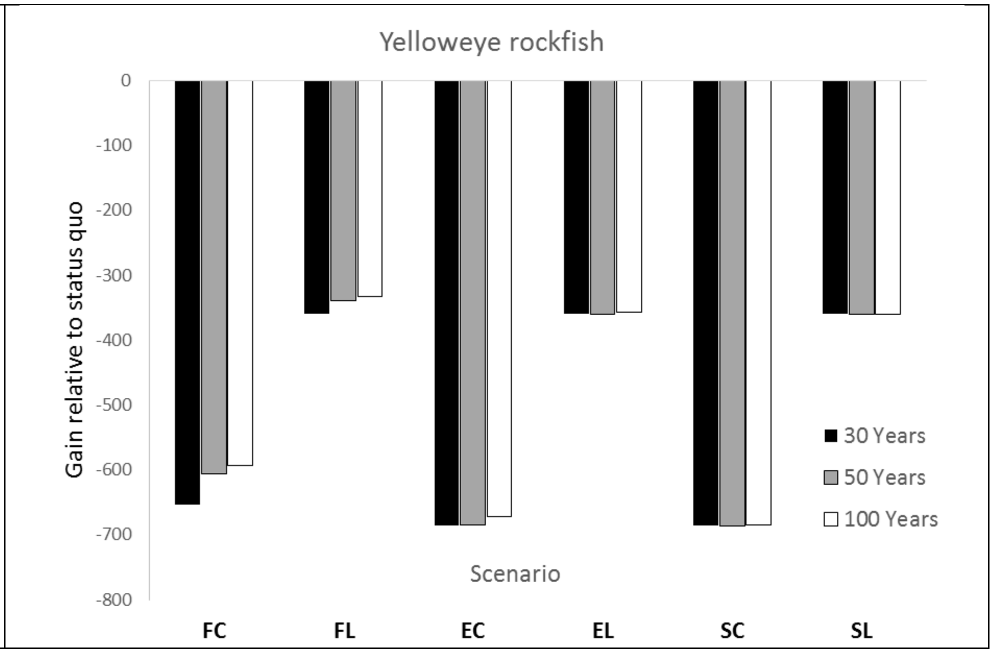
d)


Pacific herring
12
10
8
6
4
2
0
Gain relative to status quo
30 Years
50 Years
100 Years
FC
FL
EC
EL
SC
SL
Scenario

e)


WCVI Chinook
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
Gain relative to status quo
30 Years
50 Years
100 Years
Scenario
FC
FL
EC
EL
SC
SL

f)



Figures 2a–f. Proportional gain/loss in NPV relative to the status quo under each scenario at different time periods: 30 years (black bar), 50 years (grey bar), and 100 years (white bar). Y-axis values represent a proportional gain versus the status quo if >0 and loss if <0; e.g., 0.5 means 1.5 times higher than the status quo, –0.5 means 1.5 times less than the status quo.

Effect of intergenerational discounting

Compared to conventional discounting, intergenerational discounting gives more weight to benefits that occur further into the future. Consequently, using intergenerational discounting instead of conventional discounting resulted in higher NPV over the long term (Figures A7-A12). Importantly, applying intergenerational discounting resulted in potential economic gains for redfish and WCVI Chinook across all scenarios by the end of the 100-year time frame. In contrast, using conventional discounting resulted in potential economic losses for redfish under the SC scenario and for WCVI Chinook under the EC and SC scenarios (Figure A9 Figure A11). Intergenerational discounting had the largest effect under the EC and SC scenarios, both of which involved fishing closure in the initial rebuilding period (P1). Across fish stocks, intergenerational discounting under scenarios EC and SC resulted in NPV gains that were on average around 100 per cent higher than those achieved using conventional discounting at eight per cent (Table A5). In terms of fish stocks, intergenerational discounting made the biggest difference in NPV for redfish under the SL scenario and for Atlantic herring under the SC scenario (Figure A11 and Figure A12).

Economic impact

At the present time, estimated economic output supported by the fish stocks in this study range from $0.54 million for Pacific herring to $57.5 million for WCVI Chinook (Table 11). In the year at which each fish stock is rebuilt (i.e., P2), the present value of estimated economic output is expected to increase relative to the status quo across all scenarios for northern cod and Pacific herring. For Atlantic herring, it is expected to increase for all scenarios except the SL scenario. For redfish, it is expected to increase for all scenarios except SC and SL.[6] This suggests that, compared to the status quo, rebuilt stocks of northern cod, Pacific herring, Atlantic herring, and redfish can, in most cases, generate higher fisheries output (i.e., landed value), which then causes increases in related economic activities. The main point of this result is that it shows the magnifying effect fisheries rebuilding can have throughout the economies of Pacific and Atlantic Canada.

[6] Note that this assumes fisheries-related economic activities can start up as soon as the fish stocks are rebuilt.

In contrast, economic output from rebuilt WCVI Chinook is estimated to be higher than the status quo only under the FL scenario, while the economic output from a rebuilt yelloweye rockfish stock is estimated to be less than the status quo amount under all scenarios. This is likely due to the low-rebuilt-versus-status-quo catch levels for both these stocks compared to the other four stocks (Table 7). The results imply that, in general, the amount of fisheries output from rebuilt WCVI Chinook and yelloweye rockfish is not sufficient to generate the level of economic activity needed to compensate for the reduction in economic output during the rebuilding period. Not surprisingly, across all fish stocks, the slow recovery + low fishing (SL) scenario results in the lowest average amount of economic output generated at the year of stock recovery, while the fast recovery + low fishing (FL) scenario results in the highest (Table 11).

Table 11. Estimated present value of economic output ($ millions) supported by fishery production in the year that each fish stock is rebuilt (P2). Figures in parentheses indicate economic output that is lower than the status quo (SQ) amount.

Fish stock	**Scenario**						
	SQ	**FC**	**FL**	**EC**	**EL**	**SC**	**SL**
Atlantic herring	1.26	3.12	2.89	2.30	1.82	1.56	(1.15)
Northern cod	36.58	272.60	233.71	147.28	100.23	79.57	42.99
Pacific herring	0.54	6.61	6.12	4.86	4.16	3.57	2.83
Redfish	7.75	42.58	31.30	15.66	7.83	5.33	(1.96)
WCVI Chinook	57.5	(46.58)	66.42	(52.72)	(45.20)	(38.75)	(30.76)
Yelloweye rockfish	0.89	(0.17)	(0.09)	(0.02)	(0.01)	(0.00)	(0.00)

If we wait until the end of the analysis period (100 years), the economic impact of rebuilding improves. However, our results suggest that rebuilding WCVI Chinook under the EC and SC scenarios and rebuilding redfish under the SC scenario still may not provide economy-wide benefits above the status quo (Table A6. Difference between present value of total economic output at 100 years and the status quo ($ millions) As mentioned previously, this situation is likely driven by the comparatively low rebuilt catch level for WCVI Chinook and the long generation time for redfish. These factors result in fisheries output that does not appear to be high enough to offset the reduction in fishing and associated economic activity (e.g., fish processing) that occurs during the rebuilding period. This finding cautions that under some circumstances, decisions made solely on the basis of increasing economy-wide productivity may dismiss rebuilding in favour of staying with the status quo.

Sensitivity analysis

Generation time

Applying species' generation time obtained from FishBase did not affect the overall outcome of NPV gains/losses. Redfish appeared to be the most sensitive to generation time (Table 12), due to the substantially lower generation times obtained for *S. mentella* and *S. fasciatus* from FishBase (9.1 and 4.3 years, respectively). Similar to price and cost sensitivity analyses, all fish stocks except WCVI Chinook showed the highest deviation from the base case under slow recovery scenarios and the lowest deviation from the base case under fast recovery scenarios. Base case refers to NPV gain/loss at 100 years at an eight per cent discount rate.

Table 12. Percentage difference in NPV gain/loss between base case[1] and sensitivity analysis test of species' generation times. Change in G (generation time) indicates the difference in years between base case and FishBase generation times. Direction of change is negative (i.e., the base case NPV is lower than the NPV from the sensitivity test) except for cases indicated in bold.

	Scenario

Species	Change in G	FC	FL	EC	EL	SC	SL
Redfish	11	98	133	465	534	**1218**	5573
Atlantic herring	2	28	26	58	83	243	704
Northern cod	2	19	17	48	40	87	95
Pacific herring	3	18	26	53	59	84	100
WCVI Chinook	1	40	10	**183**	23	**54**	42
Yelloweye rockfish	16	**17**	**4**	**4**	**4**	**17**	**4**

[1] Base case refers to NPV gain/loss at 100 years, 8% discount rate.

Price

The range in percentage difference in NPV gains/loss between the base case and sensitivity analysis cases is summarized in Table 13. The effect of price varied depending on species' biological response. With the exception of WCVI Chinook, all stocks showed highest sensitivity to the slow response scenarios (SC and SL) and lowest sensitivity to the fast response scenarios (FC and FL). Redfish showed the highest sensitivity among all scenarios, while Pacific herring was the least sensitive (Table 13 and Table A7,Table A8, Table A9). This pattern was consistent for all ranges of price increase.

At the end of the 100-year analysis time frame, NPV losses were projected for redfish under the SC scenario and for WCVI Chinook under the EC and SC scenarios. Sensitivity analysis showed that redfish NPV loss could potentially turn positive if price increased at least 2.34 times by the end of the analysis period. For WCVI Chinook, a price increase of 2.25 times could potentially turn NPV losses to gains under the EC scenario. However, a much higher increase of up to 6.3 times would be required to turn projected NPV losses to gains under the SC scenario.

Table 13. Range of difference (%) in NPV gain/loss between base case[1] and sensitivity analysis test of 50%, 75%, and 100% price increase

	+50%	+75%	+100%
Atlantic herring	5–88	7–129	9–167
Northern cod	6–23	9–33	11–43
Pacific herring	3–17	4–20	5–23
Redfish	9–122	13–178	6–230
WCVI Chinook	3–47	5–68	7–88
Yelloweye rockfish	74–87	74–87	74–87

[1] Base case refers to NPV gain/loss at 100 years, 8% discount rate.

Cost

Net present value gains/losses were more sensitive to changes in cost compared to prices (Table 14). Overall, fish stocks were most sensitive to cost changes under the slow recovery scenarios (SC and SL), with Pacific herring showing the highest sensitivity to cost increases and redfish showing the highest sensitivity to cost decreases (Table A10,Table A11,Table A12). In contrast, the least variability occurred under scenarios of fast recovery (FC and FL), while only WCVI Chinook showed high sensitivity to an expected recovery scenario (EC). Across scenarios, Pacific herring was the most sensitive to cost changes due to its current fishing cost, which is already exceedingly high at 96 per cent of landed value. Northern cod exhibited the least sensitivity (Table 14); this is driven mainly by it having one of the lowest fishing costs (66 per cent), combined with a high rebuilt catch.

Table 14. Range of difference (%) in NPV gain/loss between base case[1] and sensitivity analysis test of –25%, +25%, and +50% change in cost

	–25%	+25%	+50%
Redfish	8–111	9–125	19–265
Atlantic herring	5–100	6–116	14–252
Northern cod	6–22	3–25	3–53
Pacific herring	19–62	134–394	129–381
WCVI Chinook	6–79	7–99	17–227
Yelloweye rockfish[2]	100	100	100

[1] Base case refers to NPV gain/loss at 100 years, 8% discount rate.
[2] Difference was the same across all scenarios.

As with price sensitivity, we tested the change in cost required to turn projected NPV losses for redfish and WCVI Chinook into gains. For redfish, a cost decrease of at least 74 per cent could potentially result in an NPV gain under the SC scenario. Under the EC scenario, a cost decrease of 35 per cent could potentially turn an NPV loss to a gain for WCVI Chinook. However, even if the cost was zero, the projected NPV for the SC scenario did not perform better than the status quo.

Rebuilt catch

Reducing P2 catch by half resulted in projected NPV gains (at 100 years) changing to losses for redfish under the EC and EL scenarios EC; for Atlantic herring under the EC, EL, SC, and SL scenarios; and for WCVI Chinook under the FC, FL, and EL scenarios (Table 15). WCVI Chinook and Atlantic herring were estimated to incur the largest losses, with NPV reduced by over 500 per cent for WCVI Chinook under the EC scenario and for Atlantic herring under the SL scenario. Pacific herring appeared to be the least affected, with no projected NPV gains turning to losses over the short and long term. While northern cod still retained all projected NPV gains at the end of the 100-year analysis period, gains under the SC and SL scenarios turned to losses in the short term (30 and 50 years). Reducing P2 catch made no difference to yelloweye rockfish due to its relatively low catch level (276 t) and high costs structure.

Table 15. Percentage difference in NPV between base case[1] and sensitivity analysis test (i.e., sensitivity analysis minus base case) with a 50% reduction in rebuilt catch in P2. Negative values indicate that sensitivity test results are lower than base case results. Figures in bold indicate cases in which NPV gains in base case scenarios turn to losses with the 50% reduction in P2 catch.

	Scenario					
Fish stock	**FC**	**FL**	**EC**	**EL**	**SC**	**SL**
Atlantic herring	–84	–82	**–111**	**–122**	**–258**	**–523**
Northern cod	–58	–55	–67	–58	–93	–69
Pacific herring	–54	–53	–56	–53	–59	–53
Redfish	–62	–55	**–102**	**–66**	98	–284
WCVI Chinook	**–252**	**–119**	549	**–132**	103	**–159**
Yelloweye rockfish[2]	0	0	0	0	0	0

[1] Base case refers to NPV gain/loss at 100 years, 8% discount rate.
[2] There is no difference because P2 catch for yelloweye rockfish is already very low (276 t), while cost is very large; therefore, halving the P2 catch essentially makes no difference.

SOCIAL IMPLICATIONS OF REBUILDING

Social impacts on fisheries participants during the rebuilding phase

For five of the six stocks, rebuilding is projected to bring overall economic benefits, even though it will entail short-term costs. This means that, with proper rebuilding strategies and management implemented, the current (status quo) situation can be improved upon. At the same time, fisheries rebuilding invariably involves a transition period in the near to medium term, during which fishing activity will need to be reduced or stopped, causing positive or negative consequent impacts on employment, income, and fish consumption. While this study assumes that First Nations food, social, and ceremonial fisheries will continue unchanged under rebuilding measures, First Nations fishers will likely also be affected through their participation in commercial fisheries and interaction with the fishing economy. These short-term costs need to be weighed against the fact that without rebuilding and effective fisheries management, we have seen significant losses over recent decades and could lose everything if fish stocks collapse. Recall the cost to fishers and society when the cod stocks off Newfoundland collapsed in 1992.

There is no definite estimate of how many people will be directly affected by fisheries rebuilding measures, as DFO does not keep track of the number of participants in a fishery. To gauge the likely magnitude of the impact (regardless of whether the impact is positive or negative), we estimated that the six fish stocks in this study currently involve around 5,130 fishers (Table 16). This represents around 12 per cent of the 44,342 harvesters employed in the Canadian fishing sector in 2016.[7] In addition, there may be around 800 First Nations participants in the Pacific herring spawn on kelp fishery (Appendix Ei. Estimating the number of recreational fishers and First Nations participants). Once rebuilt, healthier fish stocks may be able to support up to 12 times the current number of fishers (around 59,500 fishers) (Appendix Eii. Estimating the number of fishers catching rebuilt fish stocks, Table A13), if we assume that current fishing effort and fishing power does not change during the rebuilding period and that there are no barriers to new entrants entering the fishery at the year each stock is rebuilt. With this long-term benefit, however, comes one of the most pressing issues, which is how fishers can cope with the inevitable reduction in fishing during the rebuilding period.

Table 16. Estimated number of fishers in case study fisheries

Fishery	No. of active vessels or licences	Estimated no. of fishers
Gulf of St. Lawrence Atlantic herring[1]	500 to 700 gillnet vessels, 2 to 3 seiners	1,814
Redfish[2]	5 to 10 <65 ft boats in Unit 1, 15 offshore boats in Unit 2 in recent years	160
Northern cod[3]	1,526 active enterprises in 2017	1,639
Pacific herring[4,5]	419 licences	1,285
Yelloweye rockfish outside[4,6]	50 licences	125
Salmon troll[4,7]	58 licences	105
Total		**5,128**

[1] The inshore herring fleet has three crew members per vessel (DFO 2007). Assuming that each licence holder operates one boat, there are an estimated 1,800 participants based on an average of around 600 inshore herring vessels. A herring seiner usually has around five to six crew members; applying this to the two to three herring seine vessels results in approximately 14 participants for a total of approximately 1,814 fishers in the Atlantic herring (spring spawner) fishery.
[2] In recent years, there have only been five to 10 boats in the Unit 1 directed fishery. These boats are <65 ft and typically have five to six crew members. Assuming an average of eight boats with five crew members provides roughly 40 fishers in the Unit 1 fishery. Unit 2 is predominantly a large-boat fishery, with around 15 offshore boats. Redfish are mainly caught using otter trawls. Assuming eight crew members per boat results in approximately 120 fishers in the Unit 2 fishery. In total, this provides around 160 people in the redfish fishery.
[3] Around 1,300 of the 1,526 enterprises operate vessels <40 ft. We assume that each of these enterprises is an individual fish harvester. For the remaining 226 enterprises that operate vessels >40 ft, we assume one to two people per boat, resulting in 339 fishers. In

[7] Source: DFO (2018) Fisheries and the Canadian Economy – Employment, http://www.dfo-mpo.gc.ca/stats/cfs-spc/tab/cfs-spc-tab2-eng.htm. Note that the number of harvesters provided by DFO includes freshwater fish harvesters.

total, this provides approximately 1,300 + 339 = 1,639 participants in the northern cod fishery.
[4] The number of active vessels and number of persons working on each vessel were estimated from data provided in Nelson (2009; 2011) and Gislason (2011a). It should be noted that the number of fishers does not differentiate between crew members and captains.
[5] Pacific herring licences are inclusive of roe herring seine, roe herring gillnet, food and bait, and spawn on kelp. Data covers province-wide licences and not only Central Coast, and it does not include communal FJ licenses to First Nations.
[6] Licences are for all rockfish species and not only limited to those that fish for yelloweye rockfish.
[7] Licences are for all species of salmon and not limited to those that fish for Chinook only.

Fisheries rebuilding would occur against a backdrop in which commercial fishery participants have already been coping with declining returns and participation in fisheries. For instance, the number of active vessels (and, hence, presumably crew members) has been declining in B.C.'s groundfish fishery (DFO 2016c), from 304 in 2007 to 252 in 2015. The number of Pacific salmon troll participants has also declined through voluntary licence retirements. This trend may continue since recent reductions in exploitation rates for Chinook have been imposed through the Pacific Salmon Commission (PSCCTC 2017b). Further, herring roe fisheries have been hit with poor economic prospects since the decline of the Japanese roe market in the mid- to late 2000s, and the Central Coast herring roe fishery was closed in 2018.

The extent to which fisheries rebuilding will affect the short-term, long-term, and overall economic condition of commercial fishery participants depends on their current level of dependence on each fishery. Many participants in the Pacific herring, yelloweye rockfish, and Chinook fisheries also hold licences for other fisheries and may be able to diversify their income sources during the rebuilding period when restrictive fishing measures would be put in place. For example, the Pacific roe herring seine is essentially a diversification activity for the salmon seine fleet (Nelson 2009), and many herring seine operators also hold licences for Pacific salmon seine, halibut, sardine, and groundfish trawl (Nelson 2011). The majority of inshore Atlantic herring licence holders are primarily lobster fishers who fish for herring as supplemental fishing income (DFO 2007). Moreover, only around 13 per cent of active Atlantic groundfish harvesters relied on the fishery for 100 per cent of their income, and about one-third of them obtained less than 10 per cent of their earnings from groundfish (DFO 2013a). At the same time, however, dependence on northern cod in the 2J3KL area has increased in the past two years (Figure 3). Thus, restrictive fishing regulations for rebuilding the northern cod stock may likely have comparatively more short-term negative economic and livelihood effects on northern cod fishers.

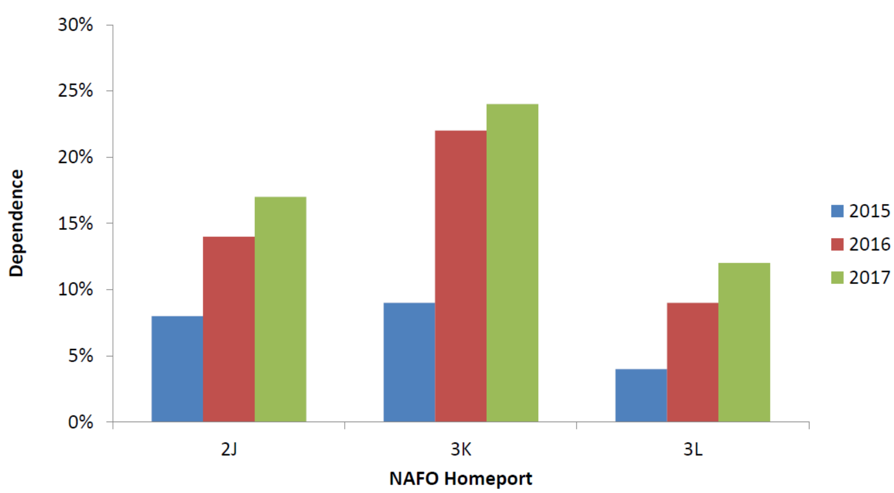


Figure 3. Percentage contribution of cod to total fishing income for active <40 ft enterprises according to NAFO home port, 2015–2017.[8]

Overall, although some of the case study fisheries serve as part of a diversified strategy, the temporary loss of these supplemental income sources is likely to decrease people's adaptive capacity and put them at increased exposure to environmental, economic, and/or social risks. Rather than diversifying into other fisheries, it may be worthwhile for fishers to diversify into other fishing-related occupations — for example, fisheries tourism (Lowitt 2011) — during the rebuilding period.

Another option for helping fishers transition out of the fishery during the rebuilding period is through carefully implemented vessel buybacks or licence retirement programs. Based on the number of current active vessels in the case study fisheries, we estimate that transition costs could potentially range from $6 million to $15 million for the Pacific case studies and up to approximately $47 million for the Atlantic case studies (Appendix Eiii. Estimating transition cost, Table A14). It is important to bear in mind that government-funded buybacks and fisher assistance programs are considered "ambiguous" subsidies (Sumaila et al. 2016), as their overall effect on reducing fishing overcapacity is inconclusive. These programs can also be extremely costly — the Canadian Fisheries Adjustment and Restructuring Plan for Pacific salmon cost $195 million in the late 1990s (DFO 2010b), while $3 billion was spent on northern cod adjustment programs from 1992–1998. Yet, the northern cod programs were not considered effective and instead served as a form of income maintenance for fishers (Schrank 2005). The magnitude of subsidization in Atlantic fisheries is already a concern (Schrank 2005). As such, the consequences of using buybacks and other capacity-reduction programs to achieve fisheries rebuilding objectives have to be carefully considered.

Besides direct fishery participants, fish processing workers will also likely be affected by rebuilding policies. For the Atlantic provinces, it was estimated that approximately 5,362 workers were employed in plants that process herring, redfish, or cod (Appendix Eiv. Estimating the number of Atlantic fish processing workers). In British Columbia, 1,473, 262, and 773 processing jobs (full time equivalents) were attributed to wild salmon, herring, and groundfish, respectively (BC Ministry of Agriculture 2011).[9] Note that the number of salmon and groundfish workers likely represents an upper limit given that it is not possible to partition out Chinook and rockfish from the broader salmon and groundfish categories. Nevertheless, the importance of fish processing jobs is magnified in small, rural coastal communities where there are limited alternative employment opportunities. For instance, the re-opening of the Heiltsuk fish processing plant in Bella Bella in 2012 was seen as key to revitalizing the region's marine fishing industry (Northern Development Initiative Trust 2012). According to a fisheries doctoral student at the University of British Columbia, the processing plant now employs around 50 Heiltsuk community members (S. Harper, pers comm). On the other hand, many processing jobs in Atlantic Canada are now being filled by foreign migrant workers (Marschke et al. 2018). Consequently, the extent of employment impact on local residents in both the short and long term may be lower than reflected here.

Recreational fishers are another user group who will be impacted in the short term by fisheries rebuilding. The northern cod recreational fishery is culturally significant as an important food fishery, while sport fishing is an important component of Chinook salmon fisheries and, to a lesser extent, yelloweye rockfish. Based on DFO recreational catch statistics for West Coast Vancouver Island and angler information from the Survey of Recreational Fishing in Canada (DFO 2012b), we estimated around 334 participants in the West Coast Vancouver Island Chinook recreational fishery and 8,770 participants in the yelloweye rockfish recreational fishery (Appendix Ei. Estimating the number of recreational fishers and First Nations participants). A survey of the recreational cod fishery in Newfoundland and Labrador estimated that 73,425 anglers participated in the 2007 season (BriLev Consulting 2008). Of these, 60,352 anglers were from areas corresponding to NAFO sub-division 2J3KL. As recreational fishing surveys from both Pacific and Atlantic coasts are several years old, they may not reflect current conditions. However, since

[8] Source: DFO Stewardship cod presentation. Presented at the 2018 2+3KLMNO Groundfish Advisory meeting, April 10, 2018.

[9] These jobs are reported from seafood processing operations that could attribute their processing activity by species and so does not represent the total number of processing jobs.

recreational fisheries have been growing (DFO 2016c), the numbers presented here can be considered a lower-end estimate. On the other hand, it was also found that participation in the northern cod recreational fishery was down 20 per cent in 2017.[10]

Besides active participants in fishing, coastal First Nations communities and those living in small, rural fishing communities will also be disproportionately impacted by fisheries rebuilding in the short term, relative to the general population. Fish stocks are an important source of nutrition (Appendix Ev. Health and nutritional impacts, Table A6), and we estimated that herring roe fisheries potentially provided food and nutrition for up to 36,853 First Nation members in British Columbia, while Chinook and rockfish were consumed by an estimated 21,187 and 23,562 First Nation members, respectively (for estimation details, see Appendix Ei. Estimating the number of recreational fishers and First Nations participants). On the Atlantic coast, Divovich et al. (2015) estimated that the proportion of people living in small fishing communities in 2010 in Newfoundland, New Brunswick, Prince Edward Island, and Nova Scotia was 48 per cent, 6.5 per cent, 20.8 per cent, and 9.3 per cent, respectively. Applying these percentages to the provinces' populations results in approximately 423,500 people who may currently depend to some extent on Atlantic fisheries — including redfish, Atlantic herring, and northern cod — to support their economic and social well-being (

Table 17). The much higher rebuilt catches (ranging from 1.3 to 18 times above status quo catches) imply increased opportunities for improving future food security and nutrition for communities along both Pacific and Atlantic coasts, although the quantity of fish available per capita may not increase proportionally due to population growth.

Table 17. Estimated number of people in Atlantic provinces who live in small rural fishing communities

Province	**Population (2017)[1]**	**% population living in small rural fishing communities[2]**	**Number of people living in small rural fishing communities**
Newfoundland	528,817	48	253,832
New Brunswick	759,655	6.5	49,378
P.E.I.	152,021	20.8	31,620
Nova Scotia	953,869	9.3	88,710
Total			**423,540**

[1] Source: Statistics Canada – Annual estimates of population for Canada, provinces and territories.
[2] Source: Divovich et al. (2015)

Aside from economic impacts, rebuilding may also affect communities because of the important social and cultural roles of fisheries (e.g., O'Donnell et al. 2013). These include:

- Cultural values — supporting community ceremonies, activities, and cultural resilience
- Preservation and transfer of traditional knowledge and teachings
- Building and maintaining social capital and community cohesion within and between communities
- Providing a sense of personal identity

Once again, as we consider the estimated losses discussed above, it is important not to lose sight of what we have already lost as a result of ineffective management and overfishing of economically and culturally significant species such as salmon, eulachon, and Atlantic cod (Price et al. 2008; Schrank and Roy 2013; McKinnon 2015), and what we can lose if there is no rebuilding and more fish stocks eventually collapse.

Access and allocation

[10] Source: CBC News Online https://www.cbc.ca/news/canada/newfoundland-labrador/food-fishery-numbers-down-2017-1.4372962

Management measures to rebuild fish populations may change current fisheries' allocations and opportunities to access fisheries resources. Changes to the amount of allowable catch through input or output controls may change the allocation of catch among user groups. For instance, changes to licence leasing or quota fees can affect who can afford to enter the fishery. This can have a particularly significant effect, either positive or negative, on the well-being of coastal and First Nations communities, who are disproportionately reliant on marine resources. The largest projected economic gains are obtained under scenarios with fishery closures, and this will likely bring up issues of access to marine resources. Potential conflicts may be addressed by looking at past public consultation processes, such as those used in establishing Rockfish Conservation Areas in British Columbia for yelloweye rockfish (Lancaster et al. 2015; Haggarty et al. 2016).

Among all case studies, Pacific herring was estimated to obtain the largest potential economic gain across all rebuilding scenarios. While this is positive for all herring fishery stakeholders, it is disproportionately beneficial for B.C. coastal First Nations, for whom herring is a socially and culturally significant species (Gauvreau et al. 2017). This again brings access and allocation issues to the forefront. As illustrated by recent disputes over access to herring resources and First Nations' overall low representation in commercial fisheries (Appendix
vi. Aboriginal fishing licences in British ColumbiaTable A9), ensuring equitable access to and allocation of projected economic gains from rebuilt fish stocks are key points that need to be addressed in rebuilding plans. Another example that may magnify access and allocation issues is WCVI Chinook. Intersectoral tension between recreational fishers and First Nations fishers has occurred in the recent past (Hume 2016). As WCVI Chinook is jointly managed with the United States through the Pacific Salmon Treaty, its rebuilding raises transboundary allocation issues as well.

Distribution of fisheries benefits is also an ongoing issue for Atlantic fisheries, where gear and intersectoral conflicts (inshore versus large-scale operations) in the Atlantic herring fishery have been ongoing (FRCC 2009). In addition, a majority of licences in the individual transferable quota herring seine fishery in New Brunswick are controlled by three processing companies, bringing up concerns about access and distribution of economic benefits (Knott and Neis 2017). Given that the Atlantic herring fishery has the highest estimated number of participants and is projected to gain in the long term under all scenarios, sorting out distribution and allocation issues will be a particularly important part of the rebuilding process.

Access and allocation issues will be especially pertinent to the redfish fishery because of the anticipated expansion of the fishery in forthcoming years. The Unit 1 redfish fishery has been under moratorium since 1995 and hence has no updated TAC allocation plan. Thus, ensuring fair and equitable allocation among different fishing groups will be a key issue for fishery managers. In particular, First Nations groups currently get less than one per cent of the redfish TAC allocation. This is likely to be a focus of negotiations, especially given recent developments with the Nuu-chah-nulth First Nations in British Columbia, in which the B.C. Supreme Court found that DFO had wrongly obstructed the fishing rights of the Nuu-chah-nulth First Nations. The Supreme Court decision effectively put Indigenous fishing rights above those of sport fishing but below conservation, which remains the first priority. Participants in other fisheries also have an interest in gaining access and allocation to redfish. For example, the redfish fishery may be a potentially important alternative fishery for shrimp fishers, who have had to deal with a declining shrimp fishery.

While it is beyond the scope of this report to speculate on how the estimated economic gains from rebuilding will be allocated among different user groups in the future, the prevailing situation is one that is still not satisfactory in terms of equitable allocation and access to marine resources. In this regard, rebuilding fisheries offers an opportunity for redesigning fisheries policies such that they can lead to more equitable distribution and allocation of the modelled economic benefits among all fishery stakeholders, once fish populations recover.

Case Study: Australia West Coast Demersal Scalefish Resource — addressing intersectoral allocations in the rebuilding process

The Australian West Coast Demersal Scalefish Resource (WCDSR) is a multi-species resource with more than 100 species. The WCDSR involves multiple commercial and recreational fisheries, with the most important species being West Australian dhufish and snapper. Prior to 2008, the WCDSR was an open-access fishery, but since then, it has been an effort-controlled fishery based on individual transferable effort (ITE) units. While the WCDSR was fished for many decades, large increases in commercial and recreational catches occurred in the 1990s. An assessment of indicator species in 2007 concluded that fishing mortality rates were too high and that overfishing was occurring across the multispecies assemblage. This led to control rules that required a 50 per cent reduction in annual effort and catch for the entire resource by all sectors. The rebuilding process involved commercial and recreational fishery management changes, summarized below.

Commercial management changes: An ITE system was implemented to change the commercial fishery from an open-access fishery to a limited-entry fishery. The ITE reduced access from a potential 1,250 licensed fishing boats to 61 permits. It also prevented fishers from other fisheries from catching demersal species. The decision on whether a fisher received a permit depended on them being able to demonstrate a minimum level of historical catch of demersal species. Those remaining in the fishery had to adhere to additional regulations, such as maximum number of allowable fishing hours, gear restrictions, and area closures.

Recreational management changes: A series of management measures was implemented, including: i) the implementation of a communications and education plan to convey to recreational fishers that there was a sustainability problem; ii) a reduction in the allowable number of demersal fish caught and retained; iii) an increase in minimum legal length for retained snapper; iv) the implementation of an annual two-month closure throughout the fishery; and v) a state-wide cap on the number of charter boat licences and a requirement that all those fishing from a powered boat hold a recreational fishing-from-boat licence.

A key part of gaining recreational fishers' support for the reform package was setting explicit sectoral catch allocations, which were determined through the establishment of an Integrated Fisheries Allocation Advisory Committee. This Committee made recommendations to the Minister of Fisheries on how the resource should be allocated. The allocation was based on historical catch levels of the demersal resource by commercial and recreational fishers. It resulted in a 64 per cent and 36 per cent allocation of the resource to the commercial and recreational sectors, respectively.

By 2010, the rebuilding measures resulted in the annual commercial catch of the demersal resource meeting the management objective of reducing catch by at least 50 per cent of the 2005/2006 level (from 950 t to less than 450 t). In 2011, the fishing mortality rate for two important demersal species (dhufish and snapper) had decreased from the previous assessment period of 2007/2008. Although this was still above the limit reference point, the spawning potential ratio was at or below the limit, indicating that, if maintained, the current level of exploitation should allow the stock to recover from overfishing. The key lessons that emerged from this rebuilding process were that, first, the long duration required for the recovery of demersal species required maintaining stakeholder engagement programs to avoid a push for premature relaxation of regulations before the end of the rebuilding process. Second, it required gaining support from all sides of politics, as the recovery extended over multiple governments and fisheries ministers.

Source: Fletcher et al. (2018).

DISCUSSION

The objective of this study was to assess the economic outcomes of rebuilding six Canadian fish stocks under different assumptions about management and biological conditions. In the long term, our results indicated that rebuilding can generate potential economic gains for five of the six assessed fish stocks.

Rebuilding may generate positive net benefits for Atlantic herring, northern cod, and Pacific herring across all modelled scenarios. Redfish will potentially benefit under scenarios of fast and expected recovery, while WCVI Chinook can potentially benefit under three scenarios: two scenarios of fast recovery and under the expected recovery + low fishing scenario. In contrast, rebuilding yelloweye rockfish does not appear to result in net economic benefits under any of the scenarios. Given recent positive growth trends for redfish and northern cod stocks, the benefits generated under expected and fast recovery scenarios may be particularly relevant to these two stocks. On the other hand, Pacific herring and yelloweye rockfish continue to be in depressed states, making the slow recovery scenarios (SC and SL) more applicable to these two stocks.

The contribution of these case studies is that they provide insights into what factors may likely affect projected economic benefits and the challenges that may be encountered in the rebuilding process. These issues, discussed below, provide valuable “lessons learned” that can inform the development of forthcoming rebuilding plans such that rebuilding can lead to stock recovery, economic gains, and social benefits for Canadian fisheries and coastal communities.

1. Biological and management effects

Among all case studies, yelloweye rockfish stands out for its long generation time and its role as a “choke” species in a multispecies fishery (i.e., a low-quota species that cuts off access to other species once its catch quota is filled). The overall negative NPV estimated for rebuilding yelloweye rockfish is mainly driven by its cost structure, which includes the cost of other groundfish fleets not being able to fish during the rebuilding period. While we were able to model the costs imposed by other fleets, we did not have sufficient information to incorporate potential future benefits to the other groundfish fleets. As such, estimated NPV for yelloweye rockfish is probably lower than it would actually be, because once the stock is rebuilt, it is anticipated that the new yelloweye rockfish quota would enable other groundfish fleets to resume their fishing activities, the economic benefits of which are not included here.

However, even when the cost of other groundfish fleets was left out, yelloweye rockfish NPV was still negative across all scenarios in the long term. Biological factors, including the relatively long generation time of yelloweye rockfish and the stock’s low MSY level relative to status quo catch, are the main drivers of the stock’s poor economic outcome. While there appears to be no economic argument for investing in rebuilding yelloweye rockfish, a pertinent question is whether or not rebuilding yelloweye rockfish can be justified from ecological or social-cultural perspectives (Eckert et al. 2018; McGreer and Frid 2017). Two main points drawn from the yelloweye rockfish case study are that: 1) choke species can severely affect the viability of non-choke fisheries; and 2) preventing fish stocks from steep declines over extended periods may likely require more aggressive management goals, particularly for vulnerable, long-lived species such as yelloweye rockfish.

2. Social impacts

We estimated that around 5,100 fishers currently participate in fisheries for the six fish stocks, while tens of thousands more people in coastal communities on both Pacific and Atlantic coasts depend on fisheries to support social and economic well-being. Despite the projected long-term benefits arising from rebuilding, the immediate concern for fishers will likely be related to job and livelihood disruptions during the initial rebuilding period. While this is understandable, rebuilding requires a shift in perspective from a short-term to long-term view. Adopting this multi-generational way of thinking is consistent with the Seventh Generation Principle[11] and values expressed by First Nations. Indeed, in most cases, choosing not to rebuild is likely to result in the loss of direct economic benefits and poses the risk of losing tangible and intangible ecosystem and cultural benefits associated with fisheries. Some of these losses, such as traditional knowledge and practices, may be permanent.

The process of rebuilding may also disrupt traditional practices and knowledge; consequently, it is necessary that rebuilding plans allow for some level of food, social, and ceremonial fishing to continue.

[11] The Seventh Generation Principle refers to the concept that decisions made today should result in a sustainable world seven generations into the future.

Overall, this would be a preferable situation compared to a situation of no rebuilding, in which potential species collapse could result in the permanent loss of the species and associated traditional knowledge.

The economic effects of rebuilding fisheries will not be confined only to the capture fisheries sector. Our results indicate that in most cases, economic output generated in the year that stocks are rebuilt exceeds the status quo level. However, it is also important to bear in mind that economic multipliers do not capture the diverse ecosystem services and intangible benefits that can arise from rebuilt fisheries, such as increasing biodiversity, restoring habitats, and supporting social-cultural values and knowledge systems (Klain and Chan 2012; Ban et al. 2017). Further, the change in fish populations will also have direct impacts on marine ecosystem food webs and community dynamics, which are not considered within this analysis but will ultimately affect the economics of these fisheries. Thus, besides direct participants in the fisheries, many other sectors and communities will be affected through the diverse social-ecological linkages and pathways between marine and human systems.

One of the most pressing issues when considering implementation of rebuilding plans is how to transition out of the fishery during the initial rebuilding period. For this aspect, experience from the northern cod collapse provides valuable lessons on how to design effective social adjustment programs (Hamilton and Butler 2001; Schrank and Roy 2013). Furthermore, rebuilding brings up complex questions around access and allocation to marine resources. While it is beyond the scope of the present study, we stress that dealing with how the anticipated benefits from rebuilding are to be allocated to different marine resource user groups should be a priority and not an afterthought in the rebuilding process. This is especially crucial for many First Nations and rural coastal communities that have suffered economic setbacks through unequitable allocation policies (Ecotrust 2004; Haas et al. 2016). Overall, the social impacts arising from rebuilding stresses the need for full stakeholder input and engagement in the entire rebuilding process.

3. Effect of environmental and non-environmental uncertainties on stock recovery

Underlying environmental, biological, and ecological uncertainties may not allow constant TAC levels to be maintained through time, as assumed in this analysis. For instance, small pelagic species such as herring inherently go through population fluctuations (Cleary et al. 2010), while variable marine survival rates affect the number of returning salmon (Riddell et al. 2013). In fact, WCVI Chinook marine survival decreased by 73 per cent in recent years compared to the 1980s and 1990s (DFO 2018b). Furthermore, both Atlantic herring and redfish populations have undergone large fluctuations in the past due to highly variable recruitment (DFO 2016b; 2018f), thus increasing the probability of unfulfilled projections. Rebuilding of the Gulf of St. Lawrence Atlantic spring spawning herring stock is constrained by low recruitment rates that are potentially driven by warmer environmental conditions (Bourne et al. 2015), as well as declines in weight at age. These trends are of concern given that most case study fish stocks were projected to experience NPV loss under the slow recovery scenarios. In addition, estimated NPV gains for all case study species showed the highest sensitivity to price and cost changes under the slow recovery scenarios.

The failure of northern cod to recover over two decades provides a clear example that projected stock recoveries may not materialize. One of the reasons for northern cod's inability to recover may be because its rebuilding was not done wholeheartedly — i.e., as soon as there was a sign of recovery, fishing started to occur again. This is a management aspect that can be fixed in future rebuilding plans, as illustrated in the West Australian Scalefish Resource case study (Fletcher et al. 2018). Other hypotheses have been put forward for northern cod's lack of recovery, including poor growth and condition, declines in reproductive success, availability of prey, environmental effects, and fishing effort in other fisheries (Shelton and Healey 1999; Rose and O'Driscoll 2002; Lilly 2008; Morgan et al. 2017). Yelloweye rockfish populations have also not shown signs of recovery inside Rockfish Conservation Areas up to seven years after establishment (Haggarty et al. 2016). The lack of yelloweye rockfish recovery is a concern for other species, because sensitivity analysis showed that if rebuilt catch levels are 50 per cent less than predicted, Atlantic herring, redfish, and WCVI Chinook would experience NPV losses, rather than gains. As such, this implies caution for not overinvesting in a fishery (see the rebuilding Japanese pelagic species case study below), especially for redfish, for which there is currently high optimism.

Aside from biological influences, changes in management and policy regimes and socio-economic conditions can also affect the maintenance of constant TAC levels. Furthermore, how climate changes will affect marine ecosystems and species is a large uncertainty that can affect the capacity for species to rebuild (Holt and Punt 2009; Schweigert et al. 2010; Rose and Rowe 2015; Bell et al. 2018). For WCVI Chinook, ocean climate is a big driver of fluctuations between good and poor marine survival (DFO 2018b). Thus, while this study assumes that a fishing reduction strategy will help stock populations to recover, it is important to recognize that other factors, such as poor habitat quality and rapidly evolving ecosystems driven by climate-induced changes, can inhibit or minimize protection benefits. This emphasizes the need for having a resilient marine ecosystem to help improve chances of fish populations recovering.

4. Multi-species and ecosystem-based management

While our analysis has focused on single stocks, it is crucial to link fisheries rebuilding to broader ecosystem-based approaches that take into consideration effects of habitat protection and species-ecosystem interactions, among others. Furthermore, we considered only two simple rebuilding strategies, but we recognize that within an ecosystem-based management approach, rebuilding could consider many other strategies, such as predator control or habitat enhancement. However, it is beyond the scope of this study to model these strategies. For species such as WCVI Chinook, this extends to addressing the impacts of terrestrial activity on freshwater habitat. Within a management context, the long-term time frame (100 years) for this analysis raises the challenge of how to ensure community- and corporate-management memory in fisheries management. Lack of memory can be a problem, because it leads to the “shifting baseline syndrome” (Pauly 1995) — i.e., a less healthy or transformed ecosystem is considered to be the norm. This results in inappropriate reference points for evaluating the status and economic losses arising from overfishing or for setting targets for fisheries rebuilding and habitat restoration. Loss of management memory can also lead to the same mistakes being repeated, thereby exacerbating the overexploited state of fish stocks.

Case Study: A social-ecological approach to rebuilding pelagic species in Japan — short- and long-term strategies to maintain social and economic sustainability in the fisheries system

Pelagic fish populations show considerable fluctuations in response to ocean conditions. This case study outlines short- and long-term strategies to avoid the boom and bust exploitation patterns characteristic of pelagic fish stocks and the resulting need to rebuild these fish stocks when they go through cyclical collapses. In the northwest Pacific, mackerel, sardine, and anchovy populations have shown successive out-of-phase fluctuations since the early 1900s. Japan’s large-scale purse seiners have been harvesting these species sequentially for the past 50–60 years, starting with mackerel in the late 1960s, sardines in the 1980s, and anchovy in the early 1990s after sardines collapsed. Anchovy, however, was not popular with purse seiners due to its poor meat quality, low price, and far-away fishing grounds. In the 1990s, the price of juvenile chub mackerel was higher than anchovy. Consequently, to avoid bankruptcy, purse-seiners targeted the more valuable juvenile chub mackerels instead. In the 1990s and early 2000s, the majority of the mackerel catch was made up of immature fish, inevitably leading to growth overfishing and preventing the full development of the mackerel stock.

In 2001, the Japanese government introduced a resource recovery plan (RRP). The recovery process was based upon a co-management approach and was implemented in co-operation with fishers. One feature was the provision of subsidies to compensate fishers for economic losses arising from implementing the RRP. The main recovery strategy was controlling fishing pressure on the mackerel stock to protect strong year classes. As part of the chub mackerel RRP implemented in 2003, purse seiners reduced days at sea. This reduction in fishing effort was an adaptive strategy, with bigger reductions in years when a strong year class occurred. Since 2007, purse seine owners also autonomously allocated total allowable catch among all fleets as an individual quota system to ensure that the total catch limit was not exceeded.

Strong year classes of chub mackerel occurred in 2004, 2009, and 2013, all of which were effectively protected. By 2016, the chub mackerel spawning stock biomass (SSB) reached 670,000 t, exceeding the full rebuilding target SSB of 450,000 t. The successful recovery of chub mackerel was due to a combination of management measures and favourable climate conditions. In the 2010s, the sardine stock started to increase again. However, the Japanese social system was not prepared for the anticipated boom, as there was a lack of required capacity (e.g., fishing fleets, processing plants, workers) to fully utilize the resource.

The Japanese experience demonstrates that unstable pelagic fish populations can lead to suboptimal timing and levels of fishery investments, resulting in either overinvestment or failure to fully utilize the fish stock. Consequently, alternating pelagic regimes resulted in overfishing as well as loss in social and economic benefits. To avoid the past boom and bust exploitation patterns and resulting need to rebuild depleted stocks, the following short- and long-term strategies that took into account social-ecological dynamics were proposed.

Short term: Ensure that the social system has the required capacity to fully benefit from a rising biomass. In the Japanese case, this involved rebuilding the highly valuable chub mackerel to a high enough level so that it can be harvested sustainably, thereby allowing accumulated mackerel profits to be invested in the necessary fisheries infrastructure to fully exploit eventual increases in sardine biomass.

Long term: Combine exploitation of alternating pelagic species with demersal species, such as walleye pollock or Pacific cod, which fluctuate less and are at good stock levels around Japan. Profits from these species can be used to stabilize overall fishery industry profits and keep the processing sector running. At the same time, efforts to increase human consumption of sardine and anchovy to reduce dependence on mackerel for investments are needed. This would require creating the necessary consumer demand and a “new” food culture.

Source: Makino (2018).

5. Size and age structure of fish populations

Size and age structure of fish populations are factors that affect population productivity (Barnett et al. 2017; Dick et al. 2017) and, hence, generation times and rebuilding benefits. While not explicitly considered in our analysis, this is a particular concern for long-lived species such as yelloweye rockfish (McGreer and Frid 2017) and redfish, and it raises the issue that rebuilding goals should encompass broader biological targets than just biomass as indicators of stock recovery.

Lessons learned

The lessons that emerge from the five issues raised above are:

a) *Precautionary and effective management of Canadian fish stocks that are currently not overfished is essential to avoid the need to rebuild stocks.*
Rebuilding is a difficult and costly process in the beginning but has the potential to substantially increase the economic benefits generated under most of the scenarios and fish stocks studied (up to 11 times in some scenarios).

b) *In terms of management intervention points, the highest potential economic gains are in most cases obtained under a longer-term, more conservation-oriented rebuilding strategy (fishing closure)*.
This highlights that taking a long-term perspective (i.e., sacrificing immediate gains for long-term gains) is essential if we want to achieve the largest possible economic benefits from rebuilding. This may involve the use of marine protected areas or seasonal closures, among other management tools and approaches.

c) *Due to future environmental and social-ecological uncertainties, fish stock recovery may not be guaranteed even if fisheries rebuilding measures were to be effectively implemented*.
These uncertainties bring up the importance of investing in areas such as alternative, non-fishing livelihoods, as well as social and health development, in order to build up people’s adaptive capacity for future change. It also cautions against overinvesting in a fishery.

d) *Mechanisms to address social impacts arising from rebuilding, especially ones that create more equitable access and allocation policies, have to be key components of the rebuilding process.* Rebuilding effects, both positive and negative, extend far beyond direct participants in the fishery, particularly for coastal First Nations and rural fishing communities. In addition to biological outcomes, rebuilding plans have to consider how peoples' access to fish, and thus impacts on human health and socio-cultural well-being, may be affected positively overall, while not ignoring short-term negative impacts.

Caveats

Our present analysis assumes that the status quo catch can be maintained over the entire 100-year analysis time frame. This may be an optimistic outlook given recent trends of weak national fisheries management (Favaro et al. 2012; Bailey et al. 2016) and temporal decline in catches of the six fish stocks. Overall, this implies that the projected NPV gains in this study are conservative and that economic benefits from rebuilding may be even larger (or, in the case of projected losses, smaller) than those presented here.

Our analysis also assumes constant real prices (i.e., price increases due to inflation are taken into account) and fishing costs throughout the analysis period. Although fish prices have remained at relatively stable levels since 1970 (Sumaila et al. 2007), we recognize that market and other influences can have short-term effects on fish prices (e.g., Japanese demand for roe herring [Burke and Phyne 2008]) and, hence, NPV. Sensitivity analysis showed that NPV was more sensitive to changes in cost compared to prices, but cost and price variations did not change the overall analysis outcome. We acknowledge that the economic cost data used in this analysis is dated due to the lack of more recent information. This raises the necessity for DFO to prioritize collection and analysis of economic performance data.

The conventional way of valuing recreational fisheries is through angler expenditure (Gislason 2017). Our method for calculating recreational fisheries' net revenues may underestimate the value of these fisheries, which are important sectors for WCVI Chinook, yelloweye rockfish, and northern cod. In fact, it was estimated that a hypothetical 50 per cent decline in B.C.'s Chinook recreational catch would annually lower provincial GDP by $11.5 million, wages and benefits by $7.2 million, and employment by 200 person-years (Gislason 2009). Overall, our conservative estimate of recreational fishing implies that the estimated rebuilding gains for WCVI Chinook and yelloweye rockfish may be on the low side.

As we used stock assessments as a guide for selecting scenario TAC levels, it is also important to recognize the inherent uncertainties and biases associated with the stock assessment methods and models. For instance, levels used to select Period 1 catch may already be biased by management considerations, because catches greater than zero with lower probabilities of decline could exist but were not evaluated in stock assessments. This is because harvest levels evaluated by scientists are often pre-defined in the assessment's terms of reference by management and senior staff. Furthermore, there is still no consensus on whether the AM1 or AM2 model should be used as the basis for providing management advice in Pacific herring stock assessments (DFO 2018e). Meanwhile, researchers have argued that biomass-based models used for yelloweye rockfish fisheries management do not appropriately account for the population's age and size structure (McGreer and Frid 2017), which may be hampering recovery. Furthermore, Duplisea (2018) found that redfish catches in the 1980s and 1990s, upon which earlier stock assessment models were based, may have been underestimated by a factor of two or more. In addition, the proportion of small fish landed may have been underestimated by a factor of 150–200. The present redfish rebuilding process attempts to address biological and fishery uncertainties through the use of Bayesian modelling to evaluate the outcomes of alternative management procedures for redfish (McAllister 2018).

CONCLUSION

Many Canadian fish stocks are in a perilous state and at risk of further decline. Fisheries loss will have serious economic, social, and cultural consequences for Canadians, especially coastal First Nations and rural coastal communities. As such, rebuilding fisheries is an urgent, national concern. However, progress towards this goal has been slow and limited. This analysis provides the impetus for intensifying fisheries rebuilding efforts because our results indicate that rebuilding has the potential to improve economic benefits to Canadian society in the long term. With the exception of yelloweye rockfish — which is a long-lived, slow-growing species — all other case study fish stocks are projected to experience some gains in net present value (relative to the status quo) once they are rebuilt in the future. Over the entire analysis time frame, Pacific herring, northern cod, and Atlantic herring are estimated to benefit under all rebuilding scenarios. While rebuilding is projected to result in economic losses for yelloweye rockfish (which is, of the fisheries studied, the smallest in terms of catch and second smallest in number of fishers) under all scenarios, its rebuilding may still be considered based on the species' wider ecological and cultural values.

Indeed, the direct economic gains estimated in this study are but one component to be considered in fisheries rebuilding. Our analysis indicates that rebuilding effects extend far beyond direct participants in the fisheries. In order to be successful, the fisheries rebuilding process will need to deal with the short-term social and cultural impacts arising from rebuilding strategies, which often involve reduced fishing activity. While we have provided a descriptive analysis of the social implications of rebuilding, this is one aspect that requires more comprehensive analysis in the future. Further analyses can also benefit from integrating economic models with biological and ecosystem models. The tight social-ecological linkages between each fish stock and their broader natural and human systems emphasize the need to view fisheries rebuilding as part of larger efforts for ecosystem-based management of marine and fisheries resources. It also brings up the importance of accounting for uncertainties arising from future global change as part of rebuilding plans.

A main message from this study is that fisheries rebuilding can be biologically and economically beneficial in the long term, but it requires going through an initial adjustment period that will likely be difficult for coastal communities. Thus, Canada will need to invest in the transition to healthy and productive fisheries by helping fishing communities while they wait for the fish stocks to rebuild. To avoid the future need to rebuild stocks and thus the short-term cost of rebuilding, it is crucial that Canada puts in place strong precautionary and effective fisheries management practices for the country's healthy stocks as quickly as possible, before it is too late.

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APPENDICES

A. Synopsis of most recent DFO stock assessments

Pacific herring (Central Coast stock) — Two models (AM1 and AM2) are used to provide science advice for Pacific herring. Estimates of median spawning biomass in 2017 (*SB*2017) were 30,474 t and 49,624 t using AM2 and AM1 models, respectively. These were equivalent to 55 per cent and 80 per cent of the equilibrium unfished spawning biomass (*SB*0). Both AM1 and AM2 models estimated *SB*2017 to be above the limit reference point (LRP) of 0.3 *SB*0 with a greater than 95 per cent probability. This stock was at a persistent low production and low biomass state starting in the mid-2000s, but estimated spawning stock biomass has shown an increasing trend since 2012, indicating stock growth (DFO 2018e).

4T Gulf of St. Lawrence Atlantic herring spring spawners — Estimated spawning stock biomass (SSB) at the beginning of 2017 and 2018 were 11,744 t and 12,446 t, respectively (DFO 2018c). The SSB has been in the Critical zone since 2004 and in recent years has been at the lowest level since the 1980s. There was over 90 per cent probability that SSB would remain in the Critical zone at the beginning of 2017 and 2018.

2J3KL Atlantic cod — SSB showed an increasing trend in the past decade, increasing from 26,000 t in 2005 to 441,000 t in 2017. However, it decreased to 315,000 t in 2018. The 2018 SSB was at 37 per cent of the LRP, a decline from 52 per cent in 2017. Ecosystem conditions appear to be in a low productivity state, as levels of key forage species for cod such as capelin and shrimp are low. Capelin is anticipated to remain at low levels to at least 2019, so cod productivity is therefore also expected to be negatively impacted (DFO 2018d).

Atlantic redfish Units 1 & 2 — Redfish in Units 1 and 2 consist of two species: *Sebastes mentella* and *S. fasciatus*. However, until recently, these two species were assessed as *Sebastes sp*. in stock assessments due to difficulty in distinguishing them. SSB of both redfish species populations in Units 1 and 2 is growing, and modelled estimates of SSB using a precautionary approach suggested that *Sebastes mentella* and *S. fasciatus* populations are in the Healthy and Cautious zones, respectively. 2013 research surveys indicated that the abundance of juvenile *S. mentella* and *S. fasciatus* were 80 and four times higher, respectively, than their average abundance from 1993–2012 (DFO 2016d). According to DFO research surveys in 2017, Unit 1 total minimum trawlable biomass was estimated to be 2,166,000 t for *S. mentella*, the highest value observed since 1984. Total biomass of *S. fasciatus* was estimated at 346,000 t, which was the same order of magnitude as the highest value observed since 1984 (DFO 2018f). Strong recruitment and biomass increase provide a positive outlook for both redfish stocks.

Yelloweye rockfish (outside population) — Biomass in 2014 (B_{2014}), the most recent year of assessment, was estimated at 3,821 t, which was equivalent to 18 per cent of the estimated initial biomass in 1918 of 21,955 t (Yamanaka et al. 2018). There was a 63 per cent probability that B_{2014} was below the LRP of 0.4 B_{MSY} (the biomass that allows a stock to deliver the maximum sustainable yield) and a 99 per cent probability that it was below the upper stock reference of 0.8 B_{MSY}. Besides being at historically low levels of abundance, yelloweye rockfish have also declined in size and age (McGreer and Frid 2017).

WCVI Chinook — According to the 2018 Salmon Outlook, wild populations of WCVI Chinook showed modest increases in escapement over the last three years, and this improvement was expected to continue in 2018 (DFO 2018a). However, in recent years, there have been fewer than 100 spawners observed in rivers in the southwest Vancouver Island Conservation Unit, putting it below biological benchmarks. With almost no age-six fish observed, wild WCVI Chinook are fished down and the stock is less productive. Consequently, wild WCVI Chinook remained a stock of concern in 2018. For the hatchery population, overall returns in 2018 were expected to be similar to levels observed in 2017. Observed returns of earlier age classes and ocean indicators of marine survival suggested that the survival rate for the 2013 brood year was below average, while 2014 and 2015 brood years appeared to be average.

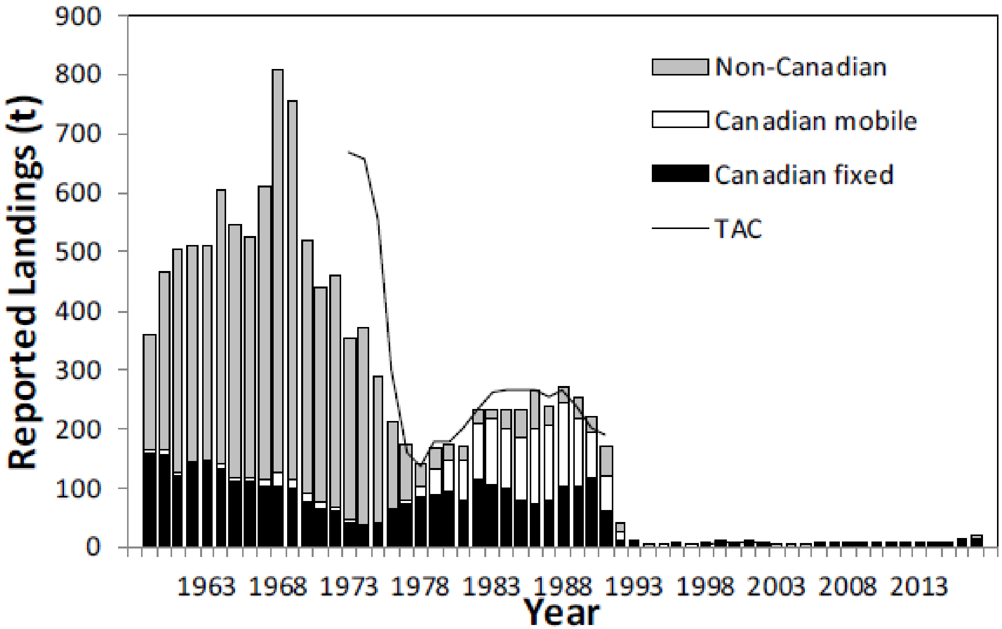

Figure A1. Landings t) and total allowable catches for northern cod, 1959–2017. Source: DFO (2018d).

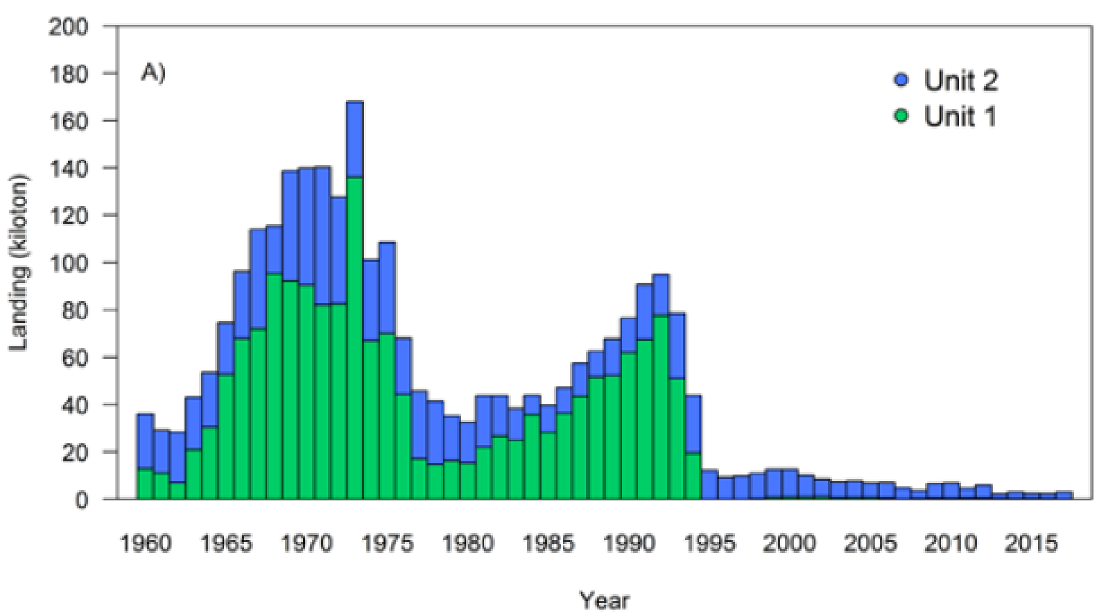

Figure A2. Annual landings (000 t) of Units 1 (green) and 2 (blue) redfish, 1960–2017. Source DFO (2018f).

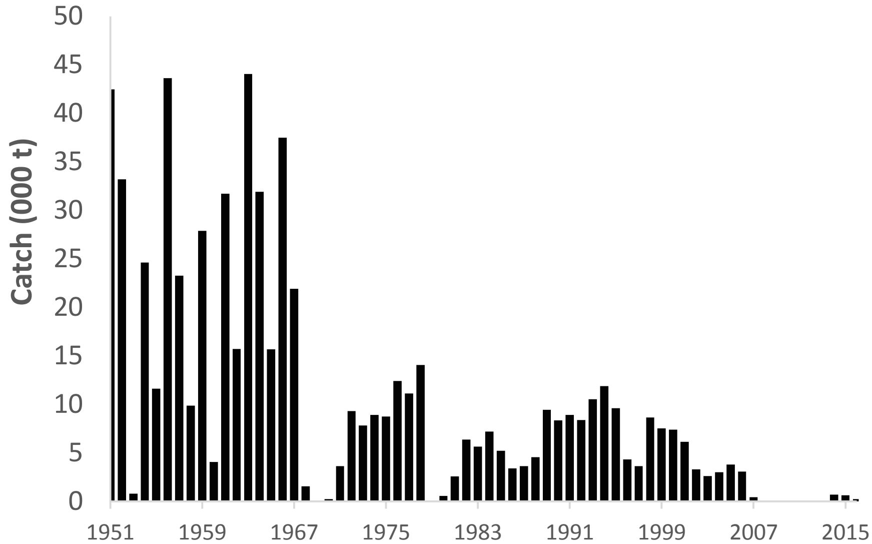

Figure A3. Annual estimated catch (000 t) of Pacific herring Central Coast management area, 1951–2016. Note that catch estimates are the same under both AM1 and AM2 models. Source: Data from Kronlund et al. (2018).

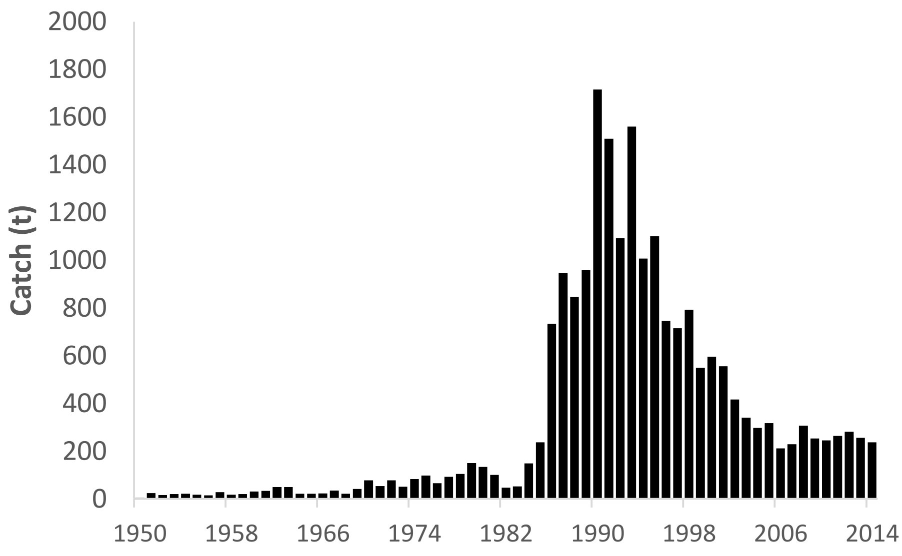

Figure A4. Reconstructed commercial catch for outside yelloweye rockfish, 1950–2014. Source: Yamanaka et al. (2018).

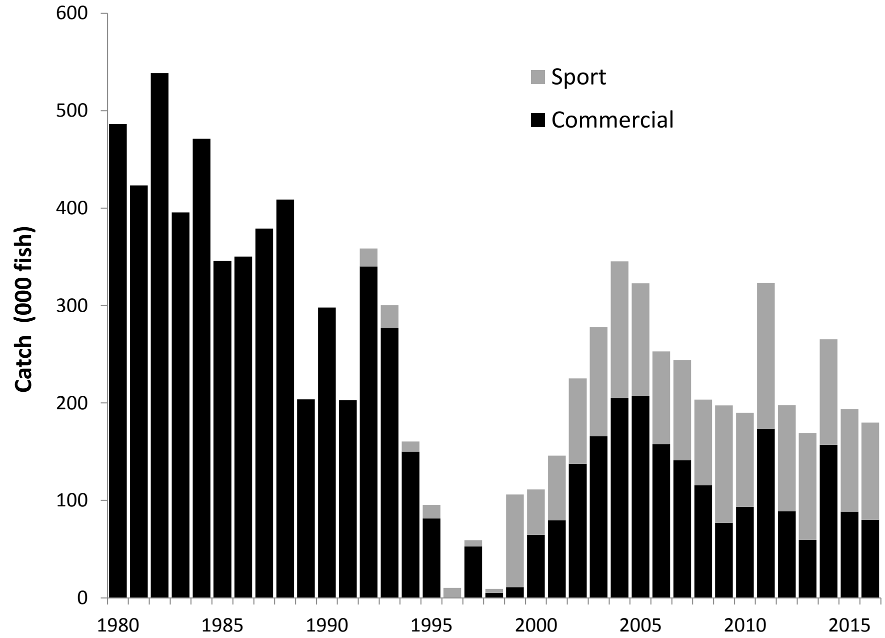

Figure A5. Commercial and recreational catch of WCVI Chinook (number of fish) for combined AABM and ISBM fisheries, 1980–2016. Source: Data from PSCCTC (2017b). AABM = aggregate abundance-based management; ISBM = individual stock-based management.

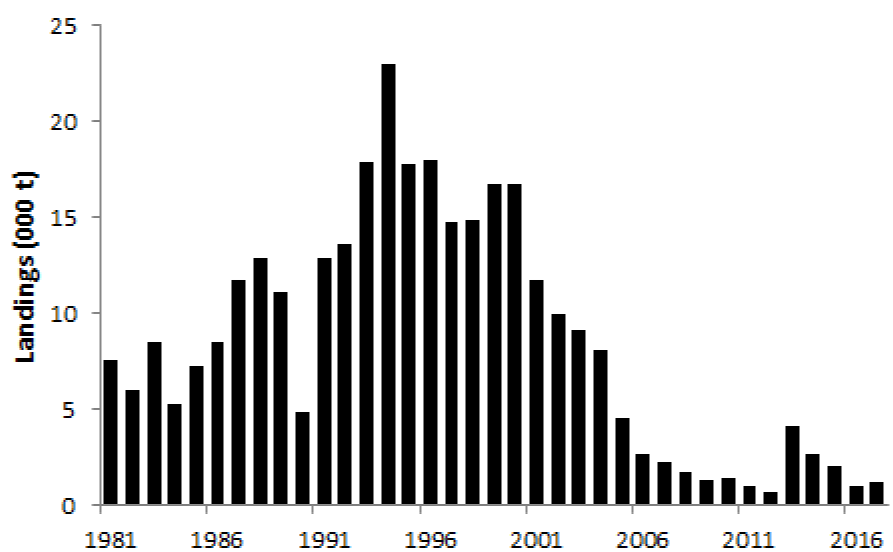

Figure A6. Landings of 4T spring spawning Atlantic herring, 1981–2017. Source: McDermid et al. (2016).

B. Selection of species generation time

There are several methods for estimating generation time of a species or a population of a species. To choose a generation time that matched the geographic location of the case study stocks as closely as possible, we searched the literature for generation times that were specific to or had been previously applied to the case study stocks (Table 4, main text). A drawback of using this approach was that the basis for determining generation time was not consistent across studies. To obtain a consistent set of generation times, we extracted generation times for each species from FishBase (Froese and Pauly 2018), which defines generation time as the average age of spawning individuals within a population. The generation times extracted from the FishBase Life History were used as the default generation times for each species. These default values can be adjusted to reflect different populations based on growth and mortality data available on the FishBase website (www.fishbase.org). Where available, data from Canadian studies provided in FishBase were used to adjust default values. We then ran a sensitivity analysis using these alternative generation times.

C. Economic analysis method

In this study, the economic benefits from rebuilding are represented by the change in net present value (NPV) generated by the capture fisheries sector under the rebuilding scenarios compared to the NPV under the status quo scenario.

It should be noted that NPV calculated in this study only covers direct-use values — i.e., the value of direct output, or product, from commercial and recreational fisheries. For commercial fisheries, the direct output is the amount of fish landed, whereas for recreational fisheries, the “product” is the angling experience (Gislason et al. 2017). In addition, the present value of economic activity generated from fisheries is also estimated through the use of economic multipliers (see the Economic Impact section in the main text). However, this study does not include a full total economic valuation — i.e., indirect, option, bequest, and existence values are not covered. Indirect use values refer to ecological services arising from properly functioning ecosystems (e.g., coastal protection). Option value is the value attached to future use of a natural resource, while bequest and existence values are considered “passive use” values that refer to the benefit individuals derive from just knowing that the ecosystem good or service exists. These values are not considered in this study because they lack quantitative data, and it is beyond the scope of this study to attempt to value these largely intangible benefits.

Fishery value

Commercial fisheries

The value of direct output from commercial fisheries is equivalent to the landed value of catch (LV_{com}), calculated as:

$$LV_{com} = c_{com} \times p$$

Where c_{com} = annual catch (i.e., total allowable catch) and p = ex-vessel price.

Ex-vessel prices for each case study species were based on DFO data (Table 8 of main text). We assumed that real ex-vessel fish prices would remain constant through time, since they have stayed at relatively stable levels since 1970 (Sumaila et al. 2007). However, we do test the sensitivity of NPV to a range of price increases (see the Sensitivity Analysis section in the main text).

Recreational fisheries

Recreational fisheries differ from commercial fisheries in that the primary “product” is the angling experience (Gislason 2017). Unlike commercial fisheries, ex-vessel prices cannot be used to measure the landed value of recreational catch, since the main purpose of recreational fishing is not to sell the catch. Instead, the revenue generated from recreational fisheries may be measured using angler expenditure. However, recreational fishing expenditures involve retail spending and therefore includes retail markups or margins that are not included in the measure of direct output for commercial fisheries. To make the analysis of recreational and commercial fisheries comparable, we followed the approach outlined in an earlier study on rebuilding U.S. fisheries by Sumaila and Suatoni (2006). In that study, a revenue multiplier of five was applied to recreational fisheries landings — i.e., it was assumed that recreational landings could generate on average five times more revenue than the same volume of commercial landings. Landed value from the recreational sector (LV_{rec}) was then calculated as:

$$LV_{rec} = c_{rec} \times p \times m$$

Where c_{rec} = annual recreational catch, p = ex-vessel price, and m = the recreational multiplier.

WCVI Chinook and yelloweye rockfish are important recreational fishery species. Projected future recreational catch for these two species was estimated by taking the average ratio of recreational catch to total catch (commercial + recreational) over the past five years and applying it to total projected catch under each scenario. Recreational catch data for WCVI Chinook was reported in PSCCTC (2016; 2017b), and in Yamanaka et al. (2018) for yelloweye rockfish. On average, recreational catch made up 51 per cent and 18 per cent of total catch for WCVI Chinook and yelloweye rockfish, respectively. Northern cod are also caught for recreation, but there has been no direct estimate of recreational landings for most of the past decade. In years when recreational landings data are available for the period 2006–2015, it has accounted for around 14 per cent of total northern cod landings (Brattey et al. 2018).

Fishing cost

In this study, we expressed fishing cost as a proportion of landed value: total cost (variable + fixed) divided by gross revenue (i.e., landed value). Fishing costs for Pacific coast case studies were taken from existing financial performance analyses of Pacific commercial fishing fleets (Gislason 2011; Nelson 2011). These assessments compile costs and earnings for different British Columbia fleets. Costs were inclusive of variable costs (e.g., fuel, ice, bait, and gear), wages, and fixed costs (e.g., insurance and repairs).

A detailed financial profile of eight salmon fleets was provided by Gislason (2011a). The majority of commercial WCVI Chinook catch is taken by troll. The Area G (West Coast Vancouver Island) salmon troll fleet financial profile (Gislason 2011) indicated that total fishing costs made up 89 per cent of gross revenue, while the corresponding figure was 87 per cent for the outside rockfish fleet (Nelson 2011). As there was no financial analysis available for the Pacific herring fishery, the next best option was to use the financial profile of the B.C. salmon seine fleet.[12] The rationale for this was that most roe herring seine vessels are also licensed in the salmon seine fishery, and almost all roe herring seine licences are placed on salmon seine vessels (Nelson 2009). We used the financial profile for double-licensed vessels to represent herring fishery costs under the assumption that a salmon seine vessel that also participated in the herring fishery would require at least two licences (herring and salmon). Fishing costs for this vessel group were extremely high, accounting for 96 per cent of landed value.

Due to bycatch regulations under the Groundfish Integrated Fisheries Management Plan, rebuilding of the yelloweye rockfish outside population will also affect the entire halibut and lingcod fleet, in that any restrictions on yelloweye rockfish catch will prevent halibut and lingcod fishing due to the unavailability of yelloweye rockfish quota. To account for this, we added the cost of halibut and lingcod fisheries not being able to operate to the cost of rebuilding yelloweye rockfish (see below). A rebuilt yelloweye rockfish stock will also have positive effects on the halibut and lingcod fisheries; however, we did not have sufficient knowledge about the nature and magnitude of these potential future benefits to incorporate into the model. Thus, projected economic benefits for yelloweye rockfish are likely to be on the low side.

Fishing costs for the northern cod, Gulf of St. Lawrence Atlantic herring and redfish fisheries were based on DFO's Atlantic region cost and earnings survey carried out in 2004 (DFO 2007). Costs were inclusive of variable costs (e.g., fuel, ice, bait, and gear), wages, and fixed costs (e.g., insurance and repairs). The

[12] While herring fishing uses both seine and gillnet, over half (55 per cent) of roe herring, which is the largest herring fishery in terms of landings, is harvested by seine. Therefore, we used the fishing cost associated with seine.

cost and earnings survey provided financial information for the following fleets: crab, lobster, shrimp, inshore herring, tuna, scallop, and "other." We used the "other" fleet, which comprises vessels targeting various groundfish species, including cod and redfish, to represent fishing costs for the northern cod and redfish fisheries. The northern cod stewardship fishery is mainly an inshore fishery using boats up to 34 ft 11 in. in length. As such, we based cost on data for vessels in the <25 ft and 25–34 ft categories. Total fishing costs[13] made up 64.4 per cent and 67.2 per cent of gross revenue (i.e., landed value) for the <25 ft and 25–34 ft vessel categories, respectively, with an average of 65.8 per cent. The number of active vessels in directed redfish fisheries in Unit 1 are predominantly <65 ft in size, although a substantial portion of landings is caught by vessels larger than 65 ft (Brassard et al. 2017), especially in Unit 1. We therefore used the average fishing costs and landed value for vessels across size classes to calculate that fishing cost made up 64 per cent of gross revenue. The majority of 4T Atlantic spring spawning herring is caught by gillnet vessels (DFO 2018c). As such, financial information for the 4T Atlantic herring fleet was based on the Gulf inshore herring fleet, for which fishing cost comprised 70 per cent of gross revenue.

Estimating cost of rebuilding yelloweye rockfish on other groundfish fleets

Rebuilding the yelloweye rockfish outside population will also affect the entire halibut and lingcod fleets, because they also operate in outside waters and will have no yelloweye quota available to them. This means that during the yelloweye rebuilding process, the halibut and lingcod fisheries will essentially not be able to operate. To account for this, we added the forgone landed value from halibut and lingcod to the cost of rebuilding yelloweye. The most recent available data we had was landed values from 2012–2015 from the 2018 Groundfish Integrated Fisheries Management Plan (DFO 2018h). The averaged halibut and lingcod landed values from 2012–2015 was $52.8 million (Table A1), which was used to represent the forgone revenue in Period 1 (rebuilding years). In scenarios involving fishing closure (scenarios FC, EC, and SC), the full amount of forgone revenue was added to the cost of fishing. In scenarios involving low fishing (scenarios FL, EL, and SL), we assumed that the proportion of forgone revenue added to fishing cost is equal to the ratio of low catch level to total catch level.

Table A1. Total annual revenue ($ million) from halibut and lingcod fishery in constant 2016 dollars. Source: DFO (2018h).

Fishery	**2012**	**2013**	**2014**	**2015**	**Average**
Halibut	41.42	45.75	51.67	59.41	
Lingcod/dogfish	3.42	3.21	2.5	3.79	
Total	**44.84**	**48.96**	**54.17**	**63.2**	**52.79**

Net commercial and recreational benefits

Net commercial revenue (R_{com}) and recreational (R_{rec}) revenue from each fish stock were calculated as the annual landed value (LV) less the cost of fishing (f):

$$R_{com} = LV_{com} - f$$
$$R_{rec} = LV_{rec} - f$$

Where f = LV x (1 – F);
F = fishing cost expressed as % of landed value for each fishery (Table 8 in the main text).

The nature of recreational fishery expenditures and cost structure differs from commercial fisheries due to its different "product" nature. To be consistent with our simplified approach for estimating recreational fisheries revenue (see the Fishery Value section above), we assumed that recreational fishing cost was the same as for commercial fisheries, while recognizing that this may be an oversimplification.

[13] Total fishing costs did not include depreciation and interest expenses, as these were not included in the financial performance analysis conducted for Pacific fleets.

The net present value (NPV) of each scenario is equal to the discounted 100-year stream of net benefits from commercial and recreational fisheries:

$$NPV = \sum_{t=0}^{T} \frac{R_{com}+R_{rec}}{(1+r)^t}$$

Where T = the end year of the rebuilding period (Year 100);
r = the discount rate, set at 8 per cent, which is the recommended rate by the Treasury Board of Canada Secretariat (2007).

Intergenerational discounting

In addition to conventional discounting (at an 8 per cent discount rate), we also calculated NPV using intergenerational discounting (Sumaila and Walters 2005). This approach provides a means of capturing the interests of future generations in economic valuation. The intergenerational discounting function considers the value of benefits received by the current generation and that received by an annual inflow of new entrants. The intergenerational discounting equation, provided below, requires a standard discount factor (d) plus a discount factor to evaluate benefits for the future generations (d_{fg}) (Sumaila and Walters 2005):

$$NPV = \begin{cases} \sum_{t=1}^{T} NB_t \left[d^t + \frac{d_{fg} \cdot d^{t-1}}{G} \left(\frac{1-\Delta^t}{1-\Delta} \right) \right] & \text{if } \delta \neq \delta_{fg} \\ \sum_{t=0}^{T} \frac{NB_t}{(1+\delta)^t} \left(1 + \frac{t}{G} \right) & \end{cases}$$

Where $\Delta = d_{fg} / d$ and where G is generation time (assumed to be 20 years);
NB_t = Net Benefit accruing in year t

D. Net present value results

Table A2. Gain/loss in NPV relative to the status quo at 30 years, 8% discount rate

Fish stock	Scenario					
	FC	FL	EC	EL	SC	SL
Redfish	3.28	2.37	-0.54	–0.19	–1.00	–0.19
Atlantic herring	1.33	1.24	0.61	0.36	–0.03	–0.20
Northern cod	5.58	4.89	1.80	1.06	–0.23	–0.27
Pacific herring	10.60	10.01	7.05	6.26	4.43	3.71
WCVI Chinook	0.19	0.45	–0.18	0.24	–0.44	0.10
Yelloweye rockfish	–653.62	–359.48	–686.28	–359.48	–686.28	–359.48
Yelloweye rockfish 2[1]	–1.00	–0.52	–1.00	–0.52	–1.00	–0.52

[1] Yelloweye rockfish 2 refers to NPV calculated without accounting for the economic impact on other groundfish fisheries.

Table A3. Gain/loss in NPV relative to the status quo at 50 years, 8% discount rate

Fish stock	Scenario					
	FC	FL	EC	EL	SC	SL
Redfish	4.25	3.41	0.71	0.46	–0.65	–0.19
Atlantic herring	1.45	1.36	0.78	0.55	0.19	0.03
Northern cod	6.28	5.64	2.78	2.09	0.90	0.57
Pacific herring	11.07	10.52	7.77	7.04	5.35	4.68
WCVI Chinook	0.24	0.48	–0.10	0.29	–0.35	0.15

Yelloweye rockfish	–605.41	–339.92	–685.17	–359.48	–686.28	–359.48
Yelloweye rockfish 2[1]	–1.00	–0.52	–1.00	–0.52	–1.00	–0.52

[1] Yelloweye rockfish 2 refers to NPV calculated without accounting for the economic impact on other groundfish fisheries.

Table A4. Gain/loss in NPV relative to the status quo at 100 years, 8% discount rate

Fish stock	**Scenario**					
	FC	FL	EC	EL	SC	SL
Redfish	4.49	3.66	1.01	0.77	–0.32	0.05
Atlantic herring	1.48	1.39	0.82	0.59	0.24	0.09
Northern cod	6.45	5.83	3.02	2.34	1.17	0.85
Pacific herring	11.18	10.64	7.95	7.23	5.58	4.92
WCVI Chinook	0.25	0.49	–0.08	0.30	–0.33	0.17
Yelloweye rockfish	–593.70	–337.34	–671.92	–357.39	–684.43	–359.46
Yelloweye rockfish 2[1]	–0.82	–0.46	–0.97	–0.52	–1.00	–0.52

[1] Yelloweye rockfish 2 refers to NPV calculated without accounting for the economic impact on other groundfish fisheries.

Table A5. Difference (%) in NPV gain/loss when calculated using intergenerational compared to conventional discounting (at an 8% discount rate) at 100 years

Fish stock	**Scenario**					
	FC	FL	EC	EL	SC	SL
Redfish	56	61	170	140	272	791
Atlantic herring	31	33	68	92	237	573
Northern cod	44	39	73	78	147	137
Pacific herring	17	18	31	34	56	49
WCVI Chinook	77	22	303	46	99	–80
Yelloweye rockfish	4	4	2	1	0	0

Table A6. Difference between present value of total economic output at 100 years and the status quo ($ millions)

Fish stock	**Scenario**					
	FC	FL	EC	EL	SC	SL
Redfish	469.5	382.7	106.0	80.7	–33.4	5.1
Atlantic herring	25.2	23.7	14.0	10.1	4.1	1.5
Northern cod	3,477.6	2,875.7	1,491.3	1,155.6	577.3	417.9
Pacific herring	81.8	77.9	58.2	52.9	44.7	36.0
WCVI Chinook	191.8	376.7	–64.8	230.1	–253.4	130.2
Yelloweye rockfish	3.8	3.8	3.8	3.8	3.8	3.8

Table A7. Percentage difference between base case and sensitivity test of 50% price increase

Fish stock	**Scenario**					
	FC	FL	EC	EL	SC	SL
Redfish	9	9	26	22	42	122
Atlantic herring	5	5	10	14	37	88
Northern cod	15	6	11	12	23	21

Pacific herring	3	3	5	5	17	8
WCVI Chinook	12	3	47	7	29	12
Yelloweye rockfish[1]	87	87	74	87	87	87

[1] The same % difference applies to sensitivity tests of 75% and 100% price increases.

Table A8. Percentage difference between base case and sensitivity test of 75% price increase

Fish stock	Scenario					
	FC	FL	EC	EL	SC	SL
Redfish	13	14	38	31	61	178
Atlantic herring	7	7	15	21	53	129
Northern cod	17	9	16	18	33	31
Pacific herring	4	4	7	8	20	11
WCVI Chinook	17	5	68	10	35	18
Yelloweye rockfish	87	87	74	87	87	87

Table A9. Percentage difference between base case and sensitivity test of 100% price increase

Fish stock	Scenario					
	FC	FL	EC	EL	SC	SL
Redfish	16	18	50	41	79	230
Atlantic herring	9	10	20	27	69	167
Northern cod	19	11	21	23	43	40
Pacific herring	5	5	9	10	23	14
WCVI Chinook	23	7	88	13	40	23
Yelloweye rockfish	87	87	74	87	87	87

Table A10. Percentage difference between base case and sensitivity test of 25% cost decrease

Fish stock	Scenario					
	FC	FL	EC	EL	SC	SL
Redfish	8	9	24	20	38	111
Atlantic herring	5	6	12	16	41	100
Northern cod	14	6	11	12	22	20
Pacific herring	19	21	35	38	62	55
WCVI Chinook	20	6	79	12	38	21
Yelloweye rockfish[1]	100	100	100	100	100	100

[1] The same % difference applies to sensitivity tests of 25% and 50% cost increases.

Table A11. Percentage difference between base case and sensitivity test of 25% cost increase

Fish stock	Scenario					
	FC	FL	EC	EL	SC	SL
Redfish	–9	–10	–27	–22	43	–125
Atlantic herring	–6	–7	–14	–19	–48	–116
Northern cod	3	–6	–12	–13	–25	–23
Pacific herring	–134	–148	–249	–271	–366	–394
WCVI Chinook	–25	–7	99	–15	10	–26
Yelloweye rockfish	100	100	100	100	100	100

Table A12. Percentage difference between base case and sensitivity test of 50% cost increase

Fish stock	**Scenario**					
	FC	**FL**	**EC**	**EL**	**SC**	**SL**
Redfish	–19	–20	–57	–47	91	–265
Atlantic herring	–14	–15	–30	–40	–104	–252
Northern cod	–3	–14	–26	–28	–53	–49
Pacific herring	129	143	240	262	372	381
WCVI Chinook	–58	–17	227	–34	45	–60
Yelloweye rockfish	100	100	100	100	100	100

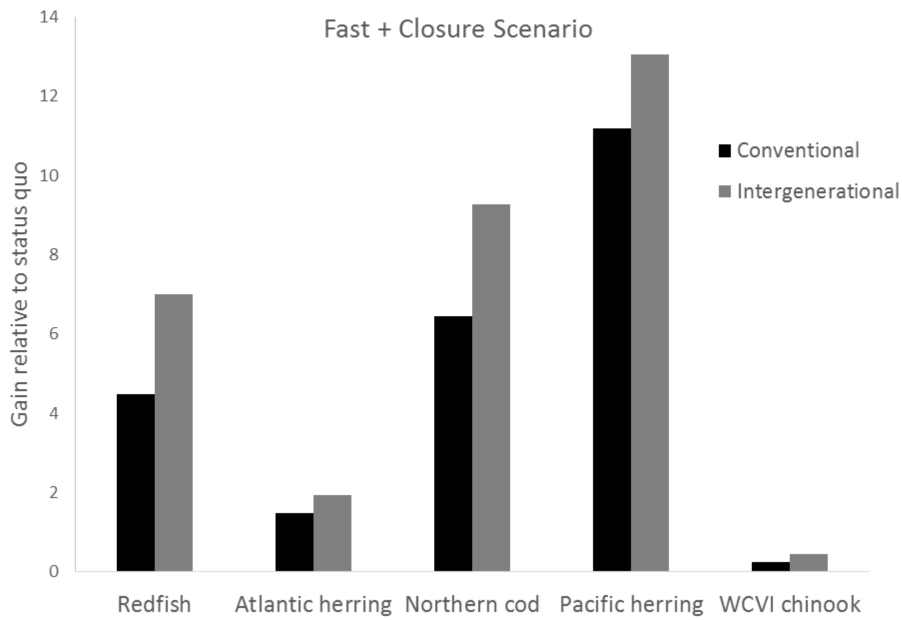

Figure A7. Gain/loss in NPV relative to the status quo at 100 years, calculated using conventional and intergenerational discounting (at an 8% discount rate) for fast + closure scenario. Note that yelloweye rockfish is not included in this figure or in Figures A8–A12 because there is almost no difference between conventional and intergenerational discounting for this stock due to its large negative NPV.

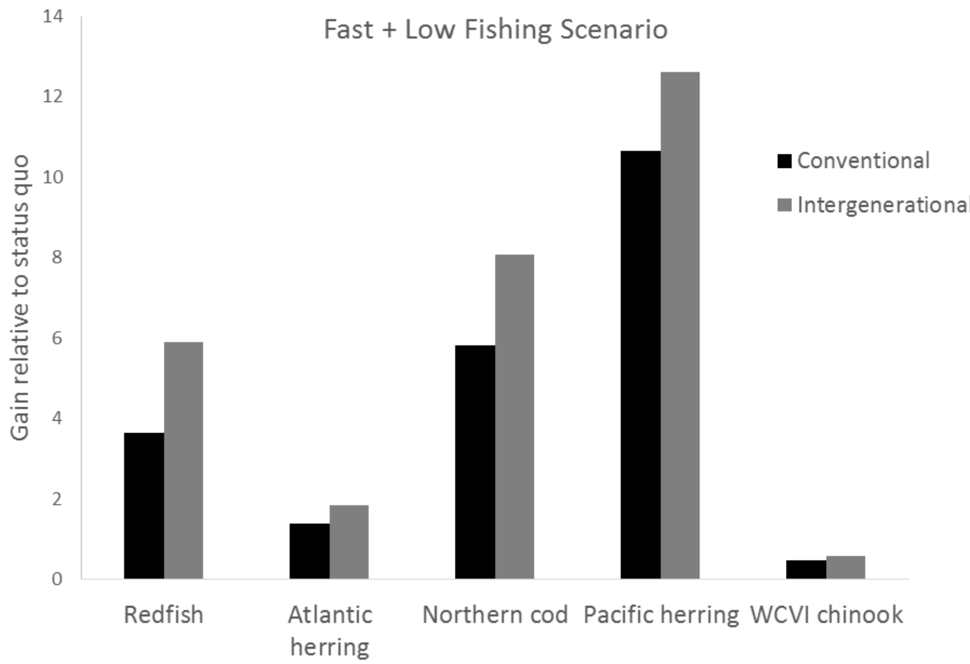

Figure A8. Gain/loss in NPV relative to the status quo at 100 years, calculated using conventional and intergenerational discounting (at an 8% discount rate) for fast + low fishing scenario.

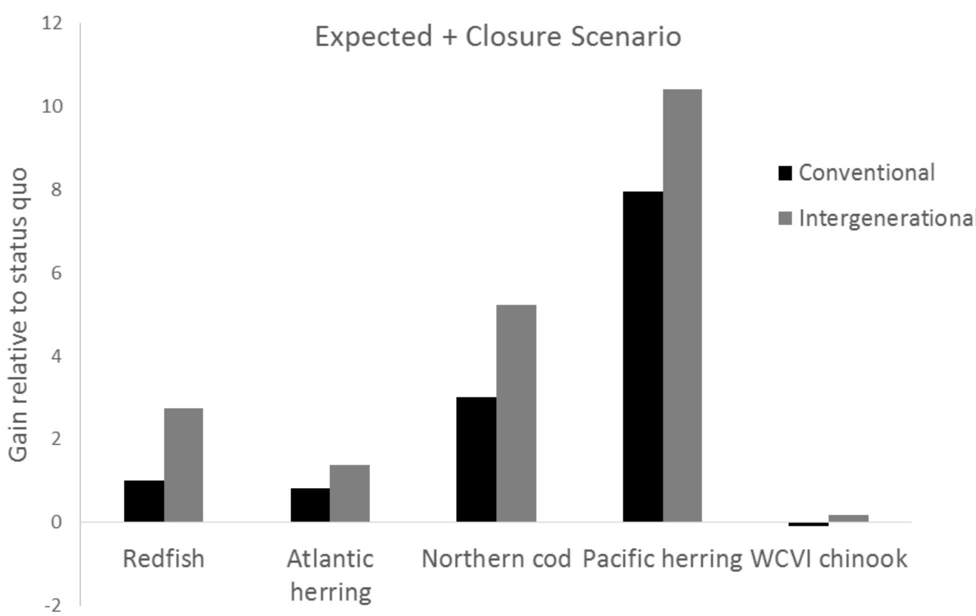

Figure A9. Gain/loss in NPV relative to the status quo at 100 years, calculated using conventional and intergenerational discounting (at an 8% discount rate) for expected + closure scenario.

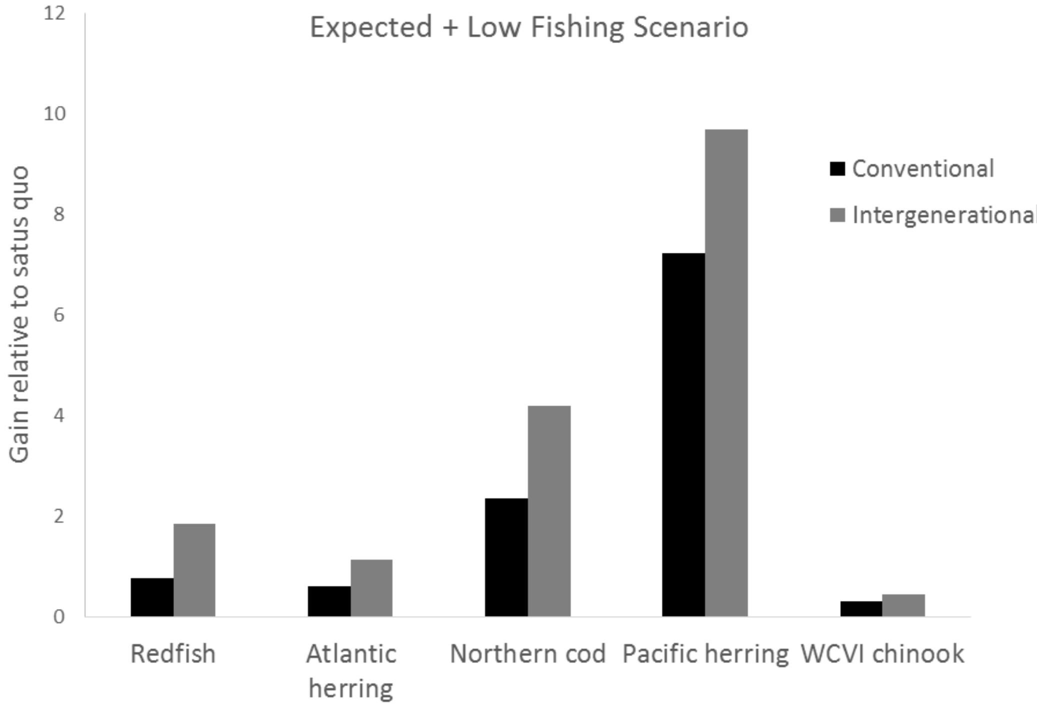

Figure A10. Gain/loss in NPV relative to the status quo at 100 years, calculated using conventional and intergenerational discounting (at an 8% discount rate) for expected + low fishing scenario.

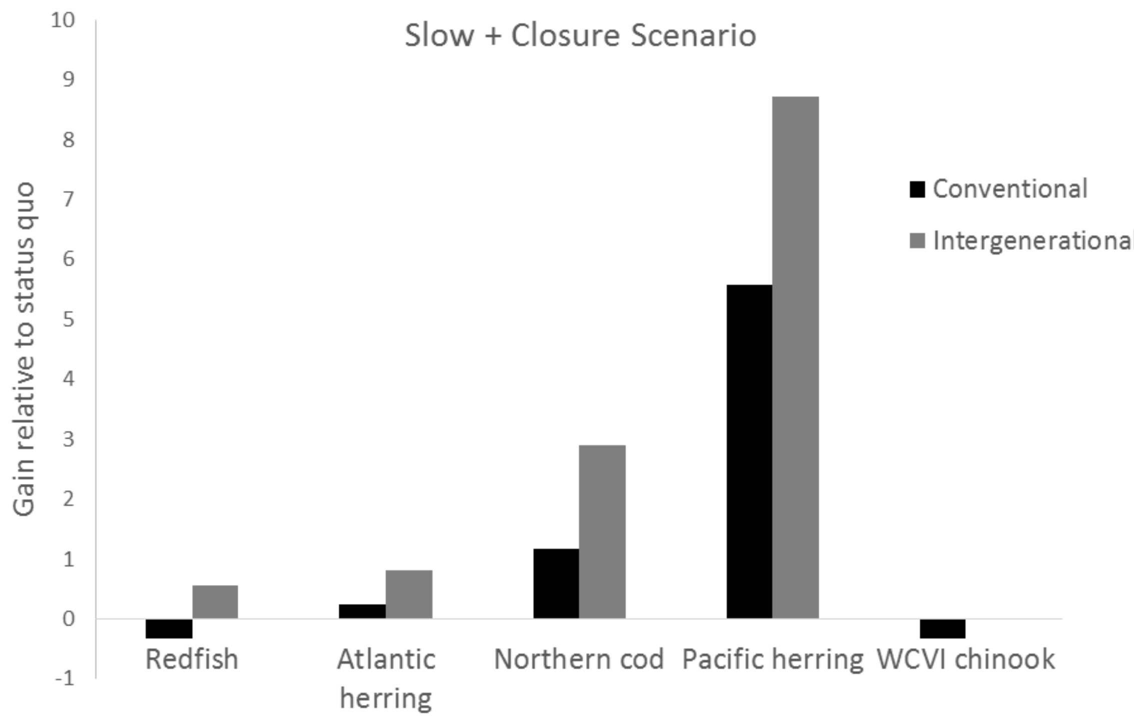

Figure A11. Gain/loss in NPV relative to the status quo at 100 years, calculated using conventional and intergenerational discounting (at an 8% discount rate) for slow + closure scenario.

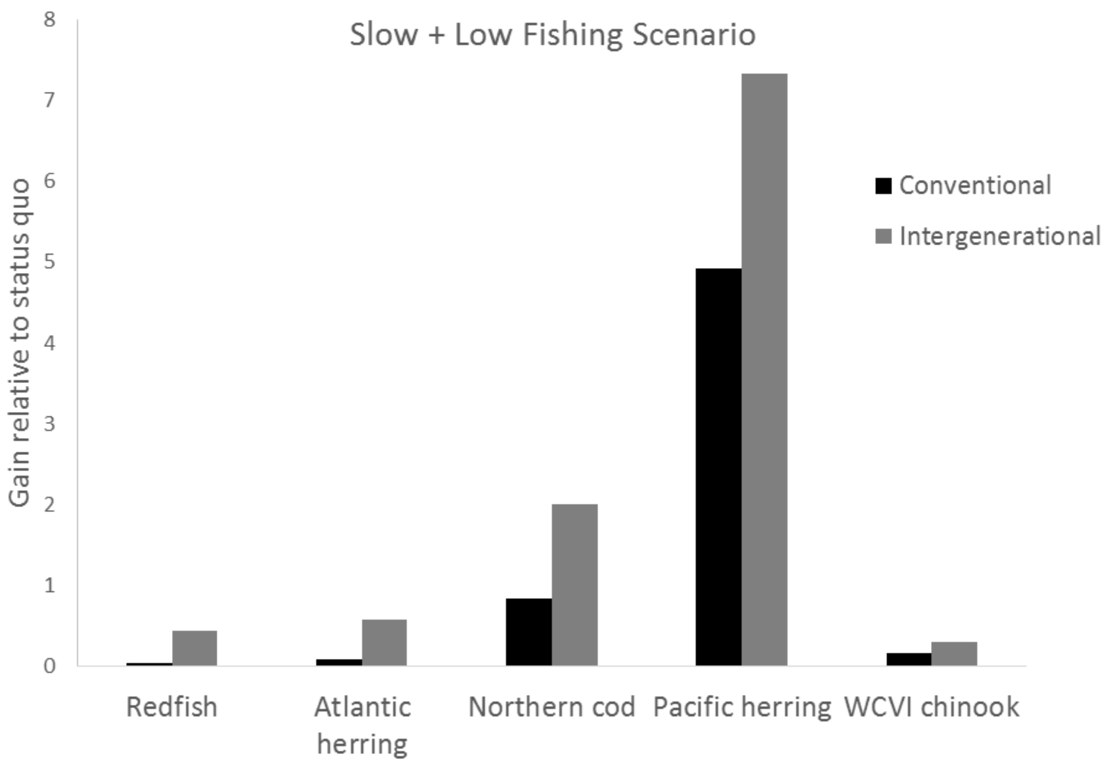

Figure A12. Gain/loss in NPV relative to the status quo at 100 years, calculated using conventional and intergenerational discounting (at an 8% discount rate) for slow + low fishing scenario.

E. Social implications

i. Estimating the number of recreational fishers and First Nations participants

Recreational fishers for WCVI Chinook and yelloweye rockfish recreational fisheries:

According to the 2010 survey of recreational fishing (DFO 2012b), the average number of fish caught and kept per angler was:

B.C. Freshwater = 31.3 fish/angler
B.C. Tidal = 14.4 fish/angler

Recreational catch data for West Coast Vancouver Island in 2009 (most recent data year online) was obtained from DFO's Annual Summaries of Catch and Effort, available at: http://www.dfo-mpo.gc.ca/stats/rec/pac/wcvi/index-eng.html

Yelloweye rockfish = 4,816 fish
Chinook = 200,416 fish

Number of anglers was obtained by dividing the number of fish caught by the average number of fish per angler. For yelloweye rockfish, the number of fish per angler for B.C. Tidal was used, while the average of B.C. Freshwater and Tidal (22.85 fish per angler) was used for Chinook.

Number of anglers:
Yelloweye rockfish = 4,816 fish/14.4 fish per angler = 334 anglers
Chinook = 200,416 fish/22.85 fish per angler = 8,770 anglers

First Nations participants in British Columbia spawn on kelp fisheries:

Estimating the number of First Nations spawn on kelp (SOK) participants is less straightforward because communal fishing licences are party-based, and there is a lack of information about the number of vessels linked to these licences. However, information from ongoing social research with the Heiltsuk Nation indicates that around 600 people participate in the Heiltsuk herring SOK fishery (Harper et al., unpublished data), representing around 38 per cent of the Heiltsuk population of 1,600 (Government of BC 2018). The Heiltsuk hold 11 SOK communal licences for an annual quota of 240,000 lbs of SOK. Five other First Nations (FN) groups hold communal SOK licences, although their quota is far less than that for the Heiltsuk. Applying the Heiltsuk SOK participation rate (38 per cent) proportionately to each FN group's SOK quota resulted in around 800 FN participants in the SOK fishery. This equates to about nine per cent of the total population of the six FN groups of 9,240.

In a broader context, there were 60,415 FN individuals residing in the Vancouver Island and Coast area and B.C. North Coast in 2016 (2016 census). According to a FN traditional food survey, 61 per cent of respondents from coastal B.C. consumed herring roe. This suggests that herring roe fisheries support food and nutrition for up to 36,853 FN (i.e., 61 per cent of 60,415 FN). Chinook and rockfish were consumed by 45 per cent and 39 per cent of respondents, respectively, implying that they contribute to the diet and health of 21,187 and 23,562 FN individuals, respectively.

ii. Estimating the number of fishers catching rebuilt fish stocks

To estimate the potential number of fishers catching the rebuilt catch level for each fish stock, we applied the current catch rate (t/fisher) to the rebuilt catch level (i.e., P2 catch) for each fish stock. This assumes that fishing power and fishing effort remains the same over the rebuilding period, and there are no barriers to new entrants into the fishery once fish stocks are rebuilt. Note that the estimated number of fishers fishing rebuilt fish stocks will occur at different points in time in the future, depending on the scenario under consideration.

Table A13. Estimated number of fishers in the current period and once fisheries are rebuilt

Fishery	Status quo catch (t)	No. of fishers (current)	Catch rate (t/fisher)	Rebuilt catch (t)	No. of fishers (rebuilt)
Gulf of St. Lawrence Atlantic herring	2,185	1,814	1.20	8,603	7,142
Northern cod	13,000	1,639	7.93	209,177	26,372
Redfish	509	1,285	0.40	9,104	22,984
Pacific herring	3,483	160	21.77	59,000	2,710
Yelloweye rockfish	201,191	105	1,916.10	368,745	192
Salmon troll	210	125	1.68	276	164
Total		**5,128**			**59,565**

iii. Estimating transition cost

Government-funded fishery restructuring programs generally provide some type of financial assistance to fishers to help them cope with the economic and livelihood disruption of having to transition out of fishing, either temporarily or permanently. Examples of transition costs include those for vessel buybacks, licence retirements, social assistance programs, and skills or job training. Transition costs are thus an important component of fisheries rebuilding plans, as they can help ease the economic pain for fishers or provide them with the skills training necessary for finding alternative sources of employment.

Pacific case studies:

Reducing fishing effort during the rebuilding period will be essential. One way of achieving this reduction is through buybacks or licence retirement programs. In Table A14, we outline the potential cost for a hypothetical licence retirement program in which 20 per cent, 30 per cent, and 50 per cent of active licences under each fishery are retired. We use average annual licence valuations provided in Nelson (2015). We assume a licence-to-vessel ratio of 1:1. However, this may underestimate the total transition cost due to the practice of licence stacking in the herring roe fishery. It should also be noted that these valuations reflect the most current (2015) market value only.

Table A14. Estimated cost for retiring 20–50% of active licences.[1] Transition cost is calculated as the no. of active vessels x % buyback x average licence value.

Fishery	**No. of active vessels**	**Average licence value ($)**	**Transition cost ($) Scenario**		
			20%	**30%**	**50%**
Roe seine	40	49,025	392,200	588,300	980,500
Roe gillnet	300	23,734	1,424,040	2,136,060	3,560,100
Herring food & bait	70	49,025	686,350	1,029,525	1,715,875
Herring spawn on kelp	9	175,000	315,000	472,500	787,500
Yelloweye rockfish	50	175,000	1,750,000	2,625,000	4,375,000
Salmon troll	58	124,714	1,446,682	2,170,024	3,616,706
Total			**6,014,272**	**9,021,409**	**15,035,681**

[1] Transition costs may be underestimated due to licence stacking.

Our results suggest that the cost of reducing the number of active vessels by 20 to 50 per cent (105 to 264 vessels) potentially ranges from $6 million to $15 million. This is comparatively less than past fleet reduction programs in B.C. For example, the federally funded Mifflin Plan in 1996 cost $80 million and resulted in the buyback of almost 800 salmon licences (Government of Canada and Government of BC 1996), retiring 19 per cent of the eligible commercial salmon fleet. Following that, the Canadian Fisheries Adjustment and Restructuring Plan in 1998 retired another 1,406 licences at a cost of $195 million. Altogether, the two licence retirement programs reduced the number of commercial salmon licences by 50 per cent (DFO 2010b). More recently (as of 2015), DFO retired 21 per cent of full-fee salmon troll licence eligibilities (approximately 104 licences) under the Pacific Salmon Treaty (PST) Voluntary Salmon Troll Retirement program (Nelson and Blewett 2015). The PST Voluntary Salmon Troll Retirement program cost $30 million and is funded by the U.S. and Canada.

Fishery buyback programs can be funded by government or industry. If funded by government, buybacks and fisher assistance programs are considered “ambiguous” subsidies (Sumaila et al. 2016), as their overall effect on reducing fishing overcapacity is inconclusive. While we did not find B.C.-specific data, Canada on the whole spends US$1.1 billion (2009 dollars) on fisheries subsidies annually (www.seaaroundus.org). Half of this (US$558.7 million) is on ambiguous subsidies, while 37 per cent and 16 per cent are on beneficial and capacity-enhancing subsidies, respectively. Therefore, the total amount of subsidies to Canadian fisheries will likely increase if buybacks are used for fisheries rebuilding.

A key lesson from past fisheries adjustment programs is that they tend to have disproportionately large effects on coastal First Nations coastal communities (Government of Canada and Government of British Columbia 1996). Importantly, social assistance programs that are appropriately designed for the communities' contexts are needed to ease the social transition towards reduced fishing activity (Teh et al. 2017). Education and skills training to help fishers shift to other job sectors and livelihoods are a particularly important component of fisher assistance programs. Employment insurance (EI) for fishers is another means of easing the economic impact of fisheries rebuilding. There were an estimated 1,515 fishers in the three Pacific case study fisheries (Table 16). EI for these estimated 1,515 commercial fishers would total to approximately $4.8 million. This was based on average EI to B.C. fishers of $4,233 in 2006 (DFO 2011) ($5,059 in 2017 dollars after adjusting for inflation using the Consumer Price Index).

Atlantic case studies:

To illustrate the potential cost of transitioning a community out of fishing, we use the example of Placentia Bay in Newfoundland, where a fleet rationalization plan is currently under consideration (FFAW 2018). Placentia Bay is located on the south coast of Newfoundland. More than 600 residents, or around 12 per cent of its population of around 5,000, are fish harvesters. The two most important fisheries — cod and crab — have experienced declines in recent years, prompting a rationalization plan (the Income Improvement/Enterprise Retirement Plan) to reduce fishing capacity by between 25 and 50 per cent. The budget for retiring 110 fishing enterprises, 90 per cent of which will be inshore vessels <40 ft, is $13.25 million. This is based on estimated average enterprise values of $88,130 for the inshore <40 ft fleet and $403,725 for the larger supplementary fleet.

In the context of this analysis, fleet rationalization is likely not a consideration for the redfish fishery, where industry is instead looking forward to an upsurge in the fishery. However, for inshore herring in 4T, the fact that less than 15 per cent of total inshore herring (both spring and fall spawning) licences are active[14] suggests that many fishers are not finding it economically viable to fish. In this case, fishers may be willing to participate in a fleet rationalization plan. Applying the same retirement scenario to the Atlantic herring fixed gear fleet (i.e., retiring 150 [25%] of the approximately 600 gillnet vessels) will result in an estimated cost of around $13.2 million. This assumes that each herring licence is equivalent in value to the estimated average enterprise value used for Placentia Bay.[15] As crab and cod are worth more than herring, our estimate may be on the high side. However, it is reasonable given that the average core licence value used in past buybacks was $101,000 (Schrank and Roy 2013). Likewise, the estimated cost for retiring 25 per cent of the 1,526 northern cod enterprises will require approximately $33.6 million.

Funding for the Placentia Bay Income Improvement/Enterprise Retirement Plan is being requested from both provincial and federal governments. Government-funded buybacks and fisher assistance programs are considered "ambiguous" subsidies (Sumaila et al. 2016), as their overall effect on reducing fishing overcapacity is inconclusive. In fact, the $3 billion spent on northern cod adjustment programs from 1992–1998 was not considered effective and instead served as a form of income maintenance for fishers (Schrank 2005). The magnitude of subsidization in Atlantic fisheries is already a concern (Schrank 2005). As such, the consequences of using buybacks and other capacity-reduction programs to achieve fisheries rebuilding objectives have to be carefully considered.

iv. Estimating the number of Atlantic fish processing workers

Fishing areas for northern cod, redfish, and Atlantic herring encompass parts of Newfoundland and Labrador, Prince Edward Island, Quebec, New Brunswick, and Nova Scotia, with Newfoundland and Magdalen Islands (Quebec) being fished by at least two of the three assessed fisheries. We therefore focused on Newfoundland and Magdalen Islands to examine how rebuilding may affect fish processing plant workers. In 2016, 92 licensed fish processing plants in Newfoundland and Labrador employed 7,557 people (Department of Fisheries and Land Resources 2017). Redfish, herring, and cod were among the species processed by seven, 19, and 28 plants, respectively.[16] There is no data available for the corresponding number of people employed in these plants. To estimate the number of people employed,

[14] Only 13 per cent of inshore herring licences in 2007 were active, which was considered to be a typical year (FRCC 2009).
[15] We note that the number of licences is not equivalent to the number of enterprises, but we do not have data on the number of herring enterprises.
[16] These figures were obtained by searching the Seafood Products Directory on the Newfoundland and Labrador Department of Fisheries and Land Resources website: http://www.geosurv.gov.nl.ca/fishaq/directory/

we multiply these 54 plants by the province-wide average of workers employed per fish processing plant (7557/92 = 82). This results in approximately 4,428 workers employed in plants that process herring, redfish, or cod. In Magdalen Islands, there was a maximum of 934 employees recorded in fishing plants in 2011 (DFO 2013b), although it is not known what proportion of these workers worked in plants that processed herring, redfish, or northern cod. Altogether, up to around 5,362 fishery plant workers may be impacted by the rebuilding of the case study species. When considering the employment benefits generated from fish processing, it is also relevant to consider that many processing jobs are now being filled by foreign migrant workers (Marschke et al. 2018). Consequently, the extent of the employment impact on local residents in both the short and long term may be lower than estimated here.

v. Health and nutritional impacts

A fishery closure will have comparatively heavier social and cultural impacts on First Nations communities. Fishing is the most common practice of traditional food harvesting among coastal FN in British Columbia, done by 35 per cent of respondents in a survey on traditional food use (Chan et al. 2011). Herring, salmon, and rockfish are all traditional foods and tightly intertwined with cultural practices and beliefs (Garner and Parfitt 2006; McKechnie 2007; Gauvreau et al. 2017). In terms of food security, it is estimated that food, social, and ceremonial catch provides 25–90 kg of fish and shellfish per on-reserve aboriginal person per year in B.C. (Gislason et al. 2011b). The food security role of fish is especially valuable because food insecurity is a serious problem for on-reserve FN — 41 per cent of FN households living on reserve in B.C. were found to be food insecure, with 34 per cent moderately and seven per cent severely insecure (Chan et al. 2011). By comparison, the corresponding figures for the general Canadian population were six per cent and three per cent for moderate and severe food insecurity, respectively (Chan et al. 2011). Given this context, it is essential that fisheries rebuilding plans build in provisions for supporting FN food security.

The dietary and nutritional benefits of herring roe and fish are especially important for supporting healthy diets for FN communities, where obesity rates are above that of the general Canadian population. Indeed, it was found that diet quality was higher on days that traditional foods were consumed (Chan et al. 2011). The nutritional contributions of herring roe, salmon, and rockfish are summarized in Table A15.

Table A15. Nutrient content provided by a 75 g serving of salmon and herring roe (% indicates the % of daily need)[1]

Food	Rating of nutrient content		
	Excellent (>25%)	**Good (15–24%)**	**Fair (5–14%)**
Herring roe (dried)	Protein, iron	Fat, niacin	Thiamin, riboflavin
Herring roe (from branches)		Protein	Iron, thiamin, riboflavin
Salmon (meat)	Protein, niacin, vitamin D	Omega 3 fatty acids, riboflavin	Fat, calcium, vitamin A, Iron, riboflavin

[1] Source: Taken from FNHA (2014).

vi. Aboriginal fishing licences in British Columbia

The number of commercial licences held by FN groups in British Columbia constitutes a small proportion of total licences in the herring, rockfish, and Chinook fisheries (Table A16), thus suggesting that FN currently have relatively smaller economic opportunities in the commercial sector. Overall, FN communal licences accounted for only around 13 per cent of total licences in British Columbia in 2011, and there is ongoing effort to increase this to 33 per cent (FNFC 2011). Equitable distribution of economic benefits is already a concern in herring and salmon fisheries, where concentration of licences owned by fish processors increased by four to five times over a 20-year period from 1993 to 2012 (Haas et al. 2016). Access to and allocation of fisheries resources will further be impacted by future climate and socio-economic change.

Table A16. Number of licences held by Aboriginal groups in herring, salmon, and rockfish fisheries

Fishery	Total no. of licences[1]	No. of licences held by Aboriginal groups	Aboriginal groups
Salmon troll (Area G)	81	7	Pacheedaht, Cowichan, Tla-o-qui-aht, T'Sou-ke, Ditidaht, Huu-ay-aht
Rockfish (outside)	117	7	T'sou-ke, Quatsino, Huu-ay-aht, Kitsumkalum, Gwa'sala-'Nakwaxda'xw, Kitasoo, 'Namgis
Roe herring gillnet	1,224	153	Haida, Kwakiutl, Kitasoo, A-Tlegay, Cowichan, Gwa'sala-'Nakwaxda'xw, Lax Kw'alaams, 'Namgis, Tsleil-Waututh, Sechelt, Musgamagw Dzawada'enuxw, Gwabalis, Hul'q'umi'num, Ahousaht, 'Namgis
Roe herring seine	250	6	Gitxaala, Kitasoo, A-Tlegay, Hul'q'umi'num, Toquaht

[1] Licence data was extracted from DFO Commercial Licence Reports, which lists all valid licences as of April 28, 2018. Note that this data does not indicate the number of active licences and that while we assume that FN fishers actually carry out the fishing under an Aboriginal group licence, this may not necessarily be true all the time. DFO Commercial Licence Reports: http://www-ops2.pac.dfo-mpo.gc.ca/vrnd-rneb/index-eng.cfm?pg=LicReportSelect