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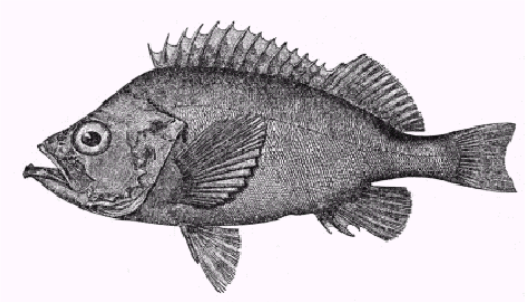
Quebec, Newfoundland and Labrador, and Maritimes Regions

Canadian Science Advisory Secretariat
Science Advisory Report 2012/004

REFERENCE POINTS FOR REDFISH (*SEBASTES MENTELLA* AND *SEBASTES FASCIATUS*) IN THE NORTHWEST ATLANTIC



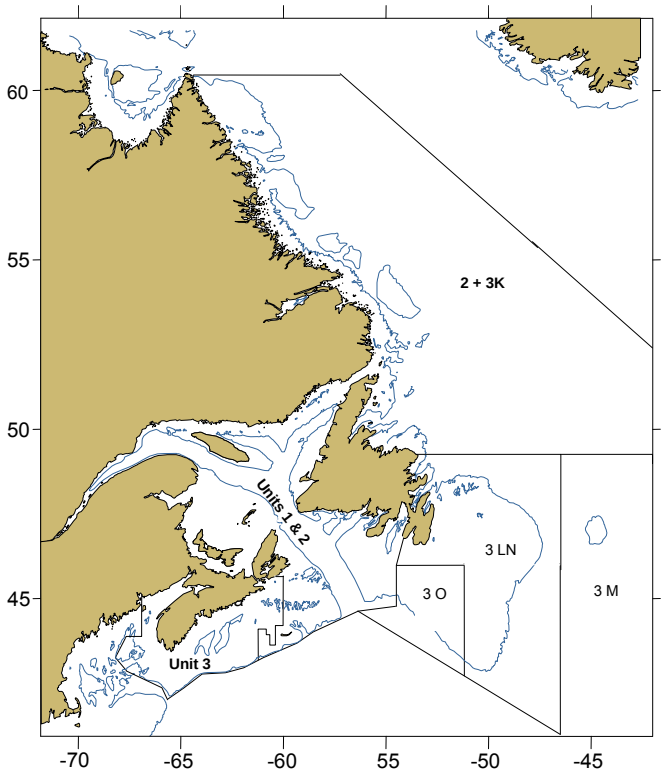


Figure 1. Map of the northwest Atlantic showing the boundaries of redfish stock areas

Context

At a DFO meeting between Science and Management in December 2010, determining limit biomass reference points was deemed a high priority for the 2011/12 year. The recovery potential assessment (RPA) in March 2011 prompted the development of a production model for redfish from which reference points could be easily derived.

Reference points derived from production model fits from the RPA work and reference points derived using other methods were tabled.

This advice provides biomass limit reference points for redfish biological populations of the Northwest Atlantic. In some cases, suggestions are also provided for other reference points such as the upper stock reference, the target and the maximum acceptable exploitation rate (part of the removal reference). Stock status relative to the limit reference points and growth status of the stocks are provided.

It is expected that the reference points described here will be in place until a substantive change in data or methodology warrants that the points be revisited – probably within 3-5 years.

July 2012

Canada

SUMMARY

- Approaches were investigated for developing limit reference points (LRP's) for five Atlantic redfish stocks based on the best science available at the present time. LRP's from the Bayesian surplus production model (BSP) were accepted for four stocks, while an empirical reference point was accepted for the fifth stock.

- The LRP consistent with the default reference points in the DFO precautionary approach (PA) policy suggests using 40% Bmsy (or 20% of the maximum unfished biomass) for the stocks modeled using the Schaefer BSP) approach.

- The Unit 3 LRP was determined from empirical methods in the survey because of insufficient signal in the survey and catch for the BSP model fitting.

- The LRP values (and stock biomass expressed as a fraction of the LRP) in 2010 or 2011 are: 2J3K *S. mentella* – 116 kt (0.14); Unit 1+2 *S. mentella* – 233 kt (0.08); 2J3K *S. fasciatus* – 29 kt (0.28); Unit 1+2 *S. fasciatus* – 148 kt (0.44 in 2011); and Unit 3 *S. fasciatus* – 29 kt (3.2).

- Growth status (increasing, unchanged, decreasing) was determined by comparing the most recent catch to the replacement yield from the production model: 2J3K *S. mentella* – increasing; Unit 1+2 *S. mentella* – decreasing; 2J3K *S. fasciatus* – increasing; Unit 1+2 *S. fasciatus* – increasing; Unit 3 *S. fasciatus* – increasing (smoothed empirical trend).

- It is expected that the current reference points will stand until some important change in information necessitates a re-evaluation of reference points. Issues identified which merit further investigation include particularly survey catchability (reservations were expressed about q>1).

- Work shows that the fish in Laurentian fan (shelf edge) area are predominantly *S. fasciatus*, and previous DFO work shows that *S. fasciatus* in this area is part of the Grand Bank (3LNO) population.

BACKGROUND

Identification of redfish species

Three species of redfish can be found in the Northwest Atlantic: *Sebastes mentella* and *S. fasciatus*, which dominate commercial fisheries, and *S. marinus* which is much less abundant. *S. marinus* can be distinguished from the two other species by its colour, eye size and the size of the bony protrusion on its lower jaw; however, *S. mentella* and *S. fasciatus* are visually similar.

Three characteristics are used to discriminate *S. mentella* from *S. fasciatus* in the Northwest Atlantic: 1) the number of soft rays in the anal fin, 2) extrinsic gas bladder muscle passage patterns, and 3) genotype at the liver malate dehydrogenase locus. In the Gulf of St. Lawrence and the Laurentian Channel, the occurrence of hybrid individuals has also been confirmed. Modern genetic methods use DNA microsatellite discrimination.

Distribution

In the Northwest Atlantic, redfish distribution ranges from the Gulf of Maine, northwards off Nova Scotia and the southern Newfoundland Banks, in the Gulf of St. Lawrence and along the continental slope and deep channels from the southwestern Grand Bank to areas as far north as Baffin Island. Redfish are also present in the area of Flemish Cap and west of Greenland (Fig. 1).

Sebastes mentella and *S. fasciatus* are distributed according to a gradient in the Northwest Atlantic. *S. mentella* is the dominant species in Baffin Bay and in Labrador waters, while *S. fasciatus* dominates in the Gulf of Maine and in the basins and on the continental slopes of the western part of the Scotian Shelf. The distribution of both species overlaps in the Gulf of St. Lawrence, the Laurentian Channel, off southern Newfoundland and in the southern Labrador Sea. The distribution of the two species is also characterized by an area of introgressive hybridization which is geographically circumscribed to the Gulf of St. Lawrence and Laurentian Channel, and to a lesser extent to the Flemish Cap area.

Biological stocks

Five biological stocks for *Sebastes* are considered on the east coast. They are more or less biological stocks but there is suspected movement between some of them and they are sometimes part of stocks in international waters in the NAFO regulatory area which have been artificially removed for our purposes here. For the most part, these stocks correspond to management units, with redfish in Unit 1 and 2 being an exception. As recommended in the 2010 stock assessment, *Sebastes* in Unit 1 and 2 are treated as one stock here (one *S. mentella* stock for Unit 1 and 2 combined and one *S. fasciatus* stock for unit 1 and 2 combined) but until now have been managed separately for Unit 1 and 2.

Sebastes mentella

In the Northwest Atlantic, two biological stocks for *S. mentella* have been recognised

1. The Gulf of St. Lawrence and Laurentian Channel population (Units 1+2 = NAFO Div. 3P4V+4RST+ 4Wfgj)
2. The northern population (including Grand Banks, the Labrador Shelf, Davis Strait and Baffin Bay) – (but only NAFO subarea 2 and division 3K was considered)

Given that the Northern population includes stocks in international waters especially in the Davis Strait and Grand Bank, DFO does not have a mandate to manage portions of the biological stock. Therefore, for the present purposes, the second stock is considered only to be the portion falling in Canadian waters in NAFO zone 2+3K.

Sebastes fasciatus

Acadian redfish in Canadian waters have been divided into three stocks:

1. The Scotian Shelf stock called Unit 3 (including portions of NAFO divisions 4WX5Y)
2. The Gulf of St. Lawrence and Laurentian Channel (Units 1+2, including NAFO divisions 4RST and parts of 4V and 3P)
3. The Labrador Shelf population (NAFO zones 2+3K)

Redfish Biology

Redfish is a slow-growing species with high longevity that can commonly live up to 40 years, and exceptionally up to 75 years. Such longevity implies low natural mortality but predation of juveniles can be an important factor in some ecosystems. The growth of *S. fasciatus* is not as rapid as that of *S. mentella*, although this difference in growth rates becomes apparent only after the age of 10 years. In both species, females grow faster than males after the age of about 10 years. Growth is usually faster in areas further south. The maximum size attained by males of the species *S. mentella* varies between 40 and 45 cm while females reach 45 to 60 cm. For *S. fasciatus*, the maximum size attained is 45 cm (Gulf of Maine). On average, 6 to 8 years are needed to reach the minimum legal size of 22 cm.

Age at maturity generally occurs between 8-10 years. Males mature 1-2 years earlier than females of the same species and at a size which is 3-5 cm smaller than females. *S. fasciatus* (males and females) mature 1-2 years earlier and at a size which is 1-3 cm smaller than that of *S. mentella*. *S. fasciatus* males mature at a younger age and smaller size than either female *S. fasciatus*, or male and female *S. mentella*.

Unlike many other marine coldwater fish species, redfish reproductive biology involves copulation and fertilization of eggs occurs internally in females. Mating takes place in the fall between September and December and females carry the developing embryos until they are extruded as free swimming larvae (7 mm) in spring (April to July). Mating and larval extrusion do not necessarily occur in the same locations. Fecundity varies according to female size, from 1,500 to 107,000 larvae, which is low compared to other commercially important fish species. It seems that fecundity is higher in *S. fasciatus* than in *S. mentella*. *S. mentella* releases its larvae about 3 to 4 weeks earlier than *S. fasciatus* in the Gulf of St. Lawrence and on Flemish Cap. Larvae are larger in *S. mentella.*

Redfish recruitment success varies considerably. Redfish exhibit episodic recruitment events with very large year-classes observed infrequently: typically 5-12 years but now approaching 30 years for Unit 1+2 *S. mentella*.

The diet of *S. fasciatus* and *S. mentella* appears similar. In the larval stage, redfish feed mainly on fish eggs and invertebrates. The larger larvae feed on copepods and euphausids. Juvenile and adult individuals add copepods, euphausids and fish to their diet.

In the Gulf of St. Lawrence, harp seals and skates are important redfish predators. However, before its decline, cod was the main predator. On the Labrador Shelf, Greenland halibut and skate are the main predators of redfish. On the eastern Scotian Shelf, haddock, pollock and grey seals are important predators.

ANALYSIS

Data used for analysis

Unit 3: The Scotian Shelf summer survey from 1970-2011 was used as the biomass index series. The index is in Western IIa swept area biomass equivalents. Historic genetic analyses indicate S. fasciatus is the predominant species. The catch series was from 1960 as reported to NAFO.

Unit 1: The DFO summer survey from 1990 was used as the biomass index. Species were separated in the survey using anatomical and genetic characteristics. The index is in Teleost-Campellen swept area equivalents. Mixed species catch data from 1960 is available from NAFO.

Unit 2: The GEAC summer survey from 2000 was used as the biomass index for this region. The GEAC survey was converted to swept area Campellen biomass equivalents. Species were separated by the same method used for Unit 1. Mixed species catch data from 1960 is available from NAFO.

2+3K: DFO has conducted an autumn survey in this region since 1978 which provided the biomass index used here. Species were separated by using anatomical characteristics. Mixed species catch data from 1959 is available from NAFO.

In all cases, mature biomass was used and all biomass estimates and biomass reference points are in mature biomass.

Methods explored for estimating reference points

Bayesian production model

A Bayesian fitted state-space Schaefer surplus production model was employed to reconstruct population trajectories using the index and catch series. Once fitted, this model provides estimates of Bmsy, Fmsy as well as past and current biomass. Additionally, the approach characterises uncertainty about all the fitted values and can be used to project under different catch scenarios.

This modelling approach was accepted as the method for determining reference points in four of the five stocks examined.

Statistical catch at age model

A statistical catch at age model was tabled at the meeting and illustrated the type of output it could generate. This modelling approach, though promising, requires more work before it can be applied to eastern Canadian redfish and therefore was not used for determining reference points here.

Empirical reference points

Empirically based reference points were examined for all five stocks and they formed the basis for the limit reference point determination for the *S. fasciatus* stock in Unit 3. Although empirically derived reference points are recommended when an adequate model is not available as proxy reference points, they are seen as transitional estimates in the movement to model based estimates.

Summary of stock status and accepted methods

The production model fits were accepted as the basis for limit reference points in four of the five stocks examined (2+3K *Sebastes mentella*; Unit 1+2 S. *S. mentella*; 2+3K *Sebastes fasciatus* and Unit 1+2 *S. fasciatus*). An evaluation was also conducted of current status relative to these points as well as potential growth status and is summarized in a separate section of this report (see also Table 1) . Empirically determined reference points were used for the fifth stock (Unit 3 *S. fasciatus*) for which the current stock biomass and stock growth trajectory were determined using series smoothed through use of a 5 year moving average.

The production model was not accepted as the basis for reference point estimation in Unit 3 because catch changes did not appear to have much impact on subsequent time series biomass. The result of this is that the model fit was imprecise and the median estimates are only slightly more likely than very different point estimates. Properly conveying this uncertainty was seen as difficult and the danger of working only with the very large median estimate without considering the uncertainty is prone to risk. For this reason, empirical methods for reference point estimation were used for Unit 3.

Unit 3 *Sebastes fasciatus*

The Unit 3 time series (Fig. 2) shows large interannual fluctuations but the smoothed series shows a decline from 1970 until about 2000 but an increase thereafter. Because of the large interannual variation, the stock state should not be evaluated on the basis of the raw survey data points but from the smoothed series. The smoothed stock series has never fallen below the limit reference point in terms of this method, which indicates the stock to be currently well above the Bmsy proxy.

Unit 1+2 *Sebastes fasciatus*

Unit 1+2 *Sebastes fasciatus* levels are very low presently at only a small fraction of the estimated 1960 biomass levels (Fig. 3). The stock is estimated to be growing in recent years but without a large recruitment event it would still take considerable time for the stock to grow to a desired healthy level.

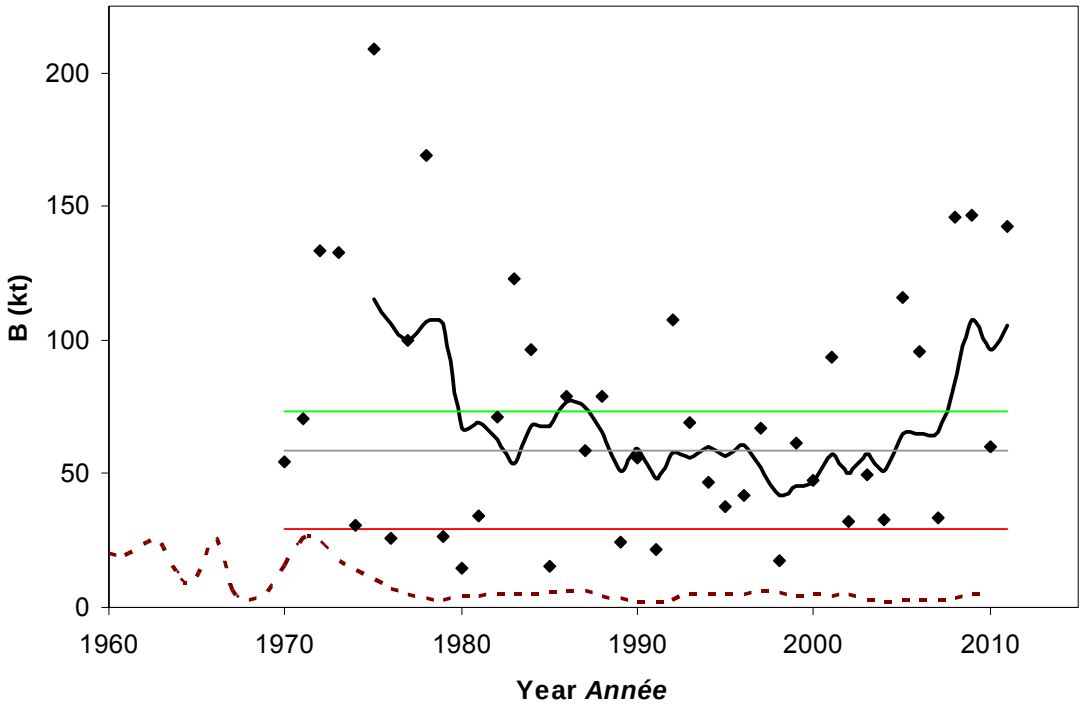


Figure 2: Unit 3 S. fasciatus mature biomass time series and catch (dashed line). A five year moving average smoother on the data is shown and the three horizontal likes are (from highest to lowest): mean series biomass, 80% mean series biomass, 40% mean series biomass. 40% mean series biomass is used as the limit reference point proxy.

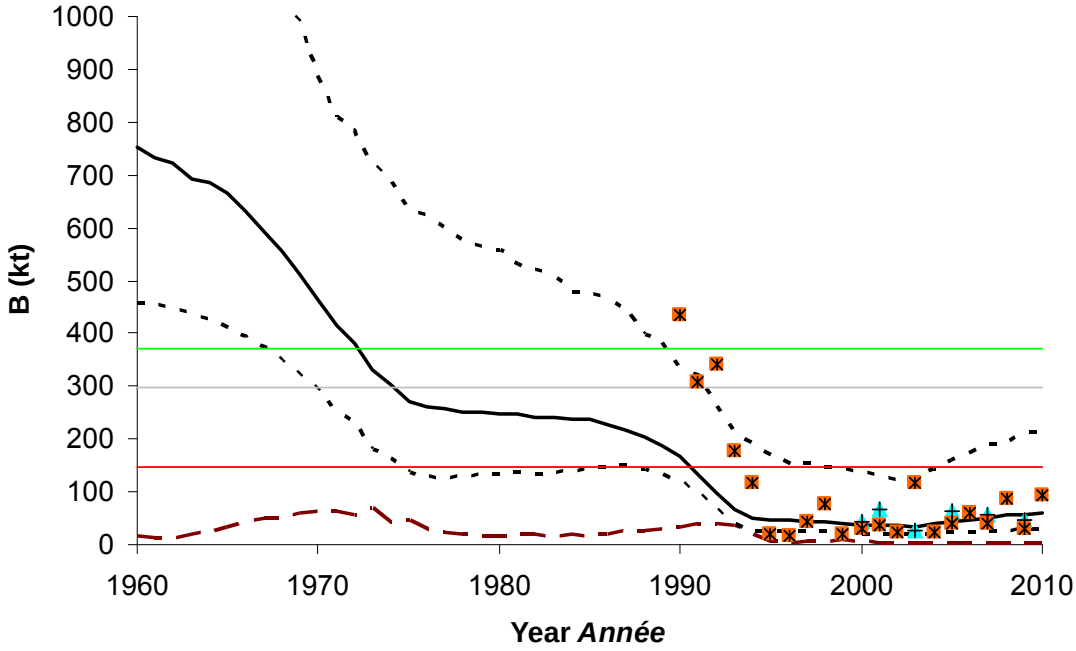


Figure 3: Production model fit to Unit 1+2 Sebastes fasciatus (thick solid line) with 90% probability interval envelope (short dashed lines), catch (long dashed line) and q scaled survey indices. The median Bmsy value as well as 80% Bmsy and 40% Bmsy (LRP) are shown from highest to lowest, respectively.

2+3K *Sebastes fasciatus*

The production model suggests that median biomass declined by about 50% from 1960 to 1980 then continued to decline rapidly over the next 10 years (Fig. 4). The stock had collapsed by over 99% of its earlier abundance to its lowest level in the mid-1990s, but has subsequently shown improvement.

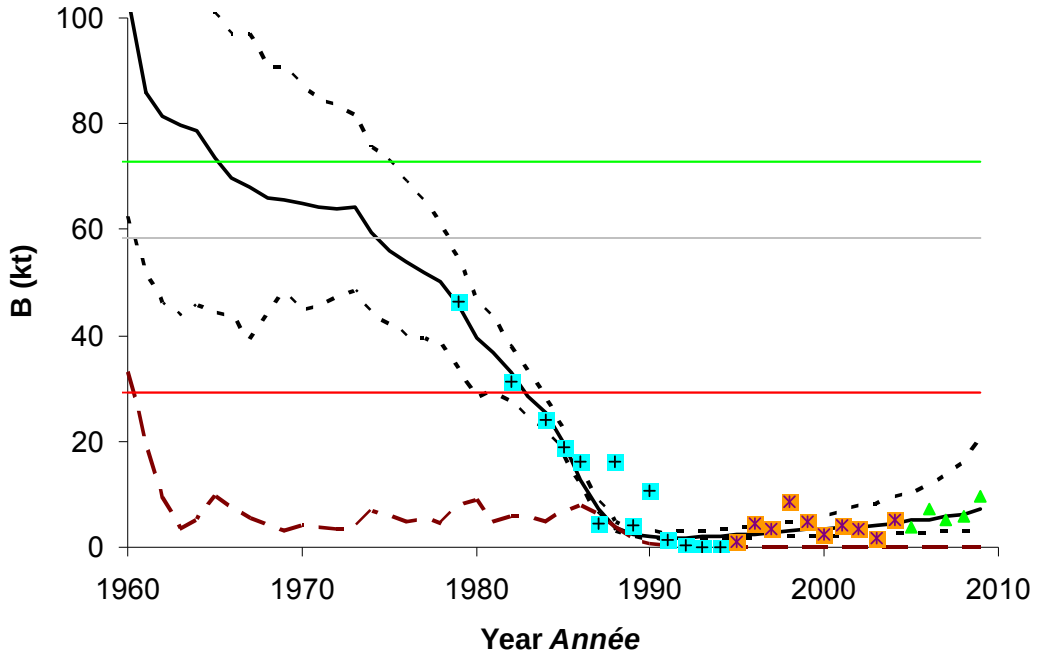


Figure 4: Production model fit to 2+3K Sebastes fasciatus (thick solid line) with 90% probability interval envelope (short dashed lines), catch (long dashed line) and q scaled survey indices. The median Bmsy value as well as 80% Bmsy and 40% Bmsy (LRP) are shown from highest to lowest, respectively.

Unit 1+2 *Sebastes mentella*

Unit 1+2 *Sebastes mentella* is estimated to have declined to only very small proportion of its 1960 biomass. This stock biomass is still decreasing (Fig. 5). Current removals are taken in a Unit 2 directed fishery (TAC currently 8,500 t for redfish spp.) and an index fishery in Unit 1 (TAC currently 2,000 for redfish spp.). A large proportion of the redfish catch in Unit 1+2 is *S. fasciatus*.

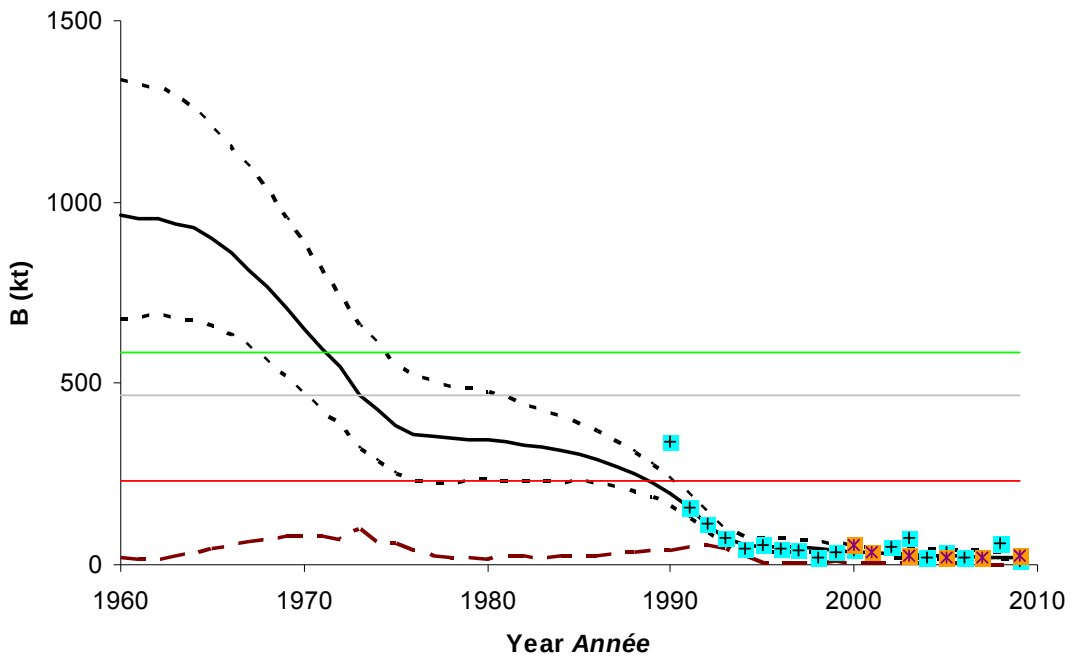


Figure 5: Production model fit to Unit 1+2 Sebastes mentella (thick solid line) with 90% probability interval envelope (short dashed lines), catch (long dashed line) and q scaled survey indices. The median Bmsy value as well as 80% Bmsy and 40% Bmsy (LRP) are shown from highest to lowest, respectively.

2+3K *Sebastes mentella*

It was not possible to conduct a separate production model fit to the 2+3K management unit. Bmsy reference points were available from the Recovery Potential Assessment in 2010 (McAllister and Duplisea 2011a) from a production model for the 2+3K+3LNO areas combined. Reference points for the 2+3K area were partitioned out of the “areas combined” production model based on a design weighted area of habitat index (DWAO) from research trawl surveys in 2J3K, 3LN and 3O. The DWAO index suggested that about 80% of 2+3K+3LNO areas combined redfish habitat was covered by the 2J3K survey index. For this reason, the raw survey values are not depicted on the plot for this stock. Raw survey values for the combined areas are presented in McAllister and Duplisea (2011a) from the 2010 Recovery Potential Assessment.

The production model suggests that median biomass was reduced by 50% in a steady continuous trend from 1960 to the mid-1980s, and then declined rapidly over a 10-year period to the mid-1990s (Fig. 6). Since then biomass has remained stable at a low level until the mid-2000s when a period of marginal increase is evident.

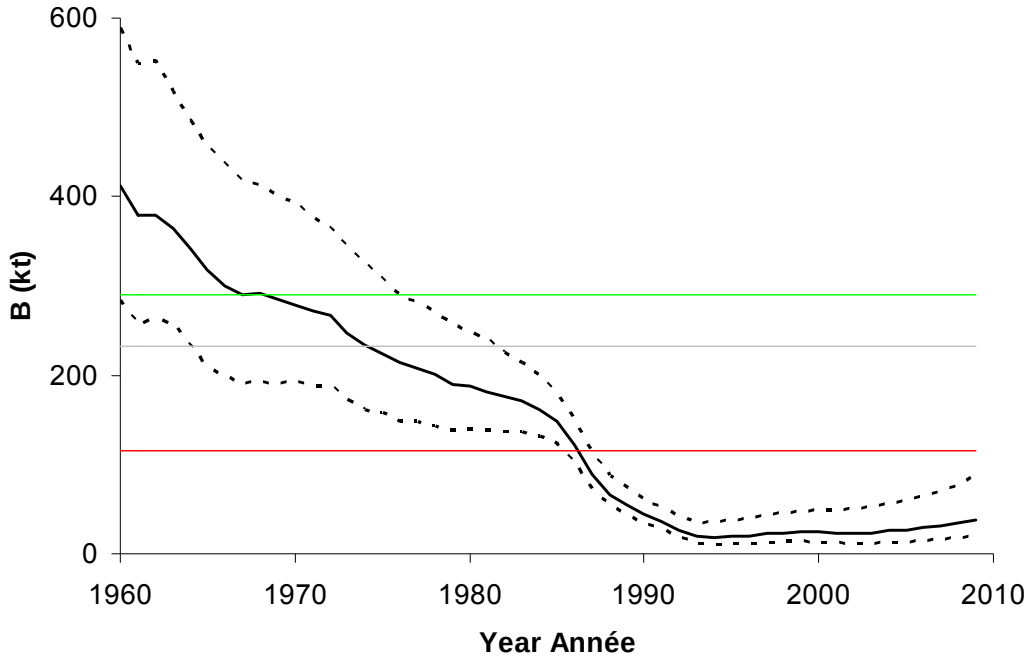


Figure 6: Production model fit to 2+3K Sebastes mentella (thick solid line) with 90% probability interval envelope (short dashed lines). The median Bmsy value as well as 80% Bmsy and 40% Bmsy (LRP) are shown from highest to lowest, respectively. This was determined by partitioning the 2+3K portion (80%) from the Northern mentella population model done for the RPA. For this reason, catch and survey indices are not also shown on the plot as there is not necessarily a direct correspondence.

Sources of Uncertainty

Episodic recruitment

Atlantic *Sebastes* are known as episodically recruiting species where large and important year-classes may occur only once a decade or less even in healthy populations. Episodic recruitment presents a problem for modelling most populations and models generally try to seek central tendencies and thus to estimate mean recruitment levels. The production model employed here does not model recruitment explicitly but it is incorporated in the r parameter. The production model does however contain an autocorrelated process error term that allows model deviations which can to some degree account for deviations from average recruitment. Further work on the production modelling may allow for larger process errors (currently sigma=0.05, ≈ ±15%) but a model that accounts explicitly for recruitment and its variability may be more appropriate.

The influence of not considering episodic recruitment events here could mean that the stock grows more quickly than the modelled median because several good recruitment events occur or *vice versa*. Probabilistic stock trajectories under different fishing scenarios are likely to capture the mean/median trend well, however. It would not be prudent to allow an increased fishing mortality than one would under a mean recruitment scenario (i.e. the production model) in the “hope” that several consecutive low probability events will occur. Additionally, at current low stock sizes, expectation of any strong recruitment events may not be realistic, especially given that there has not been a strong recruitment event in about 30 years for Unit 1+2 *S. mentella*.

Survey catchability

The catchability coefficient scales the index (survey) biomass to the absolute biomass. If a survey is expressed in swept area biomass it is generally assumed that q < 1 because the survey has imperfect catchability and thus survey estimates are sometimes called minimum biomass estimates. This is a relatively simple assumption that does not account for many issues. For example, on the one hand if there is herding into the net or if there is extrapolation from the area surveyed to overall stock area and there happened to be lower densities in the unsurveyed region, the value of q could exceed 1; however, if survey indices only sample a portion of the stock, one would expect a lower q, similarly if the fish movements out of the survey area, q would decreased. Furthermore, fish movement during the survey can also affect q either up or down depending on the movements of fish relative to the sampling. Clearly, many factors can influence q.

Here, q for the Unit 2 survey was estimated to be quite large (>4 for *S. mentella* and >2 for *S. fasciatus*) in the production model. It was considered by some participants that the estimated q value was very important as typically lower values of q result in higher estimates of current biomass in relation to Bmsy and are consequently important in the determination of whether or not a stock is below its limit reference point. Others cautioned that q is just a scalar for a relative survey for whose utility lays in the relative trend and not the absolute value, i.e. the constancy of the q is more important than the absolute q value. It is notable that the large q value was not simply a function of the production model fits but in most cases of the statistical catch at age model, the best fits (i.e. amongst the smallest negative log likelihood values) were also those with q values approach 2 or higher.

Despite discussion about q, it was recognised that presenting large q values to stakeholders may not seem credible even if it is consistent in providing the best match to trends in the indices of abundance in terms of the population model used. To help address this communication issue, it was suggested that an exercise could be undertaken to try to assemble a credible range of q values. Additionally, further work should examine all the factors that go into the swept area calculation such as extrapolation of the survey area to the stock area and gear conversions.

Choosing survey split or ecosystem productivity change

When one has a survey index that shows a large change in biomass relatively quickly between two periods that does not seem biologically realistic, there are broadly three options for model fitting:

1. Ignore the scale change and fit a model that will have a disturbing residual pattern for the survey.
2. Allow the model to fit a different catchability for the survey between the periods assuming that availablilty of fish to the gear changed for any combination of reasons.
3. Assume that a productivity regime change occurred and re-estimate appropriate model parameters between time periods thus implying fundamental changes in the biology of the species or ecosystem.

Implications of ignoring differences: The result of ignoring inexplicable scale shift in the index is that the model will produce residual patterns. A trend in residuals suggests that a model has missed some fundamental process and therefore its results should be treated with suspicion. Residual patterns analysis is the fundamental diagnostics for bad model fits and strong patterns usually lead to the rejection of a model.

Implications of splitting the survey: this assumes that the catchability of survey changed because the survey itself changed in some way or this could also be because for some biological or environmental reason the fish have become more or less susceptible to the gear. For example these could include the possibilities that fish moved into or out of the area from someplace else or that fish movements or position in the water relative to the gear changed. The US National Marine Fisheries Service performed simulations on survey splits when there appeared to be sudden scale shifts in time in the survey index and their results suggested that splitting a survey always produced more robust assessment and advice than not splitting when using a VPA (ICES 2008). However they did not address the issue of whether it was better to split the survey or assume a productivity regime shift. It is desirable to have other information for assuming a catchability change such as information on fish movement or survey changes.

Implications of assuming a productivity shift: assuming a productivity shift will allow the model to estimate different biological parameters for different periods. Thus for example the carrying capacity could be allowed to decrease. As a result, Bmsy and the LRP would also decrease making the current stock state appear to be better relative to the reference point. There is a risk that such an apparent increase in stock status would allow increases in removals that may compromise future stock productivity. One could decrease the possibility for the stock to return to previous levels were the favourable productivity regime to return. Additionally, it may not be clear which parameter is the best to one to represent a productivity regime shift. Allowing a K change (i.e. a change in carrying capacity of the environment) suggests a change in environmental factors such as food supply or habitat availability. Alternatively, one could allow for a change in a production parameter (growth recruitment or mortality) which may also be affected by a change in food supply, for example. In fact, one might allow for a change in several modelled parameters to represent a regime shift. The choice of parameters can have important implications for setting reference points. If one assumes a productivity regime shift has occurred, it would be wise to have auxiliary information on the environment or ecosystem to support the assertion.

CONCLUSION

Limit reference points and current status

Limit reference points should be based purely on species and population biology and not account for socio-economic criteria. As such, estimation of LRPs is a purely scientific exercise.

In four of the five stocks, limit reference points were determined as 40% Bmsy from the median Bmsy estimate from the production model fitting. In the fifth stock (Unit 3 *S. fasciatus*), the limit reference point was determined as 40% of the mean mature biomass index from 1970-2011; the mean biomass of that series is taken as a proxy for Bmsy.

The limit reference points for the five stocks were estimated to be:

1. Unit 3 *S. fasciatus* – 29 kt
2. Unit 1+2 *S. fasciatus* – 148 kt
3. 2+3K *S. fasciatus* – 29 kt
4. Unit 1+2 *S. mentella* – 233 kt
5. 2+3K *S. mentella* – 116 kt

Table 1 summarises the pertinent values for each stock. The growth status of a stock was determined as the ratio of catch in the last data year to the replacement yield. If that value is less than 1 then stock is increasing and *vice versa*.

Table 1: Summary of reference point estimates, current stock biomass and growth status as well as median exit times for stocks in the critical zone. Biomass, catch levels and biomass MSY points are in kilotonnes (kt), Fmsy is per year.

Stock	Bmsy	80% Bmsy	LRP (40% Bmsy)	Fmsy	$B_{2010/11}$	Stock status	Growth status**
Unit 3 *Sebastes fasciatus*	73*	58	29	NA	106 (2011)	healthy*	Increase
Unit 1+2 *Sebastes fasciatus*	370	296	148	0.06	65 (2011)	critical	Increase
2+3K *Sebastes fasciatus*	73	58	29	0.04	8 (2010)	critical	Increase
Unit 1+2 *Sebastes mentella*	583	466	233	0.03	19 (2010)	critical	decrease
2+3K *Sebastes mentella*	290	232	116	0.06	16 (2010)	critical	increase

*Bmsy calculated a mean biomass over the series; growth status from a 5 year moving average smooth trend; zone designation assumes that Bmsy is in the healthy zone
**determined by the catch/replacement yield in the last data year, except for Unit 3 which is empirical

Science suggestions for other reference points

Science has an important role to play in suggesting reference points other than limits though these other points should also take into account management and industry considerations.

Candidates for the upper stock reference, the target reference, and some elements of the removal reference can be derived directly from the production model fitting. These candidate points are described below and estimates are provided here to aid fishery managers.

Upper stock reference: the level associated with a transition into the healthy zone for a stock. The Canadian PA framework suggests the upper stock reference point be set at 80% Bmsy where the evaluation is from a production model. Estimates are available for four of the five stocks analysed. For Unit 3 where the production model was not used, Bmsy is assumed to be represented by the mean biomass of the series and 80% of this value would be the upper stock reference.

Target reference: Bmsy has been suggested as a minimum target reference point internationally. Bmsy is estimated as ½ K in the Schaefer production model fitting; for Unit 3 where the model was not used, Bmsy is assumed to be represented by the mean biomass of the series.

Fishing or removal reference: The removal reference across the three PA zones cannot be derived from the production model fitting alone. The value for Fmsy does come directly from the production model fitting and Fmsy is recognised to be the F limit reference point internationally; the removal reference (F) must therefore be less than or equal to Fmsy, depending on stock status. The choice

of how removal reference varies with stock status will depend on both socio-economic and biological considerations.

The Canadian PA framework (DFO 2009) suggests Fmsy as a limit and the target as potentially equivalent to the USR (0.8 Bmsy) or higher. It is recognized that the framework could benefit from some clarification, as a fishing removal reference of Fmsy or lower would bring the stock to Bmsy or higher. For the redfish stocks addressed here, a fishing mortality reference in the healthy zone should be lower than Fmsy with a corresponding biomass target of Bmsy or higher to be consistent with the Canadian PA framework and international standards.

A candidate PA framework for redfish

The LRP and Science suggestions for other reference points allow one to construct a complete candidate PA framework for the examined redfish stocks. Without simulation testing it is not possible to say if such a framework would succeed in keeping a stock large and economically valuable, prevent decline or allow recovery but this framework below should be one of the first to be tested in a management strategy evaluation approach.

Biomass reference points: Figure 7 shows the PA framework essentially anchored by the estimate for Bmsy which could be used as the target reference point in the Canadian PA framework. Similarly 80% and 40% Bmsy are shown as the upper stock reference and limit reference point for a stock.

Fishing mortality reference: The production model fitting estimates the value for Fmsy. Fmsy is internationally recognised as the upper limit for fishing mortality on a stock that would allow the Maximum Sustainable Yield when the stock is at Bmsy. Although Fmsy is shown as the fishing mortality strategy in the healthy zone, is must be recognised that this is the maximum F and F should be lower than that level. How much lower it should be should take into account the uncertainty in estimation of Fmsy. Removal rate in the critical zone, Fcz, is shown here to be 0 but in reality it would be higher owing to human induced mortality of various kinds such as by-catch. A directed fishing moratorium in this zone would leave a by-catch F which could be determined if appropriate data are available. A directed fishery may be allowed in the critical zone, under circumstances outlined as part of a harvest control rule and rebuilding strategy, consistent with Canada's Precautionary Approach Framework. F_{ramp} is the strategy for changing F as a function of stock size in the cautious zone. In Figure 7, F_{ramp} is shown simply as a straight line between F_{cz} and F_{msy} at B_{lim} and B_{usr}, respectively. F_{ramp} may be chosen to be non-linear or there could even be a different F_{ramp} strategy depending on whether the stock trajectory is increasing or decreasing. F_{cz} and F_{ramp} are shown as dashed lines while F_{msy} is a solid line to suggest the level of subjectivity about them. F_{cz} and F_{ramp} have some latitude for change while F_{msy} is a hard upper limit.

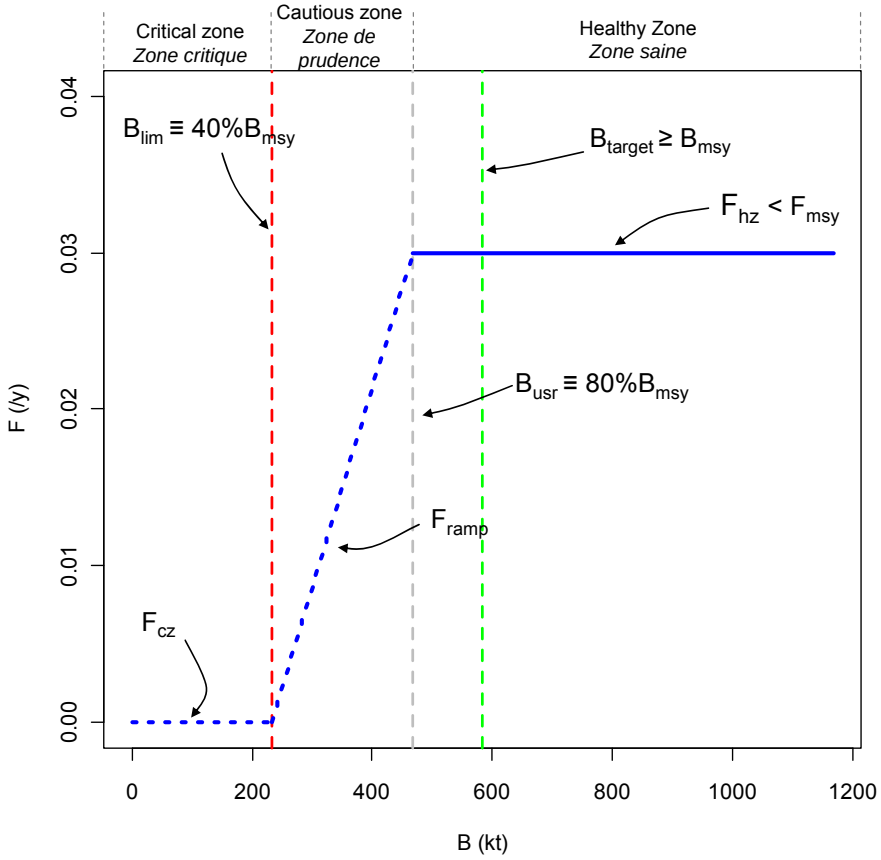


Figure 7: A candidate precautionary approach framework that results from the surplus production model fit to a stock. This is candidate because several of the points shown here are not the exclusive domain of scientists and thus are open to change by management. Axes: B is the mature biomass, F is the fishing mortality or exploitation rate per year. Reference points: F_{cz} is the fishing mortality allowed in the critical zone, F_{ramp} is the change in F strategy employed in the cautious zone, F_{hz} is the fishing strategy in the healthy zone, F_{msy} is the fishing mortality giving maximum sustainable yield when the stock is at B_{msy}. B_{lim} is the limit reference point, B_{usr} is the upper stock reference point and B_{target} is the target reference point. All points except B_{lim} have potential to be modified by management but not necessarily freely without contravening internationally accept norms for developing precautionary approach reference points.

OTHER CONSIDERATIONS

For Unit 1+2 *Sebastes fasciatus*, the production model was not able to track the steep decline in the first half of the 1990's, but produced a much shallower decline. It was suggested during the review that if the production model was forced to track the decline more closely, K estimate for the model would increase. This would then make Bmsy larger as well as 40% Bmsy as the biomass limit reference point but it would unlikely change current stock state. The result is that by forcing the production model to track the decline, the current stock state relative to the reference point may appear less optimistic for this stock. It is notable that the production model fitted the post decline data very closely and likely provided a credible estimate of current biomass.

Species identification in the catch is a continuing issue with mixed redfish catches. The approach for modelling has been to proportion catch in a region and year by the relative proportion of the two species in the survey from the same region and years. Although a reasonable first approach to the

problem, this assumes that the commercial fishery is not targeting one species over the other. The best solution for this problem in future is to speciate the commercial catch. With data already collected, joint modelling of the two species with error related to catch split could be a means to characterise uncertainty resulting from unspeciated commercial catch.

Uncertainty and random effects are more likely to have the most profound influences on stocks when they are small. This includes both decreases and increases in stock size. Probability of good recruitment is increased with larger stock size thus there would be a low probability of strong recruitment for stocks in the critical zone. It would be wise to protect mature biomass in these stocks if we wish to maximise the chance that these stocks will produce a good recruitment event should environmental conditions permit.

While the Bayesian approach used in this assessment provides a mechanism to include uncertainty in the current status of the population, managers and stakeholders are advised that not all the sources of uncertainty have been addressed and the true uncertainty is even greater.

Genetic studies have noted that *Sebastes fasciatu*s in the southern areas of Unit 2 near the slope edge has the same genetic signature as 3LNO *S. fasciatus* suggesting a link. MacAllister and Duplisea (2011a) combined *S. fasciatus* in Unit 1+2 and 3LNO for the purposes of production modelling because of the shared genetic signature. They found that this amalgamated population would be classified as healthy thus considerably changing the impression of the status relative to the reference point because the stock in the 3LNO region was relatively healthy. There is evidence that the Irminger Sea stock of *S. mentella* sometime enters the 2+3K zone and this may partly explain some of the increases in stock size after 2004. There is clearly a stock structure issue for several of the modelled populations here and this can add further uncertainty to model fits and may explain some phenomena observed in various regions.

Future work and re-evalution of reference points

Future work for east coast redfish stocks should involve refinement of statistical catch at age approaches. These models would have the advantage of allowing more of the available information, such as catch-at-age and survey age-frequency distributions into the fitting process, some of which are available (or could be derived) for redfish. Another advantage of using a statistical catch at age model would be to align the Canadian assessment methods with the ICES methods. Despite the apparent advantages of a statistical catch at age approach, there is no guarantee that it would provide more robust advice than the Bayesian production model. A management strategy evaluation that considered both the statistical catch at age and Bayesian production model as assessment models would be very useful for choosing an approach that provides robust management advice.

Further research should also work towards informatively bounding the q for estimation. An informatively bounded q would be one for which there appears little potential for bias being introduced through taking the bound into account, so that this would lead to a reduction in uncertainty and more precise stock estimates. For example, a q prior could be informed by gear expert advice and skipper knowledge covering many experts and skippers. It must be recognized however that this is a project that would take some time and resources and it is essential that it be done properly so as not to introduce bias.

It is expected that the reference points described here will be in place until a substantive change in data or methodology warrants that the points be revisited. Given the time frames for developing new and useful modeling approaches this is likely to be about 3-5 years.

Using production model reference points without the model

In the case where an assessment update is needed and stock status relative to the accepted production model reference points is required yet there is insufficient expertise to re-run the Bayesian production model, the estimated median q values can be used to scale survey indices such that status relative to the reference points can be determined.

Table 2 shows for the 2+3K region median q values that are divided by 0.8 to reflect the proportion of the biomass in the 2+3KLNO complex that is in the 2+3K area only. This is how the reference point for the 2+3K subarea was calculated from the RPA model fitting for the entire area.

Table 2: Median catchability coefficients (q) for different survey swept area biomass estimates and how they relate to the modeled population size from the Bayesian production model.

Stock	Survey area	time period	Median q
Unit 1+2 *Sebastes fasciatus*	Unit 1	1990-2010	0.64
Unit 1+2 *Sebastes fasciatus*	Unit 2	2000-2010	2.53
2+3K *Sebastes fasciatus*	2J3K	1979-1994	3.80
2+3K *Sebastes fasciatus*	2J3K	1994-2004	0.35
2+3K *Sebastes fasciatus*	2J3K	2005-2009	2.72
Unit 1+2 *Sebastes mentella*	Unit 1	1990-2010	1.22
Unit 1+2 *Sebastes mentella*	Unit 2	2000-2010	4.26
2+3K *Sebastes mentella*	2J3K	Fall 1979-1994	1.27 / 0.8
2+3K *Sebastes mentella*	2J3K	Fall 1995-2004	0.55 / 0.8
2+3K *Sebastes mentella*	2J3K	Fall 2005-2009	0.6 / 0.8
2+3K *Sebastes mentella*	3LNO	Fall 1991-1994	1.76 / 0.8
2+3K *Sebastes mentella*	3LNO	Fall 1995-2009	0.61 / 0.8
2+3K *Sebastes mentella*	3LNO	Spring 1991-1994	0.93 / 0.8
2+3K *Sebastes mentella*	3LNO	Spring 1995-2009	0.3 / 0.8

A worked example for a hypothetical situation in 2013

An example could be that in 2013 DFO wishes to have an updated stock status relative to the modelled reference point for Unit 1+2 *S. mentella* yet we cannot re-run the production model (for whatever reason) but we have the smoothed survey index biomass estimate of say 19.5 kt for the Unit 1 survey and 58.5 kt for the Unit 2 survey. One would then divide each survey estimate by the median q to get an absolute biomass for the stock in equivalent units as the reference point. One should also average the estimates to get a single value and then compare this to the limit reference point:

Unit 1 survey swept area smoothed estimate	19.5 kt
Unit 1 median q	1.22
Unit 2 survey swept area smoothed estimate	58.5 kt
Unit 2 median q	4.26
Unit 1+2 *S. mentella* LRP	233 kt

Unit 1+2 biomass estimate from Unit 1 survey	19.5/1.22 = 15.98 kt
Unit 1+2 biomass estimate from Unit 2 survey	58.5/4.26 = 13.73 kt
Unit 1+2 biomass estimate	(15.98+13.73)/2 = 14.85 kt
Unit 1+2 status relative to LRP	14.85/233 = 0.0637

The result here would suggest that the biomass decreased from the 2010 estimate to just under 15 kt and that the stock is therefore only at about 6% of the limit reference point.

One should be careful in making this kind of calculation to use a smoothed survey index as survey can have strong year effects and one would not want to base a biomass estimate solely on the raw annual index. Also, the survey q corresponding to the most recent period should be used. For example, for 2+3K *S. mentella*, only the median q from the most recent period would be used for the biomass calculation in 2013 and not the average of the median q from different periods.

SOURCES OF INFORMATION

This Science Advisory Report is from the October 25-27, 2011 Precautionary approach reference points for Atlantic Redfish (*Sebastes fasciatus, Sebastes mentella*) populations. Additional publications from this process will be posted as they become available on the Fisheries and Oceans Canada Science Advisory Schedule at www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm

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Internet address: www.dfo-mpo.gc.ca/csas

ISSN 1919-5079 (Print)
ISSN 1919-5087 (Online)

La version française est disponible à l'adresse ci-dessus.

CORRECT CITATION FOR THIS PUBLICATION

DFO. 2012. Reference points for redfish (*Sebastes mentella* and *Sebastes fasciatus*) in the northwest Atlantic. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/004.