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Proceedings of the Regional Peer Review of the Stock Assessment of Northern Cod (Divisions 2J3KL)

March 19-23, 2018
St. John's, NL

Chairperson: Brian Healey
Editor: Julia Pantin

Science Branch
Fisheries and Oceans Canada
PO Box 5667
St. John's, NL A1C 5X1

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Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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SUMMARY

A Regional Peer Review Process for the assessment of Northern cod in Northwest Atlantic Fisheries Organization (NAFO) Divisions 2J3KL was held in St. John's, Newfoundland and Labrador (NL) March 19-23, 2018. The purpose of the process was to assess the status of Northern cod in NAFO Divisions 2J3KL in order to inform management decisions for the 2018 fishing season.

The meeting was attended by participants from Fisheries and Oceans Canada (DFO) Science and Resource Management Branches (NL, Pacific, and National Capital Regions), the fishing industry, the Provincial Department of Fisheries and Land Resources, academia, and non-governmental organizations.

Detailed rapporteur's notes of the discussion that followed each presentation were produced. This Proceedings Report includes abstracts and summaries of meeting discussions, as well as a list of research recommendations. The meeting Terms of Reference, agenda, and list of participants are appended.

INTRODUCTION

In November 2010, a Limit Reference Point (LRP), as described in the decision-making framework developed by Fisheries and Oceans Canada (DFO) for the application of precautionary approach in fisheries, was determined for Northern cod in the Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 2J3KL (DFO 2011). A Regional Northern cod Framework Review Process was held November 30 to December 4, 2015 to review multiple models of population dynamics, and to discuss the utility of various data sets available for assessing this stock (DFO 2016a).The status of the stock was last fully assessed in March 2016 (DFO 2016b) based on the new integrated state space model that incorporates much of the information about the productivity of the stock. A status update was completed in 2017 (DFO 2017) and indicated that the stock is improving but remains in the critical zone.

The current assessment was requested by Fisheries Management Branch to provide the Minister with detailed advice on the status of the stock in order to inform management decisions for the 2018 fishing season.

The main objectives of this assessment were:

- Provide an ecosystem overview (e.g., physical and biological oceanography, predators, prey) for the stock. If possible, this information should be integrated into the advice.
- Provide an assessment of the current status of cod in Divs. 2J3KL using information updated to 2018.
- Assess the current spawning stock biomass (SSB) relative to the LRP (B_{lim}), total biomass, strength of year-classes entering the exploitable population in the next 1 to 3 years, exploitation rate, fishing and natural mortality, distribution, and other relevant biological characteristics.
- Identify the major sources of uncertainty, where applicable.
- To assist in the development of the management measures for 2018, conduct three year projections of Spawning Biomass relative to the limit reference point (with 95% confidence intervals [CIs]) assuming total removals are {0.8, 0.9, 1.0, 1.1, and 1.2} times the 2017 value.
- DFO's precautionary approach (PA) framework indicates there is zero tolerance for preventable decline. Identify the level of removals that provide a high probability (>95%) of continued stock growth over the medium to long term (5-10 years). If possible, provide the levels of removals that provide a 0.95 probability of 0, 25, 50 and 75% growth from the 2018 estimate of spawner biomass.

The meeting was attended by participants from DFO Science and Resource Management Branches (Newfoundland and Labrador [NL]), Pacific, and National Capital Regions), the fishing industry, the Provincial Department of Fisheries and Land Resources, academia, and non-governmental organizations.

This Proceedings Report includes abstracts and summaries of meeting discussions, as well as a list of research recommendations. Additional information can be found in the Science Advisory Report (SAR), Research Documents, or from references cited therein.

PRESENTATIONS

OCEAN CLIMATE VARIABILITY ON THE NEWFOUNDLAND AND LABRADOR SHELF DURING 2017

Presenter: E. Colbourne

Abstract

The North Atlantic Oscillation (NAO) Index, a key indicator of the direction and intensity of the winter wind field patterns over the Northwest Atlantic was weakly positive during 2017. The associated atmospheric pressure fields resulted in a reduced arctic air outflow in the northwest Atlantic during the winter months resulting in near-normal winter air temperatures, however air temperatures were below normal during the spring.

Sea ice extent across the NL Shelf between 45-55°N, although above normal during late spring, was below the long-term mean in 2017. In the inshore regions along the east and northeast coast of Newfoundland sea ice duration was up to 15-60 days longer than normal. Sea ice in these regions disappeared by mid-June which ranged from 15-45 days later than normal depending on the area.

Annual sea-surface temperature (SST) trends on the NL Shelf, while showing an increase of about 1°C since the early-1980s, were mostly below normal during 2017, driven largely by very cold spring conditions. Oceanographic data from the fall multi-species surveys in NAFO Divisions 3LNO indicate bottom temperatures were about 1.2 standard deviations (SD) below normal. In Divisions 2J and 3K fall bottom temperatures continued to decrease from the record high in 2011 to about normal conditions in 2017. Observations from spring and summer Atlantic Zone Monitoring Program (AZMP) oceanographic surveys indicated that the area of cold-intermediate-layer (CIL, <0°C) water overlying the continental shelf off eastern Newfoundland increased over 2016 to about 1 standard deviation above normal, implying more extensive cold winter chilled water throughout the region.

A standardized composite climate index for the Northwest Atlantic derived from 28 time series of meteorological, ice, water mass areas and ocean temperature and salinity conditions since 1950 reached a record low (cold) value in 1991. Since then it shows a warming trend that reached a peak in 2010 and thereafter decreased to mostly below normal conditions (cold/fresh) during the past four years. The 2015 value was the 7th lowest in 68 years of observations and the lowest value since 1993, while the 2017 value was the 15th lowest.

Discussion

There was no discussion on the presentation of the physical oceanography overview.

OCEAN PRODUCTIVITY TRENDS IN THE NORTHWEST ATLANTIC

Presenter: G. Maillet

Abstract

Seasonal oceanographic surveys across standard sections by the AZMP, combined with synoptic satellite ocean colour data, provide relatively good spatial and temporal assessment of biogeochemical indices and lower trophic levels across NAFO Divisions 2J3KL in 2017 and earlier years. In general, seasonal surveys along the standard sections across 2J3KL indicate reduction in inventories of macronutrients in 2017 and recent years. The reduction in available macronutrient pools coincided with a reduction in phytoplankton biomass along all standard

sections from 2J to 3L during the same time period. Despite the reduction in nutrient inventories and associated biomass of phytoplankton, the abundance of many different functional groups representing different components of zooplankton have increased steadily during the available time series. Substantial increases of a keystone calanoid copepod (*Pseudocalanus spp*.), and other small warm/cold water copepods along with benthic invertebrates and gelatinous zooplankton have been observed across the standard sections. The transition to smaller taxa combined with lower abundance of the large energy-rich calanoid copepod (*Calanus finmarchicus*) has resulted in a shift in the community composition of zooplankton over the past decade. The change in community composition is consistent with the general reduction in zooplankton biomass observed across 2J3KL. Evaluation of a number of physical indices including ocean climate indicators, indicate an association with primary and secondary production indices and may represent important drivers in the ecosystem. The key physical drivers indicate reduced primary and secondary inputs that may have impacted transfer of energy to higher trophic levels in recent years.

Discussion

There was a question as to whether an analysis relating the Environmental Composite Index (ECI) with biomass (similar to the analysis presented relating ECI and *Calanus finmarchicus* and *Pseudocalanus spp*. abundance) has been conducted. It was explained that this is a natural extension of the work; however time has not yet permitted this analysis. That topic will be discussed at an upcoming AZMP meeting.

There was a question regarding why the large size fraction and small size fraction zooplankton seem to be inversely related. It was noted that even though this reciprocal change suggests a predator prey relationship, there is no direct evidence to support this theory. The presenter suggested further investigation of the carnivorous fractions of zooplankton is required to see exactly what might be happening in terms of their respective time-series.

There was a question as to whether the change in zooplankton speciation observed in NL waters (i.e., switch in abundance between *Calanus finmarchicus* and *Calanus glacialis*) has happened in the past or in other locations. It was explained that a number of publications have shown these large scale changes, for example in calanoid species in the Gulf of Maine. As well, there is consistency in some of the data presented which, in some cases, supports that association with changes in the general ocean conditions.

KEY PREY (CAPELIN)

Presenter: F. Mowbray

Abstract

Capelin, a key forage species in the Newfoundland marine ecosystem, saw dramatic declines in abundance in the early 1990s from which the stock has not recovered. While abundance did reach the highest levels in 25 years from 2013 to 2015, in 2017 it declined back to low levels typical of what was observed in the late 2000s. Oceanographic conditions are important drivers of capelin population dynamics, mediating the winter survival of capelin pre-spawning and the timing of spawning, likely via calenoid copepod production. Delays in spawning are associated with poor year class strength, as adult abundance is largely driven by early larval survival. The onset of peak spawning was markedly late from 2015 to 2017 and the emergent larval index from the Bellevue has been at a series low for the past four years.

Discussion

A participant noted that the amount of capelin spawning on beaches is very small compared to the amount of capelin spawning in the water in Division 3K and did not think that larvae getting off the beach is an issue in that division. The presenter noted that DFO is aware that there is much more demersal spawning in Division 3K and is accounted for in the usage of a particular larval index. A larval index for Division 3K will be started in summer 2018.

Clarification was requested regarding why the acoustic survey is considered a juvenile survey if it catches almost all Age 2 and older capelin and a large proportion of the Age 2 capelin are mature. It was explained that the survey takes place in an area of persistent immature (i.e. juvenile) inhabitants in the fall which may or may not mature in the next year. The survey does catch a large portion of mature capelin if they are present.

There was a comment that International Council for Exploration of the Sea (ICES) reports B_{lim} for capelin stocks based on a stock recruit relationship. A participant asked why there appears to be a stock recruit relationship in the Northeast but not the Northwest Atlantic. It was explained that in the high capelin abundance period in the early-1980s there appeared to be a stock recruit relationship, but this has not been seen in the post-collapse period. It was suggested that environmental drivers are very important for survival from eggs to larvae, but when there are many fish spanning a larger spawning range, they become more robust to those environmental nuances. It was also noted that the ICES capelin stock recruit curves are very noisy.

STRUCTURE, TRENDS AND ECOLOGICAL INTERACTIONS IN THE MARINE COMMUNITY OF THE NEWFOUNDLAND-LABRADOR BIOREGION

Mariano Koen-Alonso, Nadine Wells, Jennifer Mercer, Denise Holloway, Corinna Favaro, and Pierre Pepin

Presenter: M. Koen-Alonso

Abstract

The ecosystem structure of the NL bioregion can be described in terms of four Ecosystem Production Units (EPUs): the Labrador Shelf (2GH), the Newfoundland Shelf (2J3K), the Grand Bank (3LNO), and southern Newfoundland (3Ps). These EPUs coarsely represent functional ecosystem units, and have been used as geographic boundaries for the estimation of fisheries production potential (FPP) using ecosystem production potential models. Estimated FPP distributions, together with proxies for the current productivity state of the EPU, have been used to construct guidelines for Total Catch Ceilings (TCCs) for the Newfoundland Shelf (2J3K) and Grand Bank (3LNO) EPUs. TCCs represent an upper limit for sustainable total catches by species aggregates representing functional nodes in the ecosystem. These nodes closely match the fish functional groups used to describe the status and trends of the fish community, but they do not map them perfectly; these nodes represent a higher level of aggregation. Results from comparing catches with estimated TCCs indicate that fisheries in 2J3K are concentrated on the benthivore node (which includes shrimp and snow crab), and that even though 2016 catches are below the TCC, recent catch levels have been at or above the guideline limit, suggesting that this EPU may have experienced ecosystem overfishing in recent years. Catches in 3LNO have been more evenly distributed among the piscivore (which includes turbot, cod, redfish), and benthivore nodes, and with a “boom-and-bust” type of dynamics for the suspension feeding (SF) benthos (this node includes species like clams and scallops). Catches on the benthivore node are near its TCC, but catches on piscivores and SF benthos are above. Under current low productivity conditions, the increasing trend in catches could move 3LNO into an ecosystem overfishing state.

In terms of ecosystem structure and trends, the ecosystem changes observed in the 1990s involved the collapse of the groundfish community, not just cod, and the increase in shellfish. Consistent signals of rebuilding of the groundfish community appeared in the mid to late-2000s, and coincided with the beginning of the shellfish decline. The finfish biomass in the 2010s had been relatively stable until 2014-15, when started to show signals of decline. This signal appeared earlier in Grand Bank (3LNO), but today is also evident in 2J3KL, including a significant decline in Atlantic Cod in 2017. When finfish and shellfish biomass are considered together, the overall declines in total biomass in 2J3K and 3LNO are in the 30-35% range from their 2010-13 level. It seems that the conditions that led to the start of a rebuilding of the groundfish community have eroded. This may be linked to declines in primary production and large zooplankton in recent years, and the simultaneous reductions in key forage species like capelin and shrimp.

Historically, capelin and shrimp has been key forage species in 2J3KL. Capelin was a dominant prey in the pre-collapse period, while shrimp became a dominant prey after the collapse of the fish community.

The comparison between cod and turbot diets indicates that, even though both predators show indications of reduced capelin in the diet in the 1990s, this effect is more pronounced in cod diets. The more limited American Plaice diet data also suggests a higher presence of capelin in the diet in the early part of the time series. Analyzing diets by NAFO division indicates that the reductions in capelin were more drastic and occurred earlier in the northern areas. Between 2008 and 2014, shrimp showed important declines in the diets, while capelin increased. These increases appeared more evident in cod, and seemed more pronounced in the north. However, recent years are showing declines in both capelin and shrimp in the diets. The average stomach content weights of cod and turbot suggest that the 1990s and early-2000s were associated with reduced foraging conditions. The late-2000s and early-2010s saw increases in average stomach content weights, while the most recent years are indicating a declining trend. This is consistent with current overall trends in the fish community, and further indicates lower productivity conditions linked to bottom-up effects (prey availability).

Total food consumption by predators (medium and large benthivores, piscivores, and plank-piscivores functional groups) was relatively stable in 2011-15, but started to decline since. Consumption on shrimp showed an increasing trend until 2011, and has decreased since, while consumption of capelin peaked in 2013, and declined afterwards. Current total consumption of capelin is estimated to be three times the shrimp consumption in 2J3KL. Cod per capita net production rate is associated to capelin availability. Recent declines in consumption of capelin by cod, together with currently low capelin levels, indicates reduced cod productivity conditions. This is also consistent with the overall low productivity of the ecosystem.

In summary, the build-up of groundfishes observed in the late-2000s and early-2010s appears associated to bottom-up processes, including an improved prey field with higher capelin availability in comparison with the 1990s. Since 2013-14, the conditions that led to the start of this rebuilding process have eroded. This may be linked to the simultaneous reductions in capelin and shrimp availability, as well as other changes in ecosystem conditions (e.g. declines in primary production and some zooplankton groups in recent years). This has resulted in declines in overall biomass in the 30-35% range from the 2010-13 level, including an important decline in Atlantic Cod in 2017. Given the link between cod per capita net production rate and capelin availability, current capelin levels would indicate low productivity conditions for the Northern cod stock.

Discussion

The striking difference in biomass between the Engels and Campelen trawls, especially for shellfish, was raised by a participant. It was explained that the Engels trawl had a larger mesh size and during the Engels time period shellfish data was not consistently recorded. Since the introduction of the Campelen trawl in 1995, shellfish data have been consistently recorded. While there are detailed conversion factors for cod from the Engels period to Campelen period, there are none for shellfish species. Work is currently underway to develop conversion factors to estimate shellfish biomass for the Engels time series.

There was some confusion over using the RV capelin biomass to determine prey availability as the capelin presentation stated that capelin are mostly picked up in the RV survey when they are in low abundance because that is when they are found lower in the water column. The ecosystem overview presentation implied that cod productivity is related to the amount of capelin observed in the RV survey. It was explained that the RV survey is positively correlated with the acoustic estimate of capelin abundance.

There was discussion regarding the definition of functional groups presented with reference to the diet data presented. It was observed that while cod is categorized in the piscivore functional group, data presented on fall diets show that cod does not eat only fish. There was a suggestion that cod could be categorized as an omnivore instead. It was explained that the functional groups were initially defined based on overall diet of that species for the entire time-series at that time and that in the first part of the time-series 60% of the cod diet consisted of fish. However, a species that consumes shrimp is also categorized as a piscivore as it has that type of predatory behaviour. It was explained that piscivore could be replaced by the word omnivore and it would not make a difference with respect to the overall picture as it is just a different name. Changing cod to an omnivore would result in changing turbot to an omnivore, for example, and the trophic roles performed by these species would not change. In essence, it is simply a matter of changing labels, not conclusions.

There was a question as to whether the ecosystem is in a food-limited situation as there does not appear to be an issue with food quantity rather an issue with food quality. It was noted that the stomachs appeared to be full, but consisted of a variety of species. The presenter believes the ecosystem is in a food-limited situation. Normally with food-limited situations, either availability of the overall amount of food is poor or the quality of the prey food available is poor. The lack of capelin historically was an issue of both - availability of the overall amount of food and quality of food available. In recent times when looking at capelin, shrimp, or even information from the lower trophic levels, there appear to be smaller quantities of the prey species, not just lower quality. There seems to be a clear signal of bottom-up limitations on the ecosystem.

Regarding the equation for cod per capita net production which uses RV cod biomass and fisheries catch, there was a question as to what fraction of the RV cod biomass is on the same scale as the fisheries catch. A participant suggested checking that the data used are from the same segment of the population with regards to size, as the RV survey catches more small cod that are not caught in the fishery. It was noted that it is assumed that for the most part small fish weigh less and therefore will have less of an influence on the overall signal.

ECOSYSTEM MODELLING OF NORTHERN COD

Mariano Koen-Alonso, Andrew Cuff, Pierre Pepin, Michael J. Fogarty, and Robert Gamble

Presenter: M. Koen-Alonso

Abstract

Two different modelling approaches were used to study the influence of environmental and ecological drivers on Northern cod dynamics. The first approach involved the development of Empirical Dynamic Models (EDMs). This technique aims at reconstructing a multidimensional attractor using time series through lagged coordinates embedding, and it is expected to be good for short-term forecasting. The EDM exercise was a follow-up on an exercise done in 2016 which predicted stability or decline in Northern cod for 2017, in marked contrast with the current assessment model which predicted a positive trend for the stock in 2017. This analysis involved the development of a series of EDMs each one of them using, in addition to the Research Vessel (RV) fall biomass index for Northern cod, different combinations of likely drivers for this stock. These drivers included cod fisheries catches, the cumulative Composite Environmental Index, the spring acoustic capelin index, and the fall RV biomass survey indices for capelin and shrimp. A suite of seven EDMs were fitted to the data, and used to generate an envelope of short term forecasts for Northern cod. The 1-3 year forecasts from this suite of EDMs indicated that continued rebuilding of cod biomass appears unlikely. All models predicted stable or declining trends in their 3 year forecasts.

The second modelling approach was a bioenergetics-allometric model for the Northern cod stock, considering capelin availability and fishery catches as drivers. Unlike previous models using this theoretical approach, the current version - dubbed “capcod”- assumes lognormal process error only, and in addition to capelin, incorporates a constant alternative source of food for cod in the formulation of its type III functional response. The model fitted the RV fall biomass index for Northern Cod well, and was found robust to retrospective patterns. Since it assumes process error only, it provided a platform for a series of thought experiments. The results of these explorations suggested that the stock collapse was mainly driven by the capelin collapse and unfavourable environmental conditions, although fishing was also an important driver; environmental effects on stock dynamics appear to be associated with overall climate regimes/phases. Also, taking into account capelin levels in setting catch quotas can improve the odds for stock rebuilding with potentially moderate impacts on long-term catches; however, these practices need to be maintained over the long-term to be effective. Short-term prospects for the stock are not good; under current capelin levels the stock is more likely to decline, or at best remain stable. Rebuilding to pre-collapse levels within the next five years appears very unlikely.

In summary, these modelling exercises are further showing that capelin and environmental/ecosystem conditions, together with fishing, are important drivers of the Northern cod stock, and that considering these factors in defining harvest control rules for the stock can improve the odds for stock rebuilding. In line with the overall ecosystem trends and conditions, stock rebuilding has stalled. Short-term (three year) prospects suggest that the stock is likely to decline, or at best remain at its current level. Rebuilding to pre-collapse levels (i.e.: to get above B_{lim}) before 2022 is very unlikely.

Discussion

There was a lot of discussion among participants surrounding the Empirical Dynamic Model (EDM) presented. Clarification was requested on how the model is different from multivariate time-series models. It was explained that unlike traditional time series analysis, this technique is trying to reconstruct the underlying attractor itself and then overlay different versions of attractors from the multiple time series (assuming in one particular region of the attractor) and using that to project in time. The approach is attempting to use different time-series as replicates of the attractor to build a common way forward.

There was a question regarding the forecasting and what the model is assuming about abundance of prey and catch going forward three years. It was explained that the model does not assume anything about what is going to happen. The assumption is that the underlying trajectory that is reconstructing the attractor remains. The model is assuming that the status quo conditions up to the period under consideration are influencing the move forward. It was noted that the forecasting in this model is not just adding one more year to the model. In this model, when forecasting one year, the entire attractor is used to predict three years ahead. Every point in the time series has been predicted from the last point three years before, which is why the one year forecast is different from the two year forecast and different again from the three year forecast. It was cautioned that going beyond three years in models such as this is probably looking too far ahead unless the data is very robust. There was a question regarding whether it is possible to estimate some measure of uncertainty in the forecast with this modelling. It was explained that the model can provide a measure of standard error around the prediction, nevertheless there is still a lot to explore to improve the model. The intent of this exercise was to try to bring ecosystem variables into the cod dynamics as opposed to try to use this technique to describe the internal dynamics of the population.

Clarification was requested regarding the input of catch used in the model. It was explained that catch in this model is reported landings plus the assumption of a 30% increase in total catches in the next three years associated with recreational fishery catches.

It was noted that these techniques require a long time-series of a minimum of 20-30 years of data; however, the success of the model also depends on how well-defined the underlying attractors are. For example, the model has been used with single factors such as the Atlantic Multidecadal Oscillation (AMO) and Environmental Composite Index (ECI), and was able to predict 20 years ahead fairly well because it is a long time series. There was a lot of discussion surrounding the concept of the underlying attractor for this model. It was explained that the underlying attractor is the underlying system that is following a defined trajectory and is common across all the models; however, the actual attractor is unknown. The model uses different time series to try to map that underlying trajectory in a better way. Some drivers will have more or better information on what the attractor looks like than others.

There was a comment that EDMs make a large assumption that the system is on an attractor and that if there is a structural break in the time series, there might be a shift and the system will not be on the same attractor anymore. There was a question as to whether the model would have been able to predict the stock increase first observed in 2008 to 2010. It was noted that this has not been investigated, but that in the 2016 assessment it was stated that there was a 5% probability of the stock declining by 2017 and the EDM analysis consistently predicted a decline in the stock in 2017. There was a suggestion to look at simulations and the effects of non-stationarity.

There was discussion surrounding the use of the EDM model in future assessments and providing advice to managers. It was explained that this type of technique would not be used to give direct management advice, such as advice on Total Allowable Catch (TAC) levels, at this point in time. While this model is exploratory, it is not fully predictive at the level needed for TAC decisions in the current stage. The presentation was characterized as preliminary results that are informed by additional factors beyond cod biomass. There is considerable variability in the model, and at this point it is not intended to use for planning catch levels. This model provides an idea of the ecosystem around the stock (i.e., conducive to growth or conducive to decline) and in the case of the current input the results indicate that the Northern cod stock is not likely to increase. The utility of this type of model for stock assessments would be greater for stocks that rely entirely on survey data and do not have well-developed stock models like Northern cod has. The more these types of models are explored, the more confidence there will be in their use in assessments.

There was discussion surrounding the presented bioenergetics-allometric model (Capcod) which uses capelin biomass and fishing as drivers. This model builds on previous work (Buren et al. 2014) that demonstrated that capelin availability and fishing are key drivers of Northern cod biomass. It was noted that the presented work is intended for a primary publication, but will also be described in detail in a CSAS Research Document. It was noted that this model may be the way forward for incorporating capelin levels in cod models and trying to connect how the ecosystem influences cod decisions. It was noted that even with all its potential caveats, a model such as Capcod is showing a clear way forward for implementing harvest control rules that consider more than just cod level or spawning biomass.

Further explanation was requested regarding a thought experiment where fishing mortality was turned off in the model. It was explained that the experiment uses the actual capelin level that is known for a particular year and applies the process error that was fitted for that year. There was a question as to whether the size of fishing mortality in this experiment is underestimated because the process error estimate comes from a fit to data that was produced from a fished stock. It was explained that it could be possible; however, fishing is included in the model therefore the engine of the model is incorporating the effect of fishing and the effect of capelin and accordingly the process error must be coming from elsewhere. When the model is initially fit, it is assumed that the effect of the catch is already in the explained component of the model. Consequently, whatever remains is the process error which is the unknown variable that is being linked with environment in this case. Therefore, in this experiment it is assumed that the effect of the process error is being driven by environmental conditions beyond fishing or capelin because those two factors are considered in the model.

It was clarified that the results of the Capcod model suggest that fishing was not the main driver in the collapse of the cod fishery, not that it did not have any effect. Some participants were not convinced that the collapse would have happened even without fishing due to the collapse of capelin and suggested that the stock was already compromised. It was recommended that this model be examined in more detail, especially if management advice could be based on this view of history. It was suggested that the reliability of the model could be demonstrated with the use of simulations. There was a request to present the full list of model assumptions and the sensitivity surrounding them. It was explained that looking at the ecosystem signals prior to the collapse it is apparent that everything was declining during that period, not just capelin and cod, and from the RV survey data it can be seen that cod was the last to decline. The presenter clarified that he is not questioning that overfishing was an effect in the collapse; the question is what is the relative weight at different points in time between capelin availability and fishing. If capelin abundance is high then fishing will become the main driver in the model and conversely, if there is very little capelin then that becomes the main driver. There was a comment that participants need to be objective and consider the weight of evidence in that there are two independent analyses indicating the same results, therefore, they should not be completely dismissed. There was some disagreement in that the two models are not completely independent because they use the same data.

There was discussion surrounding the fit of the model. It was noted that there is ample evidence that the model fits the data quite well and from a modelling standpoint the fact that the model is fitting three parameters and fitting the time-series so well is a strong statement about its power. There was a recommendation to put a parameter in front of the *H* parameter as a scaling factor to take into account that the survey biomass index may need to be rescaled (catchability) to relate to the scale of fisheries removals.

OVERVIEW OF FISHERY 2016-2017

Presenter: J. Diamond

Abstract

Abstract not provided.

Discussion

There was a question regarding a pilot project that took place determining cod quality and whether its landings information was incorporated in the Northern Cod Assessment Model (NCAM) model. It was explained that 500 tonnes were allocated for the cod quality project and those landings were used in NCAM. A point was made that the 12,000 tonnes of Northern cod landed in 2017 (which did not include the landings from the recreational fishery) was the second largest groundfish catch in the NL Region that year. To put in context, the highest in the Maritimes Region was haddock on George's Bank with 14,000 tonnes.

CITIZEN COD 2017: RESULTS OF CITIZEN SCIENCE RECREATIONAL FISHERY PILOT PROJECT

Presenter: H. Rockwood

Abstract

For the purpose of stock assessment, DFO Science collects data from multiple sources and these data ideally contribute to the stock assessment model. With more data sources incorporated into assessments, our understanding of the state of fish stocks improves. In recent years, removals by the recreational cod fishery were identified as a knowledge gap and a citizen science pilot project employing high school students from coastal communities across the island was developed to help improve our understanding of these removals. Public consultations indicated that there was a lack of connection between DFO Science, local communities, and the general public and the idea of hiring students to monitor catch rates was suggested in several of these consultations.

The 2017 recreational cod fishery took place over a 46 day period between July 1 and October 1, 2017. DFO Science hired 24 grade 11 and 12 students with an interest in biology to work in pairs sampling at 11 wharves and landing sites. At the end of the season, all data were collected and compiled into a central database. The Avalon Peninsula had the highest data collection rates due to three factors: this region had the largest number of student applicants; the most centralized floating wharf systems; and most fishers landed round or gutted catch which were easily measured. The mean lengths landed in different communities were not significantly different and the catch rates in NAFO Divisions 3K and 3L were not significantly different. The pilot project was considered successful because it was a first step toward filling a knowledge gap with regards to removals by recreational fishers, engaged the communities and future scientists, and these data can inform future efforts to quantify recreational removals.

Discussion

There was a question regarding feedback from recreational harvesters and the overall response to the pilot project. The project was received very well and recreational harvesters consistently brought their catch to the student samplers and developed working relationships. Regarding feedback to the communities, the project is constantly evolving and DFO is still exploring how to use the data.

There was discussion surrounding how to account for unrecorded vessels. It was explained that in some communities there were a number of wharfs that the students could not access resulting in unrecorded vessels. This was highlighted as a source of uncertainty and it was noted that the numbers presented on reported fish landed by unsampled vessels (vessels with already filleted fish or landed when samplers were busy with another vessel) was most likely an underestimation.

There was a question as to whether the length distribution presented could be affected by high grading at sea. It was explained that it could be possible that smaller fish were discarded at sea.

There was a question regarding the ability to estimate recreational catch based on data from this pilot. In order to achieve this, the following issues would need to be addressed:

- This pilot was heavily focused on the Avalon Peninsula. Need to increase spatial coverage.
- Sampling took place during only a portion of the day at some sites and the beginning of the season was missed due to delays in hiring students. Need to increase temporal coverage throughout the day and the entire season.
- Many communities are not set-up with one central location for landing and therefore landings were missed in these communities.

OVERVIEW OF ENFORCEMENT ISSUES 2015-2017

Presenter: D. Walsh

Abstract

From 2014 to 2018, Fishery Officers spent an average of 3,900 enforcement hours per year on the 2J3KL Stewardship Cod Fishery making it one of the top five enforcement activities for Conservation and Protection (C and P) staff in the Newfoundland Region. The stewardship cod fishery averages 50 violations per year. Most violations are for exceeding the weekly quota limits and mis-reporting the amount of catch onboard the vessel. Given the thousands of inspections completed each year, the compliance levels are considered good.

From 2014 to 2018 Officers spent an average of 9,600 hours per year on the Recreational Groundfish Fishery. Officers detect an average of 50 occurrences per year, mostly for persons exceeding their daily limit of cod. Each year approximately 1,100 recreational cod vessels are inspected.

The Newfoundland Region has three Dockside monitoring companies handling over 60,000 landings per year. However, the Fish Harvesters Resource Centre (FHRC) handles monitoring of all Stewardship Cod landings in the Region. They service over 200 approved cod landing sites in NL. In 2017 the Dockside Observer coverage rate for stewardship cod was 30% in 2J but exceeded 85% in 3L and 3K. Authorization numbers are issued by the FHRC when a Dockside Observer is not available. C and P typically receives 20 incident reports from the FHRC office each year on cod landings that require further investigation by Officers.

Seawatch Inc. provides all at sea observer coverage for the Stewardship Cod fishery. Seawatch averages 350 at sea observer days each year in the Region for all groundfish species. The coverage levels are very low, less than 1% coverage for the directed cod fishery each year. Each year Seawatch submits several at sea incident reports for further investigation by Fishery Officers.

Discussion

Clarification was given regarding the number of observer days presented for 2016 and 2017. Coverage is generally low and very variable.

There was discussion regarding the low number of authorization checks in 2017. It was noted that the small sample size has been brought up within the Conservation and Protection Branch of DFO and will be addressed. A similar low number of authorization checks were completed in 2016. It was questioned whether the observer deployments are random or targeted at specific vessels (e.g. as a result of tips received). The presenter noted deployments were a mix, and in recent years had been split 25/75% amongst targeted versus random deployments, respectively. Of the small number of authorization checks that were completed, two thirds of the checks were under-hailed catches. Some of the reasons for the low number of authorization checks were:

- In 2017 a lot of fisheries were open at the same time
- Some area offices were short of staff
- The checks take a lot of people and coordination
- It is difficult to get checks done due to the covert nature of the operation

CATCH AND CATCH AT AGE

Presenter: K. Dwyer

Abstract

Available landings of cod in NAFO 2J3KL were reported from the Stewardship fishery, Sentinel survey and bycatch (inside and outside the Canadian EEZ). There were no reported landings from the extensive recreational fishery that occurs in this area. In 2016, the Stewardship fishery landings increased from 9,785 t to 12,703 t in 2017, with the Sentinel survey <300 t and bycatch <200 t in both years. Most of the landings in the Stewardship fishery were taken by gillnet and handline.

Length and age sampling of catches are conducted throughout the season across the stock area. There is also at-sea sampling by observers, and dockside samples of landings. In 2016 and 2017, the amount of unsampled gillnet landings increased from less than 3% to >10%. The amount of unsampled landings from other gears (handline and linetrawl) remains high.

Otoliths are also collected from a sample of the catch in order to calculate catch at age. In 2016, catch at age show a typical gillnet pattern, with most removals aged 6-8. Large catches of age 7 in 2016 track through to age 8 in 2017 (evidence of a strong 2009 year class). There was a higher proportion of older fish (>10 years) captured in 2016 and 2017.

Although there is no direct estimate of the total removals from the recreational fishery, there are length measurements recorded from fishery officers dockside and at sea (but this number has been declining). There is a “citizen science” program carried out by high school students at select locations throughout the area that allows recreational fishers to volunteer to have their catch sampled. It is not known how this sample relates to the total estimate.

Discussion

There was discussion surrounding discarding and whether there is a bias in the size of fish measured at sea versus dockside. It was suggested that less small fish may be measured dockside if discarding is taking place. It was explained that there is no current evidence of this happening. Survival of discarded fish is very variable depending on conditions and handling.

INFORMATION ON THE NORTHERN COD FISHERY FROM FISHER LOGBOOKS

Presenter: L. Wheeland

Abstract

Catch and effort data for cod fishery is available through logbooks completed by fishers at sea, and include information on type and amounts of gear used, locations and timing of fishing activity, and weight of fish caught. Median catch rates from < 35' vessels fishing longlines (kg/hook) and gill nets (kg/net) indicated a general increase in catch rates after 2010 in NAFO Div. 3K, followed by a subsequent decrease in the most recent years, while catch rates in Div. 3L have remained relatively steady. A similar pattern was observed for gill netters in the > 35' vessels. However, as catch rates reflect both stock status and changes to management plans and the subsequent fishery, it is uncertain to what degree logbook catch rates are indicative of trends in stock size.

Discussion

There were comments from industry participants regarding observations of catch rates and timing of the Northern cod fishery which included:

- Harvesters have not observed the levels of catch rates before that they have been getting the last few years
- Catch rates are double what harvesters were expecting when using auto-line gear
- Northern cod leave Green Bay in the first to second week of September
- Northern cod in 2017 did not appear to be as healthy as in 2016 in NAFO Div. 3L; however the condition seemed to improve later in the season
- Northern cod were large and healthy in offshore waters (harvesting took place late in the season)

FISH HARVESTER QUESTIONNAIRE 2016 AND 2017

Presenter: E. Carruthers

Abstract

Abstract not provided.

Discussion

There was a question as to whether a time series of some of the responses could be constructed from the questionnaire data. It was explained that a time series could be constructed for the questions regarding gear type, condition and one of the catch rate questions. The question regarding the timing of cod movements cannot be used in a time-series as the question has changed over the years. In previous versions of the questionnaire, the question asked whether cod moved into or out of the area earlier or later, whereas the current version of the questionnaire asked for more details of the timing of the movement such as month and week. It was noted that a questionnaire time-series would be very helpful to compare with the DFO reports to see if they match.

There was a question regarding the reference period used for the question on perception of abundance and catch rates. It was stated that previous versions of the questionnaire asked the question relative to the 1980s; however, in recent years in Divs. 2J3KL and Subdiv. 3Ps there has been an increasing number of participants that are not using the 1980s as the reference period. In response to this discrepancy, the question now asks the participant to rank catch rates as excellent, good, or poor, given the amount of gear used.

There was discussion surrounding the information presented on tag catch rates and returns. There was agreement among participants that the tagging program and assumptions made regarding tag returns needs to be re-examined. Many participants felt that the relative value of a $10 reward has changed over time and is no longer appropriate. As well, it was noted that the assumption that 100% of the $100 tags are returned is not necessarily true based on the questionnaire results. This presents a source of uncertainty as knowing the fraction of each tag type returned is important for estimating reporting rate. If the fraction of tags returned is significantly less and the proportion returned has varied over time, then this greatly impacts the model results. Several suggestions were made to improve the tagging program and return rates:

- Develop an education program on how tag information is used. Knowing what the information from the tag is used for may improve tag returns.
- Include something in the license conditions regarding tags to increase advertisement.
- Use a range of different valued tags. This would get away from assuming 100% return for high rewards because you can estimate the relationship between the reporting rate and the monetary value of the tag.

There was a question regarding the information presented on cod stomach contents and whether the greater number of species reported in Divs. 3KL reflects a more diverse diet for cod in Divs. 3KL than in Div. 2J. It was explained that there was a very small sample size (five responses) in Div. 2J and therefore that observation cannot be confirmed. It was noted that crab and capelin were definitely the most mentioned stomach contents in Divs. 3KL and sand lance, herring and jellyfish were not as frequent in Div. 3L.

RV SURVEY RESULTS (INDEX TRENDS, BIOLOGICAL)

Presenter: K. Dwyer

Abstract

Research bottom-trawl multispecies surveys have been conducted by Canada during the autumn in Div. 2J, 3K and 3L since 1977, 1978 and 1981, respectively, and the information from these surveys was updated for cod to 2017. Spring surveys have been conducted by Canada in Div. 3L during the years 1971-82 and 1985-present. Spring survey results, which cover only part of the stock area (Div. 3L) for cod, were not presented at the assessment.

The full time series of autumn DFO research vessel survey index values (strata < 500 m and no inshore or deep strata) by NAFO Division and total begins in 1983 and shows that the abundance and biomass indices for Northern cod have been low since the start of the moratorium in 1992. From 2011-16, both abundance and biomass indices increased, but in 2017 dropped back to levels of 2014. Most of the abundance and biomass (>80%) is located in the northern portion of the stock area (Divs. 2J and 3K). Increased numbers of small cod (≤age 4) observed from 2012-15 have since leveled off. The three-year averages (2015-17) for the abundance and biomass indices are approximately 30% of the average during the 1980s. Abundance indices indicate a decline mainly in Div. 3K and 3L from 2016 to 2017. The index was 30% less in 2017 in Div. 3K and 19% lower in Div. 3L. Div. 2J remained about the same. Biomass indices showed varying signals by Division, with increases of 19% and 17% in Divisions 2J and 3L, respectively, but a 53% decrease in Division 3K in 2016 to 2017. Overall, the drop in abundance indices from 2016 to 2017 is 18% and in biomass index is 27%.

Cod (both weight and number per tow) were widely throughout Div 2J, 3K and northern 3L in 2014 and 2015. In 2016, however, the distribution of cod appears clustered along the edge of the Northeast Newfoundland shelf (ages 3 and up) and there are several very large tows (> 500 fish per tow) in Div 2J and 3K . In 2017, catches appear smaller (10-100 cod per tow), but the distribution pattern returns to the one seen in 2014 and 2015. Plots of distribution from 2012-17 show an expansion of fish from a small centralized distribution in the “Bonavista Channel” (slightly north of the 3KL line), increasing northward over time.

The deviation of fish in 2J3KL combined (ages 3-7) from the long term mean weight-at-age indicated that 2016 and 2017 were the lowest values observed since the 1990s. Condition index was very low in 2016. Fish reached first maturity in the most recent cohort at age 5 (A50).

Discussion

Clarification was requested regarding the assessment of maturity during RV surveys. It was explained that maturity is assessed by visual inspection and there has been no change in the methodology over the RV survey time-series. It was noted that there could be some declining quality of visual observations due to the loss of experienced at-sea technicians, but it is unlikely that this affects the trend over time.

There was discussion regarding the use of different time periods for different analyses and whether the date for the start of the NCAM model could be earlier. It was explained that most of the biological indices have good data going back to 1978; however, only data starting from 1983 is displayed in most analyses because that is what is used in the NCAM model. Catch and catch at age data extend back to the 1950s, but it is unclear whether the data are reliable. A participant reported that in the Pacific halibut fishery there are two alternative long time-series models and two alternative short time series models and the results of the four models are averaged. There was a suggestion to have one model that uses the complete time-series and the current model which uses from 1983 onward and look at how the results differ.

There was discussion surrounding the decrease in relative condition and relative liver condition in 2016, and a rebound in 2017, and whether this could be influenced by spawning history. A participant asked whether it is possible that there was more skipped spawning in 2017 that caused the rebound and if the data are standardized for this in any way. It was noted that the analyses on condition were not standardized for skip spawning; however, it is generally thought that low condition causes skip spawning. There are estimates from a long time ago on skip spawning and there is definitely a relationship between condition and the proportion spawning, although there tend to be less skip spawners in Divs. 2J3KL than in Subdiv. 3Ps and Div. 3M.

SHRIMP DISCARDS

Presenter: B. Rogers

Abstract

Bycatch of juvenile Atlantic Cod in the northern shrimp fishery was investigated using data from the at-sea observer sampling program. Protocols for the observer program ensure that cod numbers and length frequencies are recorded for observed vessels; however these catches are discarded and rarely recorded in the region catch database (ZIF). Alternatively, cod catch could be estimated directly from logbook data, but scaling the catch up to a fishery wide estimate remains problematic. The primary concerns surrounding this scaling up are: issues with the minimum weight recorded (1kg); length frequencies with no catch; differing catchability between large and small vessels; percentage of observer coverage on different vessel classes.

Estimates of cod bycatch in the shrimp fishery may be improved through modeling of Catch Per Unit Effort (CPUE) using observer data, and applying effort estimates from logbooks.

Discussion

There was discussion surrounding suggestions to further this work. It was noted that there was a previous project to estimate catch using CPUE from observers and logbooks and that this work should be reviewed if the shrimp discards work is to continue. There was a recommendation to overlay shrimp fishing effort with what is known about small Northern cod distribution from the RV survey to determine if at sea observations are occurring in known Northern cod areas and in addition what the lost potential to the spawning biomass and/or the yield is. It was noted that a move-on rule exists in the shrimp fishery whereby when a certain percentage of finfish is caught as bycatch the fishing operations must move a certain distance. This management measure should be considered in further analyses.

NEWMAN SOUND PRE-RECRUITS

Presenter: B. Gregory

Abstract

We qualitatively assessed the relative strength of three cohorts (2015-17) of Atlantic Cod (*Gadus morhua*) based on abundance of demersal age 0 and 1 juveniles in Newman Sound, Bonavista Bay in summer and autumn of two years (2016-17) at nearshore sites (<10 m deep) using a seine net. Our assessment was based on comparisons with abundance of Atlantic Cod sampled at 6-12 sites, every 2 weeks from July until November, from 1995-2017 in Newman Sound, Bonavista Bay. Analysis of annual length frequency and abundance data indicated that age 0 Atlantic Cod settled in the nearshore in several distinct pulses, the first pulse arriving in early August in 2016 and mid-July in 2017, which was typical for this coastal location. Second and subsequent pulses followed the first by as much as two months later. The 2016 and 2017 cohorts were numerically strong, especially for the first recruitment pulse. The 2015 and 2016 cohorts remained strong as age 1 fish in 2016 and 2017 seasons. Abundances of age 0 and 1 cod in Newman Sound in 2016 and 2017 suggests that all three of these cohorts will be moderate to strong, relative to other cohorts in the time series, but well below that of the large 2013 cohort, which remains the strongest cohort in the 22-year time series. Stronger than average abundances and lower than average age 0 mortality rates within season have been observed during each of the past three years (2015-17) compared to other years within 22 years of monitoring. Preliminary results of a companion study we conducted at eight additional coastal sites in both Trinity Bay and Notre Dame Bay in 2017, supported our long-held view that settlement pulse structure of Atlantic cod in Newman Sound is typical of broad spatial patterns along the northeast Newfoundland coast across all three of these major bays.

Discussion

There was discussion surrounding the analyses exploring whether Newman Sound Age 0 abundance could predict Newman Sound Age 1 abundance and inshore Sequential Population Analysis (SPA) Age 3 abundance, and whether Newman Sound Age 1 abundance could predict inshore SPA Age 3 abundance. The results presented used inshore SPA estimates from the assessments that ended in 2006/2007 and it was noted that the inshore SPA was disbanded in 2008 when there was a change in the spatial distribution of the stock. There was a question regarding whether this analysis has been tried with the NCAM outputs from 2016. It was noted that this would be of greater benefit than correlating with the defunct inshore SPA but it has not been done. There has already been a request to continue that work from 2007 onward and will hopefully be presented in the next assessment. There was a recommendation to conduct these analyses using NCAM and RV survey data.

There was a question as to whether there has been an investigation into spawners and how it relates to what is seen in Newman Sound. It was explained that through the 1990s and into the early 2000s, spawning behaviour was quite different than it is today. From tagging information it is known that the Smith Sound component was travelling along the coast to Notre Dame Bay and spawning along the way, and from other work it is known that the juveniles in Newman Sound were genetically similar to spawning groups occurring off Notre Dame Bay and Trinity Bay. It was noted that there is no evidence that the various pulses were separate spawning groups.

There was discussion regarding overwintering survival from Age 0 to Age 1. It was explained that survival is influenced by the length of winter and that severe (long) winters produce significant overwinter mortality. In earlier days there were harsher winters in Newfoundland, whereby the winters were longer, food supply was short, and small Age 0 cod would not have survived through the winter. From 2010 to present, winters have not been as harsh and even the small cod that recruit late probably survive the winter. There was a question regarding where these cod overwinter and it was explained that there is very strong evidence that Newman Sound Age 0 cod are overwintering in Newman Sound indicating that pre-recruits do not move very far to overwinter. It was noted that there have been consistent observations of a lot of Age 1 Northern cod in May very close to shore most years, implying that the fish are using the coastal shallows to feed in warm prey-abundant waters.

UPDATE ON NORTHERN COD TAGGING PROGRAM IN NAFO DIVISIONS 3KL

Presenter: L. Wheeland

Abstract

An update was provided on recent years of mark-recapture information from the conventional (floy) tagging program, including location and numbers of tag releases and recaptures, and estimates of exploitation rates based on tag returns. In 2016 and 2017, 6,537 and 1,286 tags, respectively, were released inshore in NAFO Divs. 3KL. The vast majority (>80%) of tags returned since 2000 were recaptured in the NAFO division in which they were released. Mean annual harvest rates for 2017 were estimated from tagging data, ranging between 1.06% and 13.7% by statistical unit area (3KA, 3KH, 3KI, 3LA, 3LB, 3LF, 3LJ), with an overall harvest rate of 8.0%.

Discussion

It was noted that there will be a new scientist joining the DFO Groundfish Section in April 2018 to work on the tagging program and data.

Clarification was requested regarding what the harvest rate represents; whether it is a population harvest rate or a tag supplied and returned harvest rate. It was explained that harvest rate represents the harvest rate for cod that were tagged and released in one particular unit area. It is not a harvest rate of fish that are in that unit area, it represents harvesting anywhere because fish move around. However, generally the cod are harvested in the unit area they were released in. It was stated that it is not a population harvest rate; the information gives a sense of what is going on in terms of how much is being harvested in the fishery. The harvest rate is a calculation of the surviving tagged fish from one year projected forward to the next year accounting for mortality (M) and tag loss, with returns adjusted to allow for annual reporting rates. The information is integrated across years. It was noted that M values from the NCAM model are used in this analysis.

There was discussion regarding the use of M values from the NCAM model. It was noted that the NCAM model uses tagging data and the tagging data uses NCAM M estimates, therefore, the tagging analysis and NCAM are not entirely independent. A participant asked whether DFO has tried estimating M from the tagging data and it was explained that it has been tried; however, the results were not reliable as there is not enough comprehensive tagging of Northern cod. There was a suggestion to conduct a sensitivity analysis around M and reporting rates and to present the directions of change along with the assumptions concerning M.

There was discussion surrounding the reporting rates. It was stated that reporting rates are recalculated every year based on tag returns. It was explained that there is a published model that describes the methodology. The model refits the whole time-series of data every year; recapture data in each successive year is included and the model fit is updated. It was noted that the earlier values tend to change very little. There is evidence that reporting rates have been declining (from over 80% to 50%) and it was suggested that inflation may be decreasing the value of the reward. There was a question regarding whether there are differences between the reporting rates from the stewardship fishery and the recreational fishery. It was explained that the returns are bumped up by the respective reporting rates and added together; however, typically the stewardship fishery has a higher reporting rate. As well, it is unknown whether there is a difference between the stewardship and recreational fishery with respect to returns for high reward tags versus low reward tags. Nonetheless, it is assumed in the model that there is a 100% reporting rate for high reward tags from the stewardship and recreational fisheries.

SENTINEL SURVEYS 1995-2017 – CATCH RATES AND BIOLOGICAL INFORMATION ON ATLANTIC COD (GADUS MORHUA) IN NAFO DIVISIONS 2J3KL

Presenter: L. Mello

Abstract

Catch rates and biological information for Atlantic Cod from the Sentinel Survey Program in NAFO Divs. 2J3KL are updated for 2017. Results from the standardized age-disaggregated catch rate model indicated that fish 5-7 year old accounted for most of the large mesh gillnet catches during the period 2002-08, when an increase in relative stock size was observed. However during a subsequent increase in stock size (2011-14), up to half of the sentinel catches were comprised of fish 7-10 year-old, whereas fewer fish age 5 and younger were caught by large mesh gillnet since 2015 (coinciding with a period of stock decline).

Temporal trends in gillnet (small 3¼ inch mesh, large 5½ inch mesh) and linetrawl unstandardized catch rates were initially similar for all gears, with relatively high values at the beginning of each time-series, followed by sharp declines in the late 1990s-early 2000s. Catch rates for small mesh gillnet and linetrawl oscillated around or below the series' overall mean catch rate thereafter, and increased for large mesh gillnet until 2014-15. Catch rates for all gears declined since then. Mean catch rate for large mesh gillnet was consistently higher than that of small mesh gillnet for most of the time-series.

Sentinel catch rates were standardized using Generalized Linear Models, and the explanatory variables used in both age-aggregated and age-disaggregated models (Year, Month, Fishing Site) were highly significant ($P < 0.0001$) in all cases. For large mesh gillnet, standardized catch rate-at-age in the Northern area was stable at low levels in 1995-2004 (mostly ≤ 6 year-old fish), then increased rapidly and peaked in 2015 before declining over 2016-17. The contribution of ≥ 7 year-old fish increased considerably since 2012 (coinciding with an increase in catch rates),

while several year-classes (i.e. cohorts) were represented during this period. Catch rates in the Central area were higher at the beginning of the time-series (mostly 6-8 year-old fish), declined rapidly to their lowest values in 2002, and then followed a pattern similar to that of the Northern area. Several year-classes were tracked through the late 1990s-2000s, and more recently. Catch rates in the Southern area declined rapidly over 1998-2002, then remained stable at low levels. Variations in age composition through this time-series were similar to those of the Central area. Catch rates for small mesh gillnet in Northern and Central areas indicated patterns similar to those of large mesh size gillnet. In the Southern area, catch rates declined until 2014, then increased by nearly ten-fold over 2015-16. Temporal trend for linetrawl (Central area) was also similar to those of gillnets in Northern and Central areas (mostly 3-8 year-old fish). Three to five year-old fish were well-represented in 1995-2008, but declined thereafter. Age-aggregated catch rates showed patterns similar to those of age-disaggregated estimates in all cases.

Length frequencies of cod measured in Sentinel Surveys indicated that large mesh gillnet and linetrawl captured larger fish from specific size ranges; whereas the small mesh gillnet retaining small and large fish from multiple length-classes. Indices of physiological condition for both males and females cod (Fulton's condition factor, Hepatosomatic Index, and Gonadosomatic Index) varied seasonally and annually.

Total removals (control plus experimental sites, all gears combined) of cod caught in Divs. 2J3KL Sentinel Surveys (1995-2017) peaked at 388 t in 1998, declined to 92 t in 2003, reached 270 t annually over 2012-15, and then declined to 173 t in 2017. Several fish species were recorded as Sentinel bycatch in 1995-2017: American Plaice and Winter Flounder were the most common in large mesh gillnet.

Discussion

There was discussion on the results presented for the condition indices. It was noted that the two body condition indices are declining at the same time that the gonadal index is increasing, and the population appears to be partially increasing as well. A question was asked to clarify whether this is indicating that there is a reallocation towards reproductive tissue rather than somatic growth. It was suggested that this effect could be due to a large amount of older fish in the time series in recent years and the fact that gonad growth for larger cod is not linear. It was noted that there has been a shift in the timing of the sentinel fishery that affects the condition indices. The seasonal cycles remain, but the timing has shifted in the season and that affects the actual condition indices. At least part of the trend over time is because of the change in the timing of the survey.

There was discussion regarding whether there might be overdispersion in the generalized linear model used for the sentinel survey results. It was suggested that there may be slight overdispersion apparent in the residual plots and that perhaps a negative binomial or overdispersed Poisson model would produce a better fit.

There was a question regarding the bycatch results presented and whether the clear decline in bycatch levels after 2012 are due to a change in method or lower availability of other species to catch. It was explained that the number of fishing tows for the large mesh gillnets has declined over time. There was a suggestion to investigate the impact of the site occupancy of the survey as some of the sites have been dropped throughout the years which could affect the bycatch levels.

NCAM – NEW DEVELOPMENTS (NATURAL MORTALITY AND CHANGES)

Presenter: P. Regular

Abstract

The cause of the 1991 collapse of Northern cod has long been debated, and debate continues in the context of a recent decline in the stock in 2017. Then and now, two confounded forces are at play: fishing mortality (F) and natural mortality (M). The integrated use of catch, survey and tagging data presumably helps the Northern cod assessment model (NCAM) differentiate F and M, and this model strongly suggests that M is the main factor driving the declines observed in 1991 and 2017. However, it is possible that a significant portion of M estimated by NCAM actually represents unreported catch (i.e. F). In this presentation, we modified several inputs to NCAM to explore different scenarios that may explain the dynamics observed in the stock. First we postulated that unreported catch was a bigger problem than previously assumed, and that the problem tended to be greatest when presumed M events occurred. Contrary to expectations, the model increased biomass to account for the higher assumed landings rather than decrease M and increase F. Results were similar under a scenario whereby misreporting was assumed to be greatest between 1990 to 1991 and 2016 to 2017. Second, we explored the hypothesis that significant numbers of cod died from starvation during the observed M events. For this hypothesis we approximated starvation mortality by calculating the portion of cod below a critical condition factor identified in experimental work, below which cod are very likely to die from starvation. An alternate condition-based natural mortality matrix (K shift) was therefore generated and this was the model re-run and compared to the base case NCAM model run which used the input M matrix accepted in the 2015 framework (M shift). We found good correspondence between this starvation-based estimate of M and M estimates from NCAM, and there were marginal improvements to model fits when the baseline estimates of M supplied to NCAM include starvation-based estimates of M. These explorations indicate that starvation may be playing a significant role in the trends observed in this stock. Integrating condition and other links to prey availability appears to be a promising avenue for reducing process error and improving projections.

Discussion

There was discussion surrounding the baseline M used in the model and why there is already a shift in M in the 1994 period. It was explained that this shift in baseline M was introduced to reduce the process error through that period because in earlier fits of the model the process error was high through that period. With less of a shift in the baseline, even though NCAM can estimate M it does not put the mortality into M, it puts it into process error. It was noted that baseline M is essentially the average of the autoregressive process. The presenter had previously tried to estimate baseline M, however the model would not converge. There was a suggestion to make the variance of the autoregressive process larger in that period and the presenter indicated more time was required to potentially explore this.

There was a question regarding the use of tagging data in NCAM. It was explained that tagging data does not go directly into NCAM; rather it is used to allot the portion of tags assumed to have gone into the fishery throughout the year. It was noted that within the model the assumption is that 100% of the high reward tags are returned.

There was discussion concerning the bounds surrounding the catch. There was a suggestion to consider the entire time-series of the bounds. It was noted that little time was spent on the bounds in the NCAM Framework meeting, but was the subject of considerable debate during the March 2016 assessment meeting. It was suggested that the bounds could possibly be more relaxed for the 1989-92 period because a lot of the fish went deep or outside the 200 mile limit in this period and were vulnerable to outside fleets. Therefore, the bounds should not be the same as those used for the next 15 years. There was agreement to test alternate catch bounds. It was noted that this was a source of uncertainty in the previous SAR, which recognized that the catch bounds may not be correct.

There was discussion regarding the decline in catch rates in the sentinel survey. It was noted that the age structure is different between the sentinel and RV surveys and there was a drop off of older age classes in the RV survey that was not observed in the 5.5” gillnet sentinel survey. It was noted that direct comparison of the two was not appropriate due to considerable differences in age-specific selectivity of the gear type in each survey. It was suggested that this could be due to distributional shifts or due to the extended 2017 fishery. The 2017 fishery had a longer overlap with the sentinel survey that may have had an effect. As well, it was suggested that this could be due to the RV survey covering Divs. 2J3KL and the sentinel survey primarily covering Div. 3K. It was noted that the RV survey observed the largest decline in Div. 3K. It was also noted that the overall scale of the sentinel survey is not as important as it is adjusted over time by a random walk parameter. The real utility of the sentinel data in the integrated model is from the age composition.

There was comment regarding the apparent consistent underfitting of RV survey observations in the most recent time period. It was explained that this might be exaggerated in the residual graphics by the underfitting to the Age 2 fish, which could be providing the greatest contribution to the perception of underfitting and that the age-based residuals should be of primary consideration.

There was discussion surrounding the trends of M at age presented, specifically the large increase in natural mortality in 2017. It was noted that it is peculiar that it focuses on the older ages which are selected by the fishery; however, it was explained that the pattern is also observed in ages not caught in the fishery. The results of the model indicate that this change is not completely a fishery issue. One participant noted that spikes in the natural mortality of the 2017 magnitude have been seen before in the post-collapse period; however, the age structure is different. One explanation suggested for the increased mortality in older fish was that it is the age when cod start feeding on capelin and capelin have declined. It was noted that there are many signs in the biological (condition) data that fish were of small sizes and potentially indicating that starvation and death may be a factor.

One participant commented that in the proceedings document from the 2015 Regional Northern cod Framework Review Process (DFO 2016a) there was recommendation for a leave one out type of approach where different data sources were excluded from the model to see what direction different sources of data are pulling the model. It was explained that each piece of data appears in many places and therefore there are many interacting parts to consider in this type of approach. It was suggested that a change in the down weight of different data sources might be an easier solution for testing this.

There was discussion regarding the timing of the Regional Peer Review Process and why the meeting is in late March when the fishery does not open until the summer. There were concerns that there was limited time for data to be fully analyzed and documentation circulated for review prior to the meeting. It was noted that the RV survey ends in December and then 10,000 otoliths must be aged and extensive data editing take place, which leaves limited time for analyses and modelling.

Some participants expressed concern that there was not enough time for a thorough review of the NCAM model in the present meeting or in previous meetings; however, the majority opinion of participants was that there was a quality review in the 2015 Regional Northern Cod

Framework Review Process (DFO 2016a) and 2016 Regional Peer Review Process (DFO 2016b). There was concern that a working paper on the models had not been circulated prior to the meeting and that it was difficult to provide a detailed peer review without a quantitative documented model with equations and likelihood components. There was a suggestion to set a deadline for provision of documents and if they are not provided by the deadline then they will not be part of the Peer Review Process. It was noted that multiyear assessment periods allow more time for exploring the data and model and preparing documentation.

There was extensive discussion surrounding which of the three models presented (Capcod, K shift model, and M shift model) to accept for the present assessment. Many participants felt there was promise in the K shift model, but that it is premature to use at the moment. There was agreement that there is more to explore with this model and it was recommended for further research. One participant noted the consistency in all three models in indicating similar output of the current state of the stock as well as the direction it is heading. There was a suggestion to lump the models; however, many participants felt the Capcod and K shift models were not ready for use. One participant expressed reluctance in using NCAM as the basis of advice for the current assessment as basing advice on the NCAM projection for the last two years has resulted in a decline in SSB. It was noted that there is work to be done to improve the model. One participant commented that nothing was presented to indicate that the model was drastically wrong and did not see any problems in terms of goodness of fit or the diagnostics. It was acknowledged by multiple participants that improvements can be made to the model; however, it can still be used to achieve a sensible assessment in the short term.

There was consensus to accept the NCAM M shift model to make predictions in the current assessment, particularly because the model was thoroughly reviewed in the 2015 Regional Northern Cod Framework Review Process (DFO 2016a).

NCAM – RESULTS AND PROJECTIONS

Presenter: P. Regular

Abstract

The Northern cod assessment is based on a state-space population dynamics model (Northern Cod Assessment Model, NCAM) that integrates much of the existing information about the productivity of the stock. The model integrates information from DFO RV autumn trawl surveys (1983-2017), Sentinel fishery surveys (1995-2017), inshore acoustic surveys (1995-2009) fishery catch age compositions, and partial fishery landings (1983-2017), and tagging (1983-2017). Data on distribution of the stock and catches from logbooks, biological information from the fishery and RV survey, as well as length measurement samples from the recreational fishery (though not total estimates) was also examined.

The abundance of Northern cod remained low for more than a decade after the collapse and moratorium in 1992, but increased in recent time. The latest assessment indicated that stock abundance (ages 2+) has increased from 227 million cod in 2005 to 688 million cod (95% CI, 407-1165) in 2018. Recruitment (age 2) increased from lowest estimated levels of 36 million fish in 1995 to an average of 251 million in 2011-15. This recent average is 19% of the pre-collapse period of the 1980s.Total biomass (ages 2+) shows a similar trend to abundance and increased from 86 Kt in 2005 to 467 Kt (95% CI, 343-635) in 2018 (down from over 600 Kt in 2016 and 2017).

Spawning stock biomass declined rapidly in the late-1980s and early-1990s and has remained low but shows an increasing trend in the last decade. Spawning stock biomass has increased from 26 Kt in 2005 to 315 Kt (95% CI, 224-445 Kt) in 2018, down from 441 Kt in 2017.

Spawning stock biomass has been well into the critical zone of the Precautionary Approach Framework since the stock collapse, and although it increased in 2017 to 52% of Blim, it has declined to 37% of Blim in 2018 (95% CI, 27-51%). Much of this decline in SSB from 2016 to 2017 is driven by the estimate of natural mortality (M) increasing from 0.34 in 2015 to 0.74 in 2018. Low availability of capelin, declining mean weights at age and poor condition of cod also point to evidence of low productivity of the stock and ecosystem in general.

Discussion

There was discussion on whether participants had confidence in the M projection presented. It was stated that the M projection hinges on many factors with relationships that are not well understood, making it difficult to have complete confidence in the projection. It was noted that this issue will define much of the upcoming research, as more work is needed before a reasonable M scenario can be predicted with confidence. There was a suggestion to include this in the sources of uncertainty section in the document and to include the outlook for capelin along with these uncertainties. There was agreement to keep the proposed projected M, but describe the uncertainty in the elevated M at the end and the implications in short-term projections in the Science Advisory document to be prepared. It was stressed that it should be made clear in the document that natural mortality can change year to year and that this must be kept in mind when making a decision about how far to project.

Based on the observation that the confidence intervals in the projection appear to flat line around the year 2020 indicating that the mortality cannot reach the low levels of the early-2000s, there was a question as to why the distribution of mortality appears to be unchanging. It was suggested that it probably reaches a steady state in a short period due to the dynamics of the AR-process.

The Terms of Reference for the current meeting requested three year projections of Spawning Biomass relative to the limit reference point (Appendix I) and there was discussion surrounding whether participants felt confident in providing three year projections. There was a suggestion to only consider one year projections, as all three models presented showed similar one year projections. It was asked whether three year projections were necessary given annual assessments. One participant noted that 3Ps cod assessments use one year projections due to annual assessments and very wide uncertainty, both of which apply to the Northern cod stock in Divs. 2J3KL. Many participants were not confident projecting further into the future given the sometimes large interannual changes in M. It was noted that a three year projection was provided in the previous assessment (DFO 2016b) and the observation and projection for 2017 were close; however, the 2018 observation was near the lower bounds of the confidence limits for the projection. At the conclusion of this discussion, there was consensus to present a one year projection and provide a risk based output to address the catch multipliers stated in the Terms of Reference.

BIOMASS GROWTH POTENTIAL

Presenter: J. Morgan

Abstract

This work was based on concepts and methods developed in Morgan, M.J., P.A. Shelton, F. González-Costas, and D. González-Troncoso. 2016. Compensation potential in six depleted groundfish stocks from the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 73:257-269.

The number of recruits per spawner and the spawner biomass per recruit define the productivity of a stock. These are not constant over time. RPS and SPR (at F=0) were calculated for each

year from 1983 to 2015 from the inputs to, or output from, NCAM. Both showed substantial variation over time. These were used to estimate population growth rate potential. There was large variation in biomass growth potential from +53% to -68%. Over the time period the average annual population growth potential was only +5%. There were very large changes observed from year to year. For example, in 2000 population growth potential was +53% while in 2001 it was -21% while it changed from -49% to +30% between 1994 and 1995. In both cases this large change was a result of large changes in the estimate of M in the NCAM model between years. A comparison of these results with similar analyses for 6 other gadoid populations found that no stocks had population growth as low as the lowest estimates for northern cod and that few ever had growth rates as high as the highest estimates for northern cod. The estimates of M in NCAM have a large impact on the estimated potential growth. Using the M estimated by NCAM for 2017 biomass was estimated to decline by 36% in 2018, even in the absence of fishing. If the average M from 2013-15 is used the population was estimated to grow by 32% in the absence of fishing. The large variation in M from year to year estimated by NCAM makes the prediction of upcoming productivity very difficult.

Discussion

There was a question regarding the work presented on potential annual percent SSB growth rate at F=0 when the stock is below the breakpoint and whether this used data from another project or current Northern cod work. It was explained that it is using current Northern cod data. To get that relationship, the presenter simulated the potential population growth rate at F=0 with the assumption that recruitment is recruits per spawner and that there is a stable age composition. To do this the population is driven down and then allowed to grow until there is a stable age composition and then the resultant percentage biomass growth rate at that point is the potential growth.

There was a question regarding how to account for an M that is changing in time with an essentially equilibrium model. The model is essentially presenting the spawner composition and recruits per spawner under current conditions. It is trying to come up with a metric that will give an idea of the current potential growth rate without doing an entire age structure population model.

REFERENCE POINTS – REVIEW/DISCUSSION

Presenter: K. Dwyer

Abstract

The conclusion from the last framework for cod reference points (DFO, 2010) was: “The average SSB during the 1980s is considered as the limit reference point for 2J+3KL cod. SSBs in the 1980s were the last to produce medium levels of recruitment. After the 1980s SSB has been low and recruitment poor, indicating that the stock has been below a level where serious harm occurs.” It was also concluded: “This LRP should be re-evaluated once more data, particularly at higher stock sizes, are available.”

At the 2018 Northern cod assessment RAP, two new “intermediate” SSB points were reviewed to ensure that these new points still fit the conclusions from the 2010 framework. At the 2018 Northern cod assessment there were two new stock-recruit pairs with SSB levels higher than all others since the stock collapsed. These were reviewed to ensure that these new points still fit the conclusions from the 2010 framework. and although these two new points fell in the middle of the spawning stock range of points, there was no evidence of increased productivity at these higher SSB values. Following this review, it was agreed that the current LRPs should be

maintained. Again, considering that the current SSB values were higher than all others in the collapsed period, it was agreed that new information would be frequently reviewed to see if there was improved productivity, potentially leading to a revision of the current LRP.

Discussion

Clarification was provided that reviewing the reference points was not mentioned in the Terms of Reference and that the presentation was meant as an update, not as a discussion to change the reference points. The purpose of the presentation was not to revisit the reference points decision of the Zonal Review in 2010. It was stated that when the LRPs were adopted, it was agreed that they would be reviewed as new points were available. It was explained that if there was a large spike in recruitment at the current levels, that would indicate that a review of the reference points would be required, but this is currently not the case. It was agreed that there is no evidence to reconsider the LRPs at this time.

GENERAL DISCUSSION

There was a question regarding the declines in catch rates shown in the logbook data and whether the logbook data could be analyzed with respect to soak time and the number of nets. This question stemmed from the fact that there may have been some shifts in the catch rates that were not captured in the current method due to a cod quality program that took place last year. The recommendations from the program included a soak time of less than 12 hours (many harvesters only soaked nets for 2 or 3 hours) and a limit of 600 kg per set of nets. The data was rerun for the greater than 65 ft fleet with the soak time included and the trend did not change.

There was a question regarding the apparent mismatch in the age composition of fish caught in the stewardship fishery and in the RV survey in 2016-17 and whether the RV survey missed the older age classes. There were two hypotheses brought forward from participants to possibly explain this: 1) the timing of the cod migration changed and the older cod were not in the survey area at the time of the RV survey and; 2) the older cod were in poor condition and did not make it through the summer to be caught in the RV survey. In reference to the first hypothesis, it was noted that there was acoustic work done in the past with intensive coverage in 1997 (Anderson et al. 1998) along the coast to address the issue of whether cod are shoreward of the RV survey area at the time of the survey. That work found no aggregations of cod outside the RV survey area. As well, it was noted that there was nothing in the telemetry data from the past year to indicate that this was happening. One participant stated that harvesters have indicated that this past year the cod were inshore later in the season, similar to what was observed during “the bad years”. As well, an industry participant noted that he was fishing inshore in Div. 3K at the same time the RV survey was surveying Div. 3K offshore and he was getting huge catches. One participant commented that the same question was raised with regards to the Scotian Shelf data this past year and the bottom temperature of the survey area relative to the core area of the fish was explored, as inshore and offshore migration patterns are thought to be influenced by temperature and seasonality. The Divs. 2J3KL bottom temperature data was quickly explored and the bottom temperatures at the time of the fall RV survey were very close to the long-term average indicating the 2017 RV survey was in line with previous years when this mismatch was not present. It was also pointed out during this discussion that, in general, differences in age compositions between these data sources are not unexpected because the gears employed in each survey have different selectivity (i.e. different capture efficiencies of the various age groups).

It was noted that in the model the fit is in between the two sources of data, therefore the model is not discounting one source of data over the other. In instances where the data are going in different directions, the model splits the data and tries to find the middle ground. Additionally, the model weighs in the tagging data and tries to find middle ground between all these data sources. There was a comment that since the age composition in each index is modelled separately, this mismatch in age composition between the RV survey and catch is less of a concern.

REVIEWER 1 REPORT

Presenter: T. Miller

The NCAM assessment model represents one of the most statistically advanced approaches to assessing fish stocks. It integrates tag-recovery data with relative abundance indices and commericial and recreational catches and their associated age composition observations. The state-space model separates interannual variability in population processes from the stochasticity arising from sampling the population at specific time points. Several population processes are treated stochastically including natural mortality, catchability, fishing mortality, and departures between fishing mortalities acting on the tagging and the entire stock. Below are some comments and thoughts primarily on the way the assessment model is configured.

Tagging data

Uncertainty in the reporting rates for the tag-recoveries was incorporated using a prior based on the results from previous analyses. To more accurately estimate uncertainty in the assessment model results, it could be useful to incorporate similar priors for other of the nuisance parameters associated with the tag-recovery component of the model (e.g., tag-shedding rates, tag-induced mortality).

The use of high reward tags in tag-recovery experiments allows estimation of the reporting rates for the more common tags with a much smaller reward. However, this practice requires the assumption of the reporting rate (often 100%) for the high reward tags. In future tag releases, it could be beneficial to release several reward levels because this type of experiment allows the possibility of estimating a relationship of reporting rates to the reward level (Nichols et al. 1991).

Analyses of the tag-recovery experiments outside of the model estimate reporting rates separately for different components of the fishery for northern cod. This analysis could be generalized to estimate reporting rates for high reward tags in one of the fishery components holding the reporting rate constant for the other fishery component. The obvious choice is to hold the reporting rate constant for whatever component is showing the higher reporting rate of high reward tags, but this can be determined by comparing results with the assumption made for each fishery component.

Since the original application of the NCAM model there has been further analyses of the tagging data to estimate ages of the tagged fish at release. These ages are used in the NCAM model to attribute age- specific F and M to these releases. However, these age estimates have error and incorporating this uncertainty into the NCAM model would allow more realistic uncertainty in the resulting estimates.

Finally, only a subset of tagging experiments are used in the NCAM model with release numbers greater than some criterion. Including these smaller tagging experiments seems sensible and would provide all the available data to the model.

Fishery components

If feasible, it would be beneficial and more transparent to model the fishery components as separate fleets in the NCAM model. There appears to be changes in the relative contributions of the different components over time and they likely have different selectivity at size. This would also be consistent with the treatment of reporting rates for tag-recoveries in different fishery components and allow those estimated reporting rates by fishery component to be incorporated.

Simulation testing

Cadigan (2016) performed a simulation self-test for the original NCAM model. It would be beneficial to perform analogous simulation studies for updated NCAM models, particularly when there are fundamental changes to the model (e.g., how tagging data inform the parameters of the assessment model). Adding simulation into the Template Model Builder (TMB; Kristensen et al. 2016) code would allow easy self-testing of models. It would also allow testing the consistency of the simulations and evaluation of the Laplace approximation of the marginal likelihood.

Catch multipliers

Replacing the censored likelihood with an additional random effect process would allow the propagation of uncertainty of this underreported component. It would also allow the simulation and stochastic projection of the unreported catch. For example a logistic normal random effect that is autoregressive over time could be used with the specification of upper and lower bounds in the current framework.

Natural Mortality

Estimation of natural mortality in an assessment model will include all mortality sources that are not explicitly modeled and can be effected by assumptions made for other parameters in the model such as catchability and fishery selectivity. Higher natural mortality rates for young, small fish is more likely than that for older large fish in iteroparous species. Estimates over time from the NCAM model often exhibit the opposite to this expectation for cod. Cadigan (2016) noted the high natural mortality estimates in the early 1990s for this cod stock, but the estimates from the work cited are much lower than the estimates from the NCAM model. The high natural mortality values that have been considered in some models for Gulf of Maine and Georges Bank cod stocks are also much lower than the high values of NCAM.

Given the expected changes in natural mortality with size and estimates of natural mortality for other cod stocks, I suggest exploring alternative structures for modeling natural mortality in NCAM. First, evaluate the degree of net emigration from the northern cod stock area with the extensive tag-recovery experiments. This net emigration could be modeled as a component of apparent natural mortality in NCAM. Second, it is surprising that the oldest age group is not treated as a plus group. That is it does not aggregate the oldest modeled age and those older than that in the population. The NCAM code could be modified fairly easily to make have a plus group and it would be interesting to see if and how this changes estimates of natural mortality. Third, the mean (at age) of the first-order autoregressive process for natural mortality should be estimated. At the minimum this would allow more realistic uncertainty of estimates of natural mortality by age and year. Fourth, there was a presentation at the meeting of an interesting initial approach to including effects of condition factor on annual natural mortality estimation. I suggest further investigation of the use of condition factor at age as a covariate of natural mortality. Effects of other covariates such as capelin abundance that are hypothesized to influence cod condition might similarly be estimated in NCAM. There are methods to account for uncertainty in these covariates and include process models for their transitions and projection (e.g., Miller et al. 2016, Miller et al. 2018)

Projections

In the current NCAM configuration, annual recruitment is a random effect around a time-series mean. For such processes projected recruitments are all equal to the estimated mean value. If recruitment were treated instead as an autoregressive process and the autocorrelation is estimated to be positive, projections are closer to the preceding year and eventually return to the mean. This could provide improved near-term projected recruitments and their precision.

Restricted Maximum Likelihood (REML) might also be important for projections. The maximum likelihood estimates of variance parameters will be negatively biased and REML estimation will reduce this bias. The uncertainty in the projections is a function of these variance parameters and if REML is used, the uncertainty in the projections may be more accurately estimated. REML estimation in TMB can be accomplished by treating all fixed effects parameters other than variance parameters as random effects with flat priors (Harville 1974). Miller et al. (2018) provides an example of how to do this in TMB.

Final comments

The NCAM model currently begins in 1983, but there are catch and index data prior to this. Consider extending NCAM further back in time to make use of these data sources. To accomplish this, it may be necessary to augment NCAM with other submodels for fishing mortality and catchability.

Given the difficulty in attributing total mortality in the early 1990s to fishing and natural sources, it seems an alternative limit reference point that is robust to this partitioning would be helpful because it would not affect management advice. One such approach would be to use spawning potential ratio based reference points with recruitment, selectivity, maturity, and natural mortality rates in years after the early 1990s.

Discussion

There was no discussion on the review presented by T. Miller.

REVIEWER 2 REPORT

Presenter: R. Forrest

The objective of this review is to provide an external evaluation of Northern Cod (Gadus morhua) stock assessment and, hopefully, provide some useful recommendations for work in the coming year. The next stock assessment for Northern Cod is scheduled for 2019.

A complete working paper was not available before the meeting, therefore my comments are based on reading previous documents (Cadigan 2015; 2016a,b; DFO 2016), superficial review of the NCAM model code and outputs (kindly provided by Dr Regular), and presentations and discussions in the Regional Peer Review (RPR) meeting. In future, I strongly recommend provision of a complete working paper to reviewers at least two weeks prior to the RPR meeting. This may require delay of the RPR, since this year the assessment authors only received the final data a week before the RPR. Given that the fishery does not open until the summer, this seems as if it could be accommodated. Also, if alternative models are to be presented, where reviewers are asked to comment on their acceptability for advice, these should be documented as appendices in the working paper, and also included in the RPR Terms of Reference.

Prior to presentation of NCAM results there were several presentations on ecosystem factors, including ocean and climate conditions, zooplankton abundance, abundance of Capelin (key prey for Cod), cod condition, juvenile cod observations and some ecosystem models (Empiric

Dynamic Modelling and a coupled Cod-Capelin production model). I found the ecosystem information interesting and it provided useful context for later discussions on natural mortality of Northern Cod. I think Pacific Groundfish stock assessment RPR meetings would benefit from similar ecosystem information. A framework for better reviewing and integrating this type of information into the advisory process is needed, for DFO generally.

The NCAM stock assessment model is a complex state-space model (Cadigan 2015; 2016a;b) implemented in R and C++, using Template Model Builder (TMB) libraries for estimating parameters as fixed and random effects. Features of the model include time- and age-varying fishing mortality (*F*), natural mortality (*M*), and survey catchability (*q*). The model integrates multiple sources of data, including index and composition data from tagging studies, commercial fisheries, the RV Survey, the Sentinel Survey and Smith Sound acoustic survey. The model allows for uncertainty in catch through the use of a censored log likelihood function that ensures that catch estimates are mostly constrained within upper and lower bounds.

A model configuration called “Mshift” was presented at the meeting, reflecting the assumed average *M* input to the model. The authors briefly presented two sensitivity cases but these have not yet been documented. I strongly recommend the assessment authors conduct and document a systematic set of sensitivity analyses before the next review. Model sensitivities to fixed parameters are especially important. These include:

- fixed autocorrelation parameters, where used (e.g., for fishing mortality)
- fixed variance parameters, where used (e.g., catch likelihood)
- age ranges assumed to have the same values of M, F or q
- fixed average M (see below)
- the addition of 0.5 to zero observations in the composition data
- choice of 1992 for change in average recruitment
- others that may be important

In general, the NCAM model predicts that Northern Cod dynamics are largely driven by *M* (DFO, 2016). Given the history of the Northern Cod stock, I think this aspect of model behavior bears further scrutiny to avoid possible under-estimation of the stock’s response to future increases in fishing mortality. The model estimated a value of *M* around 1.0 y^{-1} in 2017 (ages 8- 14 *y*), representing a doubling compared to the estimates for the same age classes in 2016. In the meeting, this was attributed to low abundance of key prey species (Capelin and Shrimp), although working papers were not available for review.

The model estimates a large spike in *M* in 1992 of 3.46 y^{-1} (age 7) and 2.49 y^{-1} (ages 8-14 *y*). These values are unusually high for Atlantic Cod stocks. I was surprised to learn that the average $M_{a,y}$ <u>input</u> as the base for the random walk in $M_{a,y}$ in the Mshift model includes an assumption of a large peak in *M* between 1991 and 1994 (Figure 1).

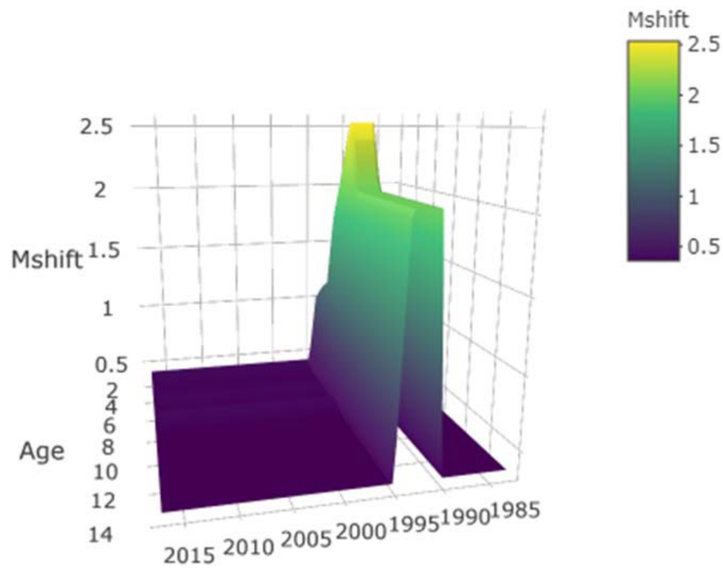

Figure 1. Input average Ma,y in NCAM (Mshift configuration).

I understand that this was done to account for very large estimated process error around *M* in 1992 in the original NCAM model (Cadigan, 2015). Some preliminary sensitivity analyses were presented at the RPR meeting ("Fshift" configuration), where the input average *M* was fixed at 0.4 y^{-1} across all ages and years, and catch bounds in 1990-91 and 2016-17 were increased to reflect the hypothesis that underreporting of catch was much greater in these periods. This did not reduce the estimated 1992 spike in *M* but appeared to result in a re-scaling of model-predicted biomass. In this case, the model estimated catch for these periods to be much lower than the lower catch bounds, which I found curious. Given that both *F* and *M* are allowed to vary with time and age, as well as *q*, which is a major predictor of model scale, I am concerned about confounding among these parameters. The model predicts extremely complex surfaces for all parameters and I would be interested to know which data sources are principally driving their estimates, especially *M*. I suspect that tagging data and the Smith Sound acoustic data may be exerting a strong influence on model predictions. Down-weighting certain data sources in the likelihood function (e.g., the tagging data, Smith Sound acoustic data, age composition data) may be a useful approach for exploring model sensitivity, or development of alternative model formulations that do not depend on all data sources could also be helpful.

In general, I strongly recommend the authors continue sensitivity testing to explore NCAM's assumptions that may be predisposing it to predict natural mortality as the main driver of Northern Cod abundance.

The ability of NCAM to incorporate so many sources of data is one of its strengths, but it may also be a weakness if there are opposing trends in some of the data sources, or if assumptions about the data sources are not well met. Population dynamics of Northern Cod are clearly very complex, with potential interpretation of index and composition data confounded by cod movement and migration, survey timing, natural mortality, tag reporting rates and uncertainty in catches from different sources. I suggest that a single model may not be able to capture all the different sources of uncertainty for this stock. Structurally alternative models (e.g., the SCA model; DFO 2016) may allow for exploration of the data in other ways. Examples could include a model that includes data going back to the 1960s to allow for a view of stock productivity with a longer time horizon; or models that specifically include selectivity functions for different components of the fleet, which might help with understanding of age composition data or help visualize potential spatial interactions between the stock and different components of the fleet.

Model averaging has been used successfully in decision making for several groundfish stocks in the Pacific region (e.g., Pacific Halibut, Pacific Cod), and recently “superensemble” models have been proposed as a means of better representing structural uncertainty in decision-making (e.g., Anderson et al. 2017). Closed loop simulation testing of assessment model performance with respect to a set of fishery objectives (e.g., rebuilding the stock to a certain level with specified probability and time frame) is also recommended as a longer term project. Development of a spatial operating model that captures scenarios of cod movement; alternative stock-recruitment formulations; and/or predator-prey dependencies may be a useful means of identifying management procedures that meet objectives despite large underlying uncertainty.

I also suggest including a simple analysis of surplus production in future meetings (Hilborn, 2001; Hilborn and Litzinger, 2009). These types of analysis can be used to quickly visualize the relationship between biomass and productivity in a fish stock of interest, conditional on model assumptions and outputs. Analyses for Gulf of St Lawrence Cod (Mohn and Chouinard, 2004) and Pacific Herring (DFO, 2017) have shown that fish stocks can rapidly move from high to low biomass states when productivity becomes low and may then remain stuck there for several years, possibly as a result of depensatory processes. Rapid reductions in productivity may be exacerbated by increased fishing pressure (Hilborn and Litzinger, 2009). An example of a biomass-surplus production phase plot, constructed from NCAM estimates of spawning biomass and predicted catch (Mshift configuration) is shown in Figure 2.

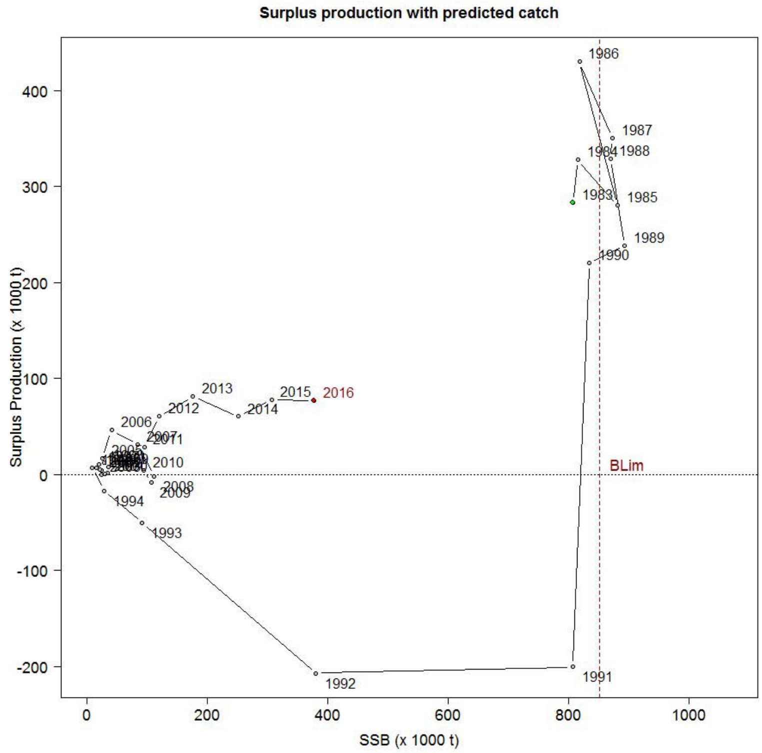

Figure 2. Spawning biomass-surplus production phase plot for Northern Cod based on NCAM outputs.

Finally, I encourage continued development of the NCAM R package that has been built for this assessment, which includes a highly interactive interface for viewing model outputs. The NCAM package enables a much deeper scrutiny of the model inputs and outputs than is usually available at review meetings. I have no doubt that this tool will prove to be useful for future assessments of Northern Cod and other species, both in Newfoundland and in other regions.

Discussion

Clarification was requested regarding the model averaging presented with an example for Pacific halibut and whether there is any weighting used. It was explained that there is no weighting. There was a question as to whether all uncertainties are added together (the highest confidence interval from the models and the lowest confidence interval from the models). It was explained that Markov Chain Monte Carlo methods (MCMCs) are run and the posterior samples that come out of each model are pooled. The probabilities are calculated based on the posterior samples.

R. Forrest gave a small presentation in addition to her assessment review regarding electronic monitoring in the British Columbia Integrated Groundfish Fishery. Discussion took place regarding at sea observer coverage and it was noted that on George’s Bank there is 75-100% at sea observer coverage which has been very successful. It was stated by one participant that the conversation was moving away from stock assessment and into management and that was not the purpose of the meeting.

DRAFTING OF SCIENCE ADVISORY REPORT BULLETS

It was noted that since an integrated model is used to provide advice, the individual sources of data would not be discussed in the SAR bullets. This was agreed upon at the last assessment and would remain for the current assessment.

There was a suggestion to present both the modelled SSB and the survey SSB. There was a concern that there is a difference in the rate of decline between the modelled and survey SSB this year that was not apparent last year; however, it was noted that the trend is the same. It was stated that since the participants accepted the model to produce the projections for one year, then they should accept the model to inform the bullets. There was consensus to only present the modelled SSB.

There was discussion surrounding the inclusion of a bullet about the juvenile recruitment data presented. It was noted that it was the most positive results to be presented in the assessment as there has been positive recruitment in the nearshore environment, daily mortality among juveniles is at an all-time low, and the trends have been demonstrated. There was discussion regarding how this information directly relates to stock wide recruitment and what the integrated model predicts. There was a decision to make this a research recommendation and not include it in the bullets until a comparison can be made with the NCAM output. With regards to recruitment of Age 2 Northern cod, it was noted that there was no bullet on this in the last assessment; however, one of the objectives in the current Terms of Reference was to “assess the strength of year-classes entering the exploitable population in the next 1 to 3 years.” It was decided to include a bullet on Age 2 recruitment, but not include the two most recent years to address the issue of the lag between the ages at which they are caught in the RV survey and to clearly address what is coming into the SSB.

One participant noted that there was a summary point about seals in the last SAR; however, there was not a proposed bullet on seals for the present assessment. As well, there was a harvester perspective that the increase in M may be due to mortality by seals. The participant noted that last year in some local areas there were more seals than ever harvested and they were present for a longer period of time. It was also noted that harvesters are finding a lot of cod in seal stomachs. It was explained that DFO samples 300 seal stomachs every year and analyzes the contents, and there was increased sampling in the offshore this year. It was clarified that there was no updated seal population status and trend data as the analysis of the harp seal survey (i.e. reading of 30000+ photos) carried out during March 2017 was currently taking place. Results from the analyses will be presented during the next harp seal assessment, which by the time of the northern cod assessments did not have a firm date. A clarification was made with regards to the expected outputs of the analysis being carried out. The assessment of harp seals will provide the current population size and trend. To carry out a full impact analysis there are several steps that need to be completed: estimation of amount of northern cod consumed by harp seals, and modelling of the northern dynamics including harp seal consumption as an explanatory variable. A participant stated that there is a published paper on seal and cod dynamics (Buren et al. 2014), that concludes that consumption by seals does not have an impact on cod dynamics; fishery and food availability are the drivers of the stock. There is no indication that the impact of the seals predation has changed since this time. It was decided that there would be some descriptive text about what is known up to this point in the Science Advisory document.

There was discussion surrounding the inclusion of a bullet referencing the ecosystem trends presented. It was noted that one of the objectives in the Terms of Reference was to “provide an ecosystem overview for the stock.” One participant stressed that the three key points from the ecosystem presentation to address were: 1) declining productivity across the board, 2) cod performance and food availability, and 3) the prognosis for these in relation to the stock. It was decided not include a bullet specific to the physical and biological oceanography data presented as it was not specific to cod and falls within the description of “ecosystem conditions” in the bullet.

RESEARCH RECOMMENDATIONS

- More exploration into Capcod model
  - What may have happened in the past?
  - Explore simulation experiments
  - Try a 1 year offset
  - Relationship to NCAM
- Optimize tagging program to better inform assessment model
- Further exploration of cod discards from all fisheries
- Investigate relationships between juvenile cod work and NCAM recruit estimates
- Explore robustness of and improvements to NCAM model
  - Sensitivity analyses to fixed model inputs and assumptions
  - Simulation self-testing
  - Inclusion of stock recruitment model?
- Studies to investigate broad-scale distribution patterns
- Continue to investigate how ecosystem status and trends relate to cod productivity and trends

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APPENDIX I: TERMS OF REFERENCE

Stock Assessment of Northern Cod (Divs. 2J3KL)

Regional Peer Review Process - Newfoundland and Labrador Region

March 19 – 23, 2018
St. John's, NL

Chairperson: Brian Healey

Context

In November 2010, a limit reference point, as described in the decision-making framework developed by Fisheries and Oceans Canada (DFO) for the application of precautionary approach in fisheries, was determined for northern cod in NAFO Divs. 2J+3KL (DFO 2011). A Regional Northern Cod Framework Review Process was held November 30 - December 4, 2015 to review multiple models of population dynamics, and to discuss the utility of various data sets available for assessing this stock (DFO 2016a). The status of the stock was last fully assessed in March 2016 (DFO 2016b) based on the new integrated state space model that incorporates much of the information about the productivity of the stock. A status update was completed in 2017 (DFO 2017) and indicated that the stock is improving but remains in the critical zone. The current assessment is requested by Fisheries Management Branch to provide the Minister with detailed advice on the status of the stock in order to inform management decisions for the 2018 fishing season.

Objectives

- Provide an ecosystem overview (e.g., physical and biological oceanography, predators, prey) for the stock. If possible, this information should be integrated into the advice.
- Provide an assessment of the current status of cod in Divs. 2J3KL using information updated to 2018.
- Assess the current spawning stock biomass (SSB) relative to the Limit Reference Point (Blim), total biomass, strength of year-classes entering the exploitable population in the next 1 to 3 years, exploitation rate, fishing and natural mortality, distribution, and other relevant biological characteristics.
- Identify the major sources of uncertainty, where applicable.
- To assist in the development of the management measures for 2018, conduct three year projections of Spawning Biomass relative to the limit reference point (with 95% [CIs]) assuming total removals are {0.8, 0.9, 1.0, 1.1, and 1.2} times the 2017 value.
- DFO's precautionary approach (PA) framework indicates there is zero tolerance for preventable decline. Identify the level of removals that provide a high probability (>95%) of continued stock growth over the medium to long term (5-10 years). If possible, provide the levels of removals that provide a 0.95 probability of 0, 25, 50 and 75% growth from the 2018 estimate of spawner biomass.

Expected Publications

- Science Advisory Report
- Proceedings
- Research Document

Participation

- Fisheries and Oceans Canada (DFO) Science and Fisheries Management
- Province of Newfoundland and Labrador Department of Fisheries and Land Resources
- Industry
- Academia
- Indigenous Groups
- Non-Governmental Organizations
- Other invited experts

References

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APPENDIX II: AGENDA

Regional Peer Review Process: Stock Assessment of Northern (2J3KL) Cod
Memorial Meeting Room
NAFC, St. John's
March 19-23, 2018

Chairperson: Brian Healey

Activity	Presenter
Monday, March 19 (0900-1700)	**Monday, March 19 (0900-1700)**
Opening/Chair remarks	B. Healey
Introductions/ ToR/ Agenda	B. Healey
Physical oceanography overview	E. Colbourne
Biological oceanography overview	G. Maillet
Key prey (capelin)	F. Mowbray
Ecosystem Overview Ecosystem Model	M. Koen-Alonso M. Koen Alonso
Overview of fishery 2016-2017	J. Diamond (RMAF)
Citizen Science (Dockside outreach of Recreational Fishery)	H. Rockwood
Overview of Enforcement Issues 2015-2017	K. Bungay (C&P)
Catch and Catch at age	B. Rogers/K. Dwyer
Logbook Data	L. Wheeland
Fish harvester questionnaire 2016 & 2017	E. Carruthers (FFAW)
RV Survey Results (index trends, biological)	K. Dwyer
Tuesday, March 20 (0900-1700)	-
Newman Sound pre-recruits	B. Gregory
Tag reporting rates	P. Regular
Sentinel survey	L. Mello
NCAM - new developments (Natural Mortality and changes)	P. Regular
NCAM - results and projections	P. Regular
Reference points - review/discussion	K. Dwyer
Wednesday, March 21 (0900-1700)	-
Reviewer reports	R. Forrest/ T. Miller
Drafting of Science Advisory Report Bullets	All
Drafting of Science Advisory Report	All
Thursday, March 22 (0900-1700)	-
Drafting of Science Advisory Report	All
Friday, March 23 (0900-1700)	**Friday, March 23 (0900-1700)**
Report to Plenary (if Applicable)	All

APPENDIX III: LIST OF PARTICIPANTS

Participant	Affiliation
Brian Healey	DFO Science-NL Region (Chair)
James Meade	DFO Science-NL Region (CSAS)
Mark Simpson	DFO Science-NL Region
Dave Coffin	DFO Resource Management-NL Region
Julie Diamond	DFO Resource Management-NL Region
Darrell Mullowney	DFO Science-NL Region
Joanne Morgan	DFO Science-NL Region
Erin Carruthers	Fish, Food and Allied Workers Union
Deborah Austin	DFO Science-NL Region
John Brattey	DFO Science-NL Region
Tom Bird	DFO Science-NL Region
Everett Roberts	Harvester
Basil Goodyear	Harvester
Timothy Miller	National Oceanographic and Atmospheric Administration
Robyn Forrest	DFO Science-Pacific Region
Rob Kronlund	DFO Science-Pacific Region
Karen Dwyer	DFO Science-NL Region
Julia Pantin	DFO Science-NL Region
Alejandro Buren	DFO Science-NL Region
Andrew Cuff	DFO Science-NL Region
Laura Wheeland	DFO Science-NL Region
Kris Vascotto	Groundfish Enterprise Allocation Council (GEAC)
Shelley Dwyer	NL Department of Fisheries and Land Resources
Derek Butler	Association of Seafood Producers (ASP)
Gary Maillet	DFO Science-NL Region
Eugene Colbourne	DFO Science-NL Region
Fran Mowbray	DFO Science-NL Region
Hannah Murphy	DFO Science-NL Region
Hilary Rockwood	DFO Science-NL Region
Paul Regular	DFO Science-NL Region
Bob Rogers	DFO Science-NL Region
Jenna Makrides	DFO Science-NL Region
Gillian Forbes	DFO Science-NL Region
Luiz Mello	DFO Science-NL Region
Sherrylynn Rowe	Marine Institute-CFER
Janice Ryan	WWF Canada
David Belanger	DFO Science-NL Region
Eric Pedersen	DFO Science-NL Region
Robert Gregory	DFO Science-NL Region
Eugene Lee	DFO Science-NL Region
Chelsey Karbowski	Ecology Action Centre
Greg Robertson	DFO Science-NL Region
Mariano Koen-Alonso	DFO Science-NL Region
Daryl Walsh	DFO – Conservation and Protection – NL Region