Calculation of the food provision index

for the Western Scotian Shelf and Bay of Fundy

(NAFO division 4X).

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# Introduction

Bay of Fundy Ecosystem Partnership (BoFEP) has initiated a project to recalculate the Ocean Health Index score for the Western Scotian Shelf and Bay of Fundy (NAFO Division 4X). This report documents the project section focusing on wild-caught fisheries status in the region. The mandate was to aim at using a similar methodology as that used for the coast of the western U.S. (California, Oregon, Washington), adapted to Canadian available data and assessments. Reference points were derived based on 3 methods: stock assessment, survey indices, and catches. Stock scores were mainly calculated using biomass indices (B/Bmsy). This report compiles data, results using various methods, and explores sources of uncertainty.

# Methods

## Data

I used landings for NAFO division 4X which straddles Nova Scotia and New Brunswick. The summary of catches provided by DFO for this work did not correspond to what I had for some species (e.g. herring, cod and halibut) and were often too aggregated to be useful (e.g. other finfish includes 26 taxa among which: mackerel, swordfish, tuna, sharks etc.). Thus, catches were extracted from stock assessment documents or taken from an extraction of catches from DFO databases used in a previous project (de Araujo, 2010, DFO, Dartmouth, pers. comm.). This has 2 implications. 1. catches from stock assessments documents sometimes included 5Y depending on the stock structure (e.g. white hake, western pollock). 2. species landings from the catch data I had obtained in 2010 stop in 2008 while landings from stock assessments are compiled up to 2008-2013 (except for cusk: 2006). Thus the present calculation represents the period 2008-2013, depending on the source of the landings, stock assessment or 2010 landing extraction from the database.

Biomasses were extracted from stock assessment documents or from DFO survey biomass index ([D. Clark, 2015, pers. comm., published in DFO 2013](#_ENREF_14)). The distribution range of some stocks is larger than the study area (e.g. tuna, swordfish, halibut, sharks) and reference points convey the entire stock status without indication of possible changes in the study area due to changes in behaviour, for instance. The importance of a stock in the study area is based on the long-term average of catches in 4X or 4X/5Y as available. Details on the species/stocks used in the analysis are listed in Table 1 while stocks for which no information was available are listed in Table 2.

## Indices and reference points

The global Ocean Health Index (OHI) 2013 ([Lowndes Stewart et al. 2014](#_ENREF_26)) used catches and biomass data and reference points within each Exclusive Economic Zone (EEZ) to calculate an index of health. The biomass indices are typically derived from the ratio of current catch (yield, Y) and the yield at maximum sustainable yield (MSY) using the method described in Martell and Froese ([2013](#_ENREF_27)). The ratio Y/MSY is then transformed into B/Bmsy ([Froese et al. 2012](#_ENREF_17)) used to characterise the stock status, utilizing:

B/Bmsy = 1 ± (1- Y/MSY)0.5 equation 1

For the data-rich US west coast, reference points were derived from stock assessment and both ratios B/Bmsy and F/Fmsy were used in the calculation of the food provision score ([Halpern et al. 2014](#_ENREF_20)). Given data limitations and lack of estimates for Fmsy and/or F in Canadian stock assessments, I used mainly B/Bmsy while F/Fmsy was included in one occasion only.

Reference points are preferably based on the stock assessments published by the Canadian Department of Fisheries and Oceans. Following the precautionary approach, Canadian reference points can be based on analytical assessments or on rule-based criteria ([see Box 1 and DFO 2012c](#_ENREF_13)). In absence of reference points for a stock, I used DFO survey biomass indices to derive *ad hoc* reference points inspired from the rules listed in Box 1, and chosen in order of preference, as follows:

1. the average survey biomass index of a productive period was used as a proxy for Bmsy.
2. In absence of a discernable productive period, 50% of the maximum historical biomass was used as a proxy Bmsy.
3. When biomass index has been increasing over time (e.g. barndoor, little and winter skates) the long-time series average was used.

Biomass indices and reference points were obtained using all possible methods: stock assessments, surveys, and catches (Y/MSY). For comparison purposes, B/Bmsy based on the surveys were calculated for the same years as that of the stock assessment and for current years i.e. the 2012-2014 average biomass. The latter was kept for calculating the Fisheries provision score.

### **Box 1. Canadian Reference Points**

In Canada, reference points were defined for several stocks on formal analytical assessments **or** based on rules developed in the national precautionary approach guidelines ([DFO 2009](#_ENREF_7)).

In absence of an estimate of Bmsy from an explicit model, the provisional estimate of Bmsy could be taken from the 3 options listed below in a decreasing order of desirability:

1. The biomass corresponding to the biomass per recruit at F0.1 multiplied by the average number of recruits;
2. The average biomass (or index of biomass) over a productive period;
3. The biomass corresponding to 50% of the maximum historical biomass.

In absence of an estimate of Fmsy from an explicit model, the provisional estimate of Fmsy could be taken from the 3 options listed below in a decreasing order of desirability:

1. The fishing mortality corresponding to F0.1;
2. The average fishing mortality that did not lead to stock decline over a productive period;
3. The fishing mortality equal to natural mortality inferred from life history characteristics of the species.

## Stock score calculation

The stock score calculation for fisheries includes 2 forms of penalty for biomass indices. A stock score is low when B/Bmsy is lower than 1, indicating overfishing, while an underfished species (B/Bmsy >1) is also penalised but in a lesser proportion. The 2013 global OHI assessment set a 5% threshold below or above B/Bmsy=1 to account for normal fluctuations in stock biomass so that stocks were underfished when B/Bmsy ≥ 1.05 and overfished when B/Bmsy< 0.95. However, in agreement with Halpern et al. ([2014](#_ENREF_20)), I took the perspective that a stock not fished at MSY is not endangered and it is easier to increase fishing than reduce it ([Halpern et al. 2014](#_ENREF_20), [Lowndes Stewart et al. 2014](#_ENREF_26)). In addition, there should be a lower penalty for stocks experiencing exceptionally productive years (e.g. lobster). Thus equations 2-5 are taken from the west coast of the US ([Halpern et al. 2014](#_ENREF_20), [Lowndes Stewart et al. 2014](#_ENREF_26)).

Individual stock scores (SS) were equal to the biomass index (B’) obtained from:

B’= B/Bmsy when B/Bmsy< LT

B’= 1 when LT ≥ B/Bmsy ≤ T equation 2

B’= max(1-α(B/Bmsy - T), β) when B/Bmsy > T

where T = the upper threshold beyond which there is penalty for being underfished, set at 1.5;

LT= the lower threshold, set at 0.95

α = is the penalty for being underfished and is set at 0.5, meaning that underfished stocks are half as penalised as overfished stocks;

β = is the minimum score that an underscore fish can obtain and set at 0.25.

On the west coast of the US, the score was based on both biomass (B’) and on fisheries mortality (F/Fmsy) ratios ([supplementary material Halpern et al. 2014](#_ENREF_20)). The former indicates the level of depletion and the latter the level of exploitation. Thus a species with a biomass larger than Bmsy and low F/Fmsy would receive lower scores as they are underexploited and the low rate of fishing is unlikely to lead to a lower ratio B/Bmsy.

The rules of attribution of a fishing index F’ (see equation 3) depends on both the ratio F/Fmsy and the value of B/Bmsy ([Halpern et al. 2014](#_ENREF_20)). I modified rule 3g by increasing the upper threshold from 2.5 to 3.1 to cover the observed Scotian Shelf range for B/Bmsy.

|  |  |  |
| --- | --- | --- |
|  | a  b  c  d  e  f  g | equation 3 |

Unfortunately, for the stocks reviewed here, the emphasis has been put on B/Bmsy in most Canadian stock assessments and although the values of F and Fmsy estimated have been compiled, they were not always available for all stocks and thus, could not systematically be included in the calculation of the fisheries provision score.

The ratio F/Fmsy was calculated for only 9 of the 26 stocks considered, including bluefin tuna. For this species, it was necessary to use F’ because the estimation of Bmsy and Fmsy varied with scenarios of recruitment level in the stock assessment document, yielding either large B/Bmsy and low F/Fmsy or the inverse. Using both estimates of F/Fmsy and B/Bmsy led to similar values of Stock Score (0.54 and 0.58, the latter was used in the rest of the analysis; see Table 3). When using both B’ and F’, the stock score SS is the simple average:

SS= (F’ +B’)/2 equation 4

The average score for fisheries provision (XFIS) is the average of all species *i* scores weighted using the average long-term catch for a species ( ) for the whole time series available (since 1953) such that:

where equation 5

## Scenarios for uncertainty

Given data restrictions, the biomass index (B’) could be calculated based on one or several methods in order of preference: stock assessment-based reference points (iB1), survey-based (iB2), Y/Ymsy (iB3). The first stock score (SS1) was based on the higher rank method available in the order of preference (Table 3). For comparison purposes, SS has been calculated using both B’ and F’ (SS2) when possible. In absence of formal uncertainty measurements for each stock score, several scenarios were devised to give an idea of the uncertainty. In addition to the two previous methods, minimal and maximal stocks scores were compiled into 2 arrays: SSH= max(SS1, SS2, SS3) and SSL= min(SS1, SS2, SS3) (Table 4). For stocks without SS2 value, SS1 was used to complete the array in order to calculate XFIS. The species with the largest average catch, herring, cod, haddock, and pollock (see *wi* in Table x) were removed one at a time to assess the effect on the global score XFIS. The impact of changes in scores for herring was also explored by substituting the calculated SS1 with a lower value (0.1) and two higher value (0.4; a value close to other stock average). Finally, the parameters used in equation 2 (T, LT and α) were modified in turn to determine their effect on XFIS.

# Results

It was possible to evaluate the status of 26 stocks (Table 1) for which the average catch over the time series sums up to 177,413 t while it was not possible to characterise 11 taxa accounting for 27,823 t (mostly scallops) or 14% of the total catch (see Table 2).

## Stock scores

Reference points were based on analytical methods for 8 species (cod, halibut, haddock, porbeagle shark, dogfish, swordfish, bluefin tuna, mackerel) and based on stock assessments. The biomass indices for 7 others (pollock, white hake, American plaice, Brown Bank scallops, mackerel, lobster, redfish) were derived using historical biomass to estimate Bmsy (empirical rule #2, Box 1) (see Table 3). An additional 11 species (skates, flounders, wolfish), totalling 2,887 t, were characterized based on the *ad hoc* method described above, using survey historical biomasses as a proxy for Bmsy. It was possible to calculate the ratio F/Fmsy for 9 stocks (iF1, Table 4). Attempts to calculate Y/MSY were made for 12 taxa but it was impossible to obtain estimates for stocks that show continually increasing catches (e.g. lobster) or for species for which other factor than fisheries influence the stock dynamics (e.g. herring and changes in production).

In the case of herring, the virtual population analysis (VPA)-based assessment was rejected in 2011, with no other valid analytical assessment replacing it ([DFO 2011b](#_ENREF_9)). Current management is based on acoustic survey biomass using recent biomass as the lower reference point; there is no available estimate of Bmsy. I used an older virtual population analysis ([VPA, Power et al. 2010](#_ENREF_30)) to determine the 2009 population biomass and used the estimated population biomass of the 1970-1993 period as Bmsy. Given that herring is not well represented in bottom trawl surveys it was not possible to use survey biomass nor was it possible to estimate Y/MSY. Nevertheless, given that herring represent long-term average landings of 106 thousand tonnes, i.e. 50% of the average total catch for the region, it was important to characterise the population status albeit imperfectly. In absence of species-specific catches for skates, the stock score calculated as the average B/Bmsy computed by species weighted with the species-aggregated long-term catch average.

More than half (15/26) of stock scores (SS1) are distributed in lower values (0.2-0.6) among which are herring, cod, pollock plaice and some of the lobster stocks (Table 3, Figure 1). Less than a fourth (6/26) obtained the higher scores (>0.8, swordfish, dogfish, scallops, winter flounder, halibut and lobster LFA34). Wolfish obtained the lower score. The coefficient of variation for B/Bmsy ratios (standard deviation/average) is relatively high (22-113%), conveying the importance of interannual variation in annual biomass estimates, and differences among methods used to derive biomass indices. For instance, the values obtained from the catch analysis (iB3 in Table 4) are systematically lower than that obtained from stock assessments (iB1) and surveys (iB2).

## OHI scores

Stock scores derived from the higher ranked method (SS1) using biomass indices (B’) only is generally higher than the stock scores SS2 which include F’ (Table 4). Thus, the OHI score XFIS calculated using the US West Coast methodology and SS1 is 32. This decreased to 24 when using SS2 for available 9 stocks and SS1 for the 17 others. Using only the highest SS values (SSH) XFIS=33 is close to that using SS1, which is understandable because the stock assessment stock scores based on assessments were generally the highest, and the values of only 2 stocks were modified. Using the lowest values (SSL) led to the lowest XFIS value. Removing herring from the calculations results in XFIS increasing to 46, while the removal of the 3 other species results in very small changes (0.5-4.5%; Table 5). Similarly, substituting herring SS1 for higher and lower values results in large changes in XFIS consistent with the importance of this species (25-43; Table 4). Changes in equation 2 parameters lead to very small variations in XFIS because these changes would only modify lobster scores, their B/Bmsy being larger than 1.5.

# Discussion

The present estimation is based on the NAFO divisions reported catches, stock assessment and survey biomasses. Despite the uncertainty in reference points for several stocks, the localised data is bound to be an improvement over the 2013 global status model which uses FAO catches spatially allocated to half-degree cells within the Canadian EEZ. Nevertheless, there is room for improvement in the score calculation. The most important source of uncertainty is the score attributed to herring because of its large biomass. Given the historical series of catches and perception of stock abundance from previous stock assessments, and availability of juveniles to inshore fisheries, it is however unlikely that herring stock score approaches 1. The scores for several species were approximated and unfortunately skates species had to be grouped because of aggregated catches. For instance, the lack of species disaggregated catches prevented from using the individual biomass trends for skates. Finally, 14% of the catch was composed of taxa I could not find data for.

Examination of the OHI report tables for the Maritimes show that there is no score (=0) for fishery status for New Brunswick and Prince Edward Island, and low for Newfoundland(9) and Nova Scotia (4) <https://github.com/OHI-Science/can/tree/draft/subcountry2014/reports/tables>. I interpret the discrepancies to problems with problems with the catch spatial distribution.

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Table 1. List of stocks/species included in the analysis, their status and comments.

|  |  |  |
| --- | --- | --- |
| **Species** | **Latin name** | **Known status and comments** |
| Atlantic cod | *Gadus morhua* | **Critical**. Low population biomass, high mortality of adults from unknown origin. |
| Pollock | *Pollachius virens* | **Cautious**. This concerns the western component of 4X, faster growing than the eastern component. High variability in surveys especially since the mid -2000s due in part because of semi-pelagic schooling behaviour ([DFO 2015](#_ENREF_15)). |
| Cusk | *Brosme brosme* | **Endangered**. By-catch in longline groundfish fishery ([Harris and Hanke 2010](#_ENREF_22)). |
| Atlantic Halibut | *Hippoglossus hippoglossus* | **Healthy** (Not at risk). Current high productivity due to recruitment ([DFO 2012c](#_ENREF_13)). |
| White hake | *Urophycis tenuis* | **Cause for concern**. No analytical assessment, low catch, higher level of adult mortality of unknown source ([Guénette and Clark 2015](#_ENREF_19)). |
| Haddock | *Melanogrammus aeglefinus* | **Cautious**. Given the ongoing mortality of the strong 2006 year class, followed by two poor year classes (2007, 2008), and limited growth of 4+ fish, it is expected that SSB would decline in 2013 and 2014 without any fishing ([DFO 2012b](#_ENREF_12)). |
| Porbeagle shark | *Lamna nasus* | **Critical**. Population of the northwest Atlantic ([Campana et al. 2009](#_ENREF_2)). |
| Herring | *Clupea harengus* | **Cautious**. There is no analytical assessment and thus no current estimate of F0.1. Management based on comparison with limit reference point defined as the acoustic survey biomass for 2005-2010 German Bank and Scots Bay spawning components. Several biological objectives have also been set ([see Singh et al. 2014](#_ENREF_32)). Declining trends in mean-weight at age since the 1970’s have reduced productivity of the stock. Some rebuilding of the spawners biomass in Scots Bay but not in German Bank, the main spawning area ([Singh et al. 2014](#_ENREF_32)).  I used an older assessment model to give an idea of the level of depletion compared to productive years. |
| American plaice | *Hippoglossoides platessoides* | **No information on status of 4X stock.**  The model regards all of 4VWX American plaice as one population, such that the reference points are intended to sustain the population as a whole. However, American plaice in 4X/5 (Bay of Fundy) are marginal to the population distribution, thus the indicators of stock status cater mostly to 4VW American plaice ([Fowler 2012](#_ENREF_16)). |
| Redfish | *Sebastes fasciatus* | **No information on status of 4X stock.**  The analytical assessment considers only the Eastern Scotian Shelf while the survey aggregates 4X and 4VW so they were not used here. Only catches were specific to 4X. |
| Lobster | *Homarus americanus* | **Healthy.** Present catches are higher than the long-term median used as reference. Landings have been used as a proxy for biomass because the exploitation rate is high (removing 60-90% of legal size lobsters each year) and other lines evidence ([Tremblay et al. 2012](#_ENREF_37)). Lobster stocks have been resilient in the face of high estimates of exploitation rates for at least 30 years. During this period, lobster abundance has increased substantially. This is likely due to a combination of sound conservation measures and favourable conditions for lobster recruitment and survival in the last 30 years ([Tremblay et al. 2012](#_ENREF_37)). |
| Dogfish | *Squalus acanthias* | **Not overfished.**  Although the dogfish stock straddles US and Canadian waters, the assessment was carried with US data only ([Rago and Sosebee 2010](#_ENREF_31)). The Canadian summer survey occurs when adult females move inshore and become catchable ([Campana et al. 2007](#_ENREF_3)). The species is structured in metapopulations irregularly present in certain areas depending on the years, which means that the abundance index in 4X may not be an indication of the trend in population abundance as much as an indicator of its presence in the area. The Canadian survey shows an increase in abundance since the 1970s, which is consistent with fishermen complaining since the late 1990's that dogfish abundance was much higher than in the past (D. Clark, 2010, DFO, pers. comm.) and that dogfish were regularly observed in large numbers around purse seines being emptied (M. Power, DFO, 2010, pers. comm.), constituting the main by-catch in the herring fishery ([Power 2006](#_ENREF_29)). However, this problem subsided starting in 2005. As a consequence, catches in 4X were not used to derive MSY. |
| Swordfish | *Xiphia gladius* | **Healthy**. Stock distributed in the North Atlantic, not just 4X. |
| Mackerel | *Scomber scombrus* | Stock distribution ranges US waters to the Gulf of St. Lawrence and Newfoundland. This biomass decrease, reaching a low level in 2001 was caused by a lack of recruitment combined with historically higher-than-sustainable fishing mortalities ([DFO 2012a](#_ENREF_11)). |
| Bluefin tuna | *Thunnus thynnus* | Stock has been rebuilding in recent years ([ICCAT 2014](#_ENREF_25)).  Bluefin tuna reaches Canadian waters in the course of its annual migration only as adults (age 6+) and are believed to be present in the 4X region for about 4 months a year, from July to October (John Nielson, 2010, DFO, St. Andrews, unpublished data). |
| Scallops (offshore) | *Placopecten magellanicus* | Browns Bank stock only (offshore). |
| Witch flounder | *Glyptocephalus cynoglossus* | No assessment. Survey-based only |
| Yellowtail flounder | *Limanda ferruginea* | No assessment. Survey-based only |
| Wolffish | *Anarchichas lupus* | **Threatened**. Score estimated from by-catches only. |
| Monkfish | *Lophius americanus* | No assessment. Survey-based only |
| Longhorn sculpin | *Myoxocephalus octodecimspinosus* | No assessment. Survey-based only |
| Smooth skate | *Malacoraja senta* | No assessment. Survey-based only |
| Thorny skate | *Leucoraja ocellata* | No assessment. Survey-based only |
| Barndoor skate | *Dipturus laevis* | No assessment. Survey-based only |
| Winter skate | *Amblyraja radiata* | No assessment. Survey-based only |
| Little skate | *Raja erinacea* | No assessment. Survey-based only |

Table 2. List of species/stocks not included in the analysis for lack of data, and the mean long-term catch.

|  |  |  |  |
| --- | --- | --- | --- |
| **Species** | **Latin name** | **Known status and comments.** | Mean catch (t) |
| Inshore scallops | *Placopecten magellanicus* | Reference points for inshore stock need further work ([Smith and Hubley 2012](#_ENREF_34)). | 14,398 |
| Gaspareau | *Alosa pseudoharengus* | Reports on abundance in a few rivers in Nova Scotia only. Anadromous species. | -- |
| salmon | *Salmo salar* | Some reference points expressed as number of eggs per m2 of river, not in terms of population numbers. Anadromous species. | -- |
| American eels and elvers | *Anguilla rostrata* | **Medium concern** for Atlantic coast of Nova Scotia and Bay of Fundy ([Chaput et al. 2014](#_ENREF_4)).  Catadromous species. Commercial fishing, turbine mortality and physical obstruction to freshwater habitats are threats to eel recovery ([Cairns et al. 2014](#_ENREF_1)). At the present time, a substantial portion of New Brunswick fresh waters are located upstream of artificial barriers. Standing stock indices have declined by 58% in the last 28 years and 38% in the last 16 years ([Cairns et al. 2014](#_ENREF_1)). No recovery target has been defined. | 39 |
| Striped bass | *Morone saxatilis* | **Endangered**.  No information | **--** |
| Silver hake | *Merluccius bilinearis* | Assessment cover only 4VW, excluding the western 4X and BoF which is closer to Gulf of Maine than fish from the Eastern Scotian Shelf ([Stone et al. 2013](#_ENREF_35)). | 4,325 |
| Tilefish | *Lopholatilus chamaeleonticeps* |  | 2 |
| Crabs | including snow crab (*Chionoecetes opilio)* | there is only marginal habitat for snow crab in 4X ([Cook et al. 2014](#_ENREF_6)). | 720 |
| shrimps | *Pandalus borealis* | very marginal habitat in 4X ([Hardie et al. 2011](#_ENREF_21)) | 59 |
| unidentified groundfish |  |  | 999 |
| other pelagics |  |  | 2,701 |
| echinoderms |  |  | 1,069 |
| squids |  |  | 866 |
| bivalves |  |  | 1,710 |
| gastropods |  |  | 89 |
| **Total** |  |  | **27,863** |

Table 3 Compilation of reference points, current biomass, type of biomass, and F by species, results from the Y/MSY method ([Martell and Froese 2013](#_ENREF_27)), B/Bmsy based on assessment (iB1), on surveys (iB2) and from the method Y/Ymsy (iB3; showing the estimated intrinsic rate of growth (r),unfished population size (K),and MSY and the estimated Y/Ymsy and the corresponding B/Bmsy), F/Fmsy when available, mean long-term catch (meanC), and resulting F’, B’ and stock scores (SS1). Column *s* contains codes for sources and column *c* codes for comments. *SSB*= Spawning stock biomass, *Tbiom*= total biom, *cpue* = catch per unit effort. *Refpts* refers to the stock assessment and the summary of reference points documents; *na*= not available, *ne*= not estimated.

| Species | type | region | Reference points | | | | | | | Current biomass | | | | | | | Catch-based (Y/Ymsy) | | | | | | | B/Bmsy ed on | | | F/Fmsy | meanC | Results | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Bmsy | | Fmsy | s | model | | | Biom | F | Year | | model | units | c | K | r | MSY | MSY (-2SD) | MSY +2SD) | Y/MSY | minB/BMSY | iB1 | iB2 | iB3 | F' | B' | SS1 |
| Atlantic Cod | Refpts | 4X5Yb | 60000 | | 0.2 | a | t | | | 10600 | 0.34 | 2008 | | n, aq | SSB |  |  |  |  |  |  |  |  | 0.18 |  |  | 1.70 | 17,067 |  | 0.18 | 0.18 |
|  | y/msy | 4X5Yb | 145072 | |  |  |  | | |  |  |  | |  |  |  | 290143 | 0.271 | 19667 | 18262 | 21181 | 0.21 | **0.11** |  |  | 0.11 |  |  |  |  |  |
|  | survey | 4X | 22017 | |  | b | u | | | 3278 |  | 2008 | | b | Tbiom |  |  |  |  |  |  |  |  |  | 0.15 |  |  |  |  |  |  |
|  | survey | 4X |  | |  | b | u | | | 2613 |  | 2012-14 | | b | Tbiom |  |  |  |  |  |  |  |  |  | 0.12 |  |  |  |  |  |  |
| Pollock (western component) | Refpts | 4Xopqrs5 | 39000 | | na | c | v | | | 11426 | ne | 2012-14 | | b | Tbiom | ba |  |  |  |  |  |  |  | 0.29 |  |  | ne | 10,643 |  | 0.29 | 0.29 |
|  | y/msy | 4Xopqrs5 | | | | | | | | | |  | |  |  |  | 172243 | 0.3 | 12926 | 10272 | 16267 | 0.25 | **0.13** |  |  | 0.13 |  |  |  |  |  |
| Cusk | Refpts | maritimes | 33 | |  | a,d | x | | | 18 | ne | 2009-11 | | a, ar | cpue,  x |  |  |  |  |  |  |  |  | 0.55 |  |  | ne | 2,895 |  | 0.55 | 0.55 |
|  | y/msy | 4X5ze |  | |  |  |  | | |  |  |  | |  |  |  | 98748 | 0.12 | 2955 | 1897 | 4605 | 0.06 | **0.03** |  |  | 0.06 |  |  |  |  |  |
| Atlantic Halibut | Refpts | 3NOPs4  VWX+5 | 4900 | | 0.36 | a | y | | | 6527 | 0.2 | 2009 | | o, as | SSB | bb |  |  | 1945 |  |  |  |  | 1.33 |  |  | 0.56 | 508 |  | 1.00 | 1.00 |
|  | y/msy | 4X |  | |  |  |  | | |  |  |  | |  |  |  | 26110 | 0.0621 | 406 | 213 | 773 | 1.17 | ne |  |  | >1 |  |  |  |  |  |
| White hake | RPA | 4X | 17167 | | ne | e | z | | | 8426 | ne | 2014 | | e, at | SSB | at |  |  |  |  |  |  |  | 0.49 |  |  | ne | 4,809 |  | 0.49 | 0.49 |
|  | survey | 4X |  | |  |  |  | | | 7207 |  | 2012-14 | |  | Tbiom |  |  |  |  |  |  |  |  | 0.42 |  |  |  |  |  |  |  |
|  | y/msy | 4X/5 |  | |  |  |  | | |  |  |  | |  |  |  | 154396 | 0.117 | 4499 | 3097 | 6535 | 0.13 | **0.07** |  |  | 0.13 |  |  |  |  |  |
| Haddock | Refpts | 4X5Y | 52000 | | 0.43 | f | y | | | 33313 | 0.12 | 2006-08 | | l, au | SSB | bc |  |  | 14700 |  |  |  |  | 0.64 |  |  | 0.28 | 12,349 |  | 0.64 | 0.64 |
|  | survey | 4X |  | |  |  | aa | | | 48270 |  | 2006-08 | | b | Tbiom |  |  |  |  |  |  |  |  |  | 0.82 |  |  |  |  |  |  |
|  | survey | 4X | 58785 | |  |  | aa | | | 36148 |  | 2012-14 | | b | Tbiom |  |  |  |  |  |  |  |  |  | 0.61 |  |  |  |  |  |  |
|  | y/ymsy | 4X5Y |  | |  |  |  | | |  |  |  | |  |  |  | 234871 | 0.27 | 15842 | 13495 | 18598 | 0.36 | **0.20** |  |  | 0.20 |  |  |  |  |  |
| Porbeagle shark | assess | NW Atl. | 27945 | | 0.04-0.08 | g | ab | | | 11339 | <0.03 | 2009 | | g, av | SSN, bd | bi |  |  |  |  |  |  |  | 0.41 |  |  | 0.18 |  |  | 0.41 | 0.41 |
| Herring | assess | 5Y5Z | 292804 | | 0.228 | h | ac, ad | | | 63472 | 0.7 | 2009 | | h, aw, ax | SSB |  |  |  |  |  |  |  |  | 0.22 |  |  | 3.07 | 105,874 |  | 0.22 | 0.22 |
|  | y/ymsy |  |  | |  |  |  | | |  |  |  | |  |  |  |  |  | ne, bg |  |  |  |  |  |  |  |  |  |  |  |  |
| American plaice | survey | **4X** | 2414.41 | |  |  | ae | | | 534.571 |  | 2012-14 | |  | Tbiom |  |  |  |  |  |  |  |  |  | **0.22** |  | **na** | 1,044 |  | 0.22 | 0.22 |
|  | y/msy | **4X/5** |  | |  |  |  | | |  |  |  | |  |  |  | 29856 | 0.112 | 837 | 578 | 1211 | 0.29 | **0.15** |  |  | **0.15** | **na** |  |  |  |  |
| Redfish | y/msy |  |  | |  |  |  | | |  |  |  | |  |  |  | 104476 | 0.241 | 6292 | 5463 | 7248 | 0.61 | **0.38** |  |  | **0.61** |  | 5,048 |  | 0.61 | 0.61 |
| Lobster | Refpts | LFA34 | 11071 | | ne | a | af | | | 19620 |  |  | p | | Tbiom | be |  |  | ne, bh |  |  |  | | 1.77 |  |  | ne | 7,560 |  | 0.86 | 0.86 |
|  | Refpts | LFA35 | 731 | | ne | a | af | | | 1982 |  |  | p | | Tbiom | be |  |  | ne, bh |  |  |  | | 2.71 |  |  | ne | 428 |  | 0.39 | 0.39 |
|  | Refpts | LFA36 | 666 | | ne | a | af | | | 1506 |  |  | p | | Tbiom | be |  |  | ne, bh |  |  |  | | 2.26 |  |  | ne | 447 |  | 0.62 | 0.62 |
|  | Refpts | LFA 38 | 648 | | ne | a | af | | | 1851 |  |  | p | | Tbiom | be |  |  | ne, bh |  |  |  | | 2.86 |  |  | ne | 559 |  | 0.32 | 0.32 |
| Dogfish | assess | US stock | 159288 | | 0.207 | i | ag | | | 163256 | 0.11 | 2009 | i, q, ay | | SSB, bd |  |  |  |  |  |  |  |  | 1.02 |  |  | 0.53 | 821 |  | 1.00 | 1.00 |
| Swordfish | assess | North Atlantic | 65 | | 0.21 | j | ah | | |  |  |  | j, av | | T biom |  |  |  |  |  |  |  |  | 1.14 |  |  | 0.81 | 88 |  | 1.00 | 1.00 |
| Bluefin tuna | low R | W Atl | 13226 | | 0.2 | k | ai | | | 27966 |  |  | r, aw | | SSB |  |  |  |  |  |  |  |  | 2.13 |  |  | 0.32 | 184 | 0.40 | 0.68 | 0.54 |
|  | high R | W Atl | 63102 | | 0.08 | k | aj | | |  |  |  | r, aw | | SSB |  |  |  |  |  |  |  |  | 0.44 |  |  | 0.84 |  | 0.73 | 0.43 | 0.58 |
| Mackerel | assess | NW Atl | 440021 | | 0.217 | m | ak | | | 103405 | 0.66 | 2008 | m, az | | SSB, bd |  |  |  |  |  |  |  |  | 0.24 |  |  | 3.04 | 3,503 |  | 0.24 | 0.24 |
|  | y/msy | 4X |  | |  |  |  | | |  |  |  |  | |  |  | 56743 | 0.269 | 3817 | 3507 | 4154 | 0.10 | **0.05** |  |  | 0.05 |  |  |  |  |  |
| Scallops | Refpts | Browns Bank | 7281 | | ne | a | al | | | 9096 | 0.024 | 2010 | s | | Biom, bf | bb |  |  |  |  |  |  |  | 1.25 |  |  |  | 593 |  | 1.00 | 1.00 |
| Winter flounder | survey | 4X | 3557 | | ne | b | am | | | 5138.74 |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 1.44 |  |  | 902 |  | 1.00 | 1.00 |
|  | y/ymsy |  |  | |  |  |  | | |  |  |  |  | |  |  |  | | ne, bg |  |  |  |  |  |  |  |  |  |  |  |  |
| Witch flounder | survey | 4X | 1797 | | ne | b | am | | | 1064.19 |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 0.59 |  |  | 420 |  | 0.59 | 0.59 |
|  | y/msy |  | | | | | | | | | |  |  | |  |  | 11442 | 0.124 | 356 | 256 | 496 | none |  |  |  |  |  |  |  |  |  |
| Yellowtail flounder | survey | 4X | | 651 | ne | b | | am | 184.281 | |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 0.28 |  |  | 134 |  | 0.28 | 0.28 |
|  | y/msy |  | | | | | | | | | |  |  | |  |  |  | | ne, bg |  |  | none |  |  |  |  |  |  |  |  |  |
| Wolffish | survey | 4X | | 2017 | ne | b | | am | 114.482 | |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 0.06 |  |  | 674 |  | 0.06 | 0.06 |
|  | y/msy | bycatch | |  |  |  | |  |  | |  |  |  | |  |  | 26196 | 0.108 | 709 | 508 | 989 | 0.04 | 0.02 |  |  | 0.02 |  |  |  |  |  |
| Monkfish | survey | 4X | | 2181 | ne | b | | am | 683.728 | |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 0.31 |  |  | 538 |  | 0.31 | 0.31 |
| Longhorn sculpin | survey | 4X | | 2798 | ne | b | | am | 1314.03 | |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 0.47 |  |  | 95 |  | 0.47 | 0.47 |
| Smooth skate | survey | 4X | | 834 | ne | b | | an | 259 | |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 0.31 |  |  |  |  |  |  |
| Thorny skate | survey | 4X | | 7936 | ne | b | | ao | 287 | |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 0.04 |  |  |  |  |  |  |
| Barndoor skate | survey | 4X | | 1764 | ne | b | | ap | 1700 | |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 0.96 |  |  |  |  |  |  |
| Winter skate | survey | 4X | | 1131 | ne | b | | ap | 1035 | |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 0.92 |  |  |  |  |  |  |
| Little skate | survey | 4X | | 904 | ne | b | | ap | 1087 | |  | 2012-14 |  | | Tbiom |  |  |  |  |  |  |  |  |  | 1.20 |  |  |  |  |  |  |
| **avg skate** | survey | 4X | |  |  |  | |  |  | |  |  |  | |  |  |  |  |  |  |  |  |  |  | 0.41 |  |  | 124 |  | 0.41 | 0.41 |
| **Notes**  **a**. ([DFO 2012c](#_ENREF_13)); **b**. DFO survey ([DFO 2013](#_ENREF_14)); **c**. ([DFO 2011c](#_ENREF_10)); **d**. ([Harris and Hanke 2010](#_ENREF_22), [Harris et al. 2012](#_ENREF_23)); **e**. ([Guénette and Clark 2015](#_ENREF_19)); **f**. ([DFO 2012b](#_ENREF_12));  **g**. ([Campana et al. 2009](#_ENREF_2)); **h**. ([Power et al. 2010](#_ENREF_30)); **i**. ([Rago and Sosebee 2010](#_ENREF_31)); **j**. ([ICCAT 2013](#_ENREF_24)) table 17; **k**. ([ICCAT 2014](#_ENREF_25)) table 14 **l**. ([Mohn et al. 2010](#_ENREF_28)); **m**. ([Grégoire and Maguire 2010](#_ENREF_18)); **n**. ([Clark et al. 2011](#_ENREF_5));  **o**. ([Trzcinski et al. 2011](#_ENREF_38)); **p**. ([Smith et al. 2012](#_ENREF_33)); **q**. ([TRAC 2010](#_ENREF_36)); **r**. ([ICCAT 2014](#_ENREF_25)); **s**. ([DFO 2011a](#_ENREF_8));  **t**. BH S-R, 1970-2007; **u**. survey biomass 1970-1998; **v**. geom mean of survey biomass for high productive period: 1984-1993; B4+; empirical based survey index ratio  **x**. cpue (kg/100 hooks) commercial scaled to halibut survey 1986-1992 - productive period  **y**. Sissenwine-Shepard, Ricker SR; **z**. GM survey SSB 1970-1998;  **aa**. long-term mean (1970-2003); **ab**. based on spawning stock numbers: SSNmsy fem, yield-per-recruit + stock -recruits;  **ac**. 1970-1993 productive period in VPA-based population SSB;  **ad**. assuming Fmsy=F0.1; **ae**. survey avg 1970-2000;  **af**. median of 1985-2009 catch as a proxy Bmsy assuming catch is proportional to biomass ([Tremblay et al. 2012](#_ENREF_37));  **ag**. stock recruit relationship with covariates; **ah**. dynamic surplus-production model;  **ai**. Spawners recruit relationship with low recruitment curve; **aj**. Spawners recruit relationship with high recruitment curve;  **ak**. yield-per recruit (analytical results); **al**. BMSY is avg of 1981-2009 from delay-difference model; **am**. average of survey biomass time series;  **an**. average of 1970-1984 survey biomass time series; **ao**. average of 1970-1985 survey biomass time series;  **ap**. 0.5max ;  **aq**. VPA assuming an increase M for adults; **ar**. cpue in groundfish longliners; **as**. Catch at length model; **at**. survey SSB; **au**. Sequential population analysis;  **av**. surplus production model; **aw**. Virtual population analysis; **ax**. VPA has been rejected rejected;  **ay**. USA survey; **az**. Extended Survivors Analysis (XSA), stochastic;  **ba**. survey very noisy; **bb**. stock in high productivity period because of high recruitment; **bc**. shows large retrospective;e pattern; **bd**. spawning stock females only;  **be**. High productivity in part because of environmental conditions, good governance; **bf**. Fully recruited biomass;  **bg**. too few combinations found; **bh**. increasing catches; **bi**. used F=0.01 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Table 4. Summary of biomass indices calculated (see text for further explanation).

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | **F and biomass indices** | | | | **Stock scores** | | | | |
|  | **Stock** | **meanC** | **wi** | **iF1** | **iB1** | **iB2** | **iB3** | **B'=SS1** | **F'** | **SS2** | **SSH** | **SSL** |
| 1 | cod | 17,067 | **0.096** | 1.7 | 0.18 | 0.15 | 0.11 | 0.18 | 0 | 0.09 | 0.18 | 0.09 |
| 2 | pollock | 10,643 | **0.060** |  | 0.29 |  | 0.13 | 0.29 |  |  | 0.29 | 0.13 |
| 3 | cusk | 2,895 | 0.016 |  | 0.55 |  | 0.06 | 0.55 |  |  | 0.55 | 0.06 |
| 4 | halibut | 508 | 0.003 | 0.56 | 1.33 |  |  | 1 | 0.7 | 0.85 | 1 | 0.85 |
| 5 | Whake | 4,809 | 0.027 |  | 0.49 | 0.42 | 0.13 | 0.49 |  |  | 0.49 | 0.13 |
| 6 | haddock | 12,349 | **0.070** | 0.28 | 0.64 | 0.82 | 0.2 | 0.64 | 0.64 | 0.64 | 0.82 | 0.2 |
| 7 | porbeagle | 106 | 0.001 | 0.18 | 0.41 |  |  | 0.41 | 0.86 | 0.63 | 0.63 | 0.41 |
| 8 | herring | 105,874 | **0.597** | 3.07 | 0.22 |  |  | 0.22 | 0 | 0.11 | 0.22 | 0.11 |
| 9 | plaice | 1,044 | 0.006 |  |  | 0.22 | 0.15 | 0.22 |  |  | 0.22 | 0.15 |
| 10 | redfish | 5,048 | 0.028 |  |  |  | 0.61 | 0.61 |  |  | 0.61 | 0.61 |
| 11 | lobster #34 | 7,560 | 0.043 |  | 1.77 |  |  | 0.865 |  |  | 0.87 | 0.87 |
| 12 | lobster #35 | 428 | 0.002 |  | 2.71 |  |  | 0.395 |  |  | 0.40 | 0.40 |
| 13 | lobster #36 | 447 | 0.003 |  | 2.26 |  |  | 0.62 |  |  | 0.62 | 0.62 |
| 14 | lobster #38 | 559 | 0.003 |  | 2.86 |  |  | 0.32 |  |  | 0.32 | 0.32 |
| 15 | dogfish | 821 | 0.005 | 0.53 | 1.02 |  |  | 1 | 0.66 | 0.83 | 1 | 0.83 |
| 16 | swordfish | 88 | 0.000 | 0.81 | 1.14 |  |  | 1 | 1 | 1 | 1 | 1 |
| 17 | tuna | 184 | 0.001 | 0.84 | 0.43 |  |  | 0.58 | 0.73 | 0.58 | 0.58 | 0.43 |
| 18 | mackerel | 3,503 | 0.020 | 3.04 | 0.24 |  | 0.05 | 0.24 | 0 | 0.12 | 0.24 | 0.05 |
| 19 | scallops | 593 | 0.003 |  | 1.25 |  |  | 1 |  |  | 1 | 1 |
| 20 | winter flounder | 902 | 0.005 |  |  | 1.44 |  | 1 |  |  | 1 | 1 |
| 21 | witch flounder | 420 | 0.002 |  |  | 0.59 |  | 0.59 |  |  | 0.59 | 0.59 |
| 22 | yellowtail | 134 | 0.001 |  |  | 0.28 |  | 0.28 |  |  | 0.28 | 0.28 |
| 23 | wolffish | 674 | 0.004 |  |  | 0.06 | 0.02 | 0.06 |  |  | 0.06 | 0.02 |
| 24 | monkfish | 538 | 0.003 |  |  | 0.31 |  | 0.31 |  |  | 0.31 | 0.31 |
| 25 | sculpin | 95 | 0.001 |  |  | 0.47 |  | 0.47 |  |  | 0.47 | 0.47 |
| 26 | skates | 124 | 0.001 |  |  | 0.41 |  | 0.41 |  |  | 0.41 | 0.41 |
|  | **N** |  |  | **9** | **17** | **11** | **9** | **26** | **9** | **9** | **26** | **26** |
|  | **Total** | **177,413** |  |  |  |  |  |  |  |  |  |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Changes in parameters | | |  |
| scenarios | LT | T | alpha | XFIS |
| **Using different methods** | | | | |
| SS1 |  |  |  | 31.7 |
| SS2 |  |  |  | 23.9 |
| SSH |  |  |  | 33.0 |
| SSL |  |  |  | 17.9 |
| **Removing species** | | | | |
| wo herring |  |  |  | 46.1 |
| wo cod |  |  |  | 33.2 |
| wo haddock |  |  |  | 31.2 |
| wo pollock |  |  |  | 31.9 |
| **Modifying herring SS1** | | | | |
| SS1 herring =0.1 |  |  |  | 24.6 |
| SS1 herring =0.4 |  |  |  | 42.5 |
| **Changing equation 2 parameters** | | | | |
| initial parameters | 0.95 | 1.5 | 0.5 | 31.7 |
| lower T | 0.95 | **1.05** | 0.5 | 31.7 |
| higher T | 0.95 | **1.8** | 0.5 | 31.7 |
| lower alpha | 0.95 | 1.5 | **0.2** | 32.3 |
| lowert LT | **0.85** | 1.5 | 0.5 | 31.7 |
| **min** |  |  |  | **17.9** |
| **max** |  |  |  | **46.1** |

Table 5. Uncertainty on XFIS values using various methods of calculating reference points, removing abundant species, modifying herring SS1, and changes in equation 2 parameters.

Figure 1. Frequency of occurrence of stock scores (SS1).