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Further considerations regarding reference points, harvest control rules and rebuilding strategies for 3LNO American plaice and 3NO cod

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Abstract

MSY-based reference points are estimated for 3LNO American plaice and 3NO cod to further the application of the Precautionary Approach on NAFO stocks. In 3LNO plaice the MSY reference points, particularly Fmsy, are sensitive to the time period over which biological inputs are averaged. A management strategy is presented based on MSY reference points that could be applied to a number of stocks for which there are analytical assessments, including 3LNO plaice and 3NO cod. Initial stochastic simulation testing suggests that the strategy could, at least partially, meet the NAFO PA framework risk tolerance requirements.

Key words: cod, American plaice, MSY, biological reference points, management strategy, Precautionary Approach, harvest control rules, rebuilding strategy

Introduction

Both the 3LNO American plaice (*Hippoglossoides platessoides*) and 3NO cod (*Gadus morhua*) stocks collapsed in the late-1980s and early-1990s from overfishing, and were placed under moratoria on directed fishing in 1994. However, ongoing bycatch mortality in Grand Bank fisheries for skate (*Raja spp*.), yellowtail flounder (*Limanda ferruginea*) and Greenland halibut (*Reinhardtius hippoglossoides*) has impeded recovery (Shelton and Morgan, 2005). Spawning stock biomass (SSB) had been trending slowly upwards in plaice since the mid 1990s (Dwyer et al., 2010) while cod has flat-lined at near minimum SSB levels with a slight increase in the last two years (Power et al., 2010). As members of larger population units, Grand Bank American plaice has recently been determined to be threatened (COSEWIC, 2009) and Grand Bank cod endangered (COSEWIC, 2010) under Canada's Species at Risk Act (SARA) by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). This does not afford greater protection in Canadian waters unless these designations are agreed to by the Canadian Government and the populations officially listed under SARA (Species at Risk Act) as species at risk of extinction. Only a single marine species has been listed as threatened or endangered (basking shark, *Cetorhinus maximus*, Pacific population) since SARA came into effect in 2002 (Powles, 2011).

As straddling stocks, Grand Bank cod and plaice are managed by NAFO. The Fisheries Commission of NAFO formally adopted a Precautionary Approach (PA) framework in 2004 (NAFO/FC Doc. 04/17) as proposed by NAFO Scientific Council (NAFO SCS Doc. 03/23). The SC framework is consistent with the 1995 United Nations Fish Stocks Agreement (UNFSA) and provides a structure that included limits, buffers, targets and management strategies that would reduce fishing mortality to rebuild and keep stocks in the Safe Zone.

Although adopted by NAFO, implementation of the PA framework has lagged. SSB limit reference points (Blim) for both 3NO cod and 3LNO plaice have been estimated by SC and both stocks remain below their respective Blim values (Power et al., 2010; Dwyer et al., 2010) and consequently remain under moratoria with regard to directed fishing. However, the full PA framework and PA compliant management strategies have not been developed for either stock.

Recently FC has indicated a renewed interest in moving forward with implementation of the PA on NAFO stocks. In 2007 FC adopted a "Cod Recovery Strategy" for 3NO cod (NAFO/FC Doc 07/8) followed in 2010 with the adoption of an "Interim 3LNO American Plaice Conservation Plan and Rebuilding Strategy" (NAFO/FC Doc. 10/13). The cod strategy does not provide many details on implementation of the NAFO PA framework on this stock, beyond a commitment to reduce bycatch and rebuilding the stock to above Blim. The interim plaice strategy is more structured and includes limits, buffers, targets and partially specified harvest control rules, however this strategy was developed independently of SC and it has not been reviewed to determine whether or not it conforms with the NAFO PA framework and associated risk tolerance criteria.

In a further step towards implementing the PA, NAFO FC struck a "Conservation Plan and Rebuilding Strategy Working Group" in September 2010 (NAFO/FC Doc. 10/11) with the objectives: *(1) Comprehensive review of the interim 3LNO American plaice and the existing 3NO Cod Conservation Plans and Re-Building Strategies; and (2) Consider risk management approaches in the review, update and future development of Conservation Plans and Rebuilding Strategies. More specifically, the WG is tasked with reviewing and updating conservation plans and rebuilding strategies in respect of: a) Limit reference points, as provided by Scientific Council, and recovery target(s); b) Buffer reference points, developed in the context of precautionary approach framework and in support of robust rebuilding plans; c) Timelines or time frames that can reasonably be expected to achieve established targets; d) Conditions at which a directed fishery might occur; e) Harvest control rules which incorporate target, limit and buffer reference points, as well as, rebuilding timelines or timeframes; and f) An implementation strategy which promotes stability in response to natural resource fluctuations that may be expected to occur over the life of the rebuilding plan.*

Concurrent with these initiatives, FC expanded its request to SC for scientific advice in 2011 (NAFO/FC Doc. 10/29) to include *the identification of Fmsy, Bmsy and advice on the appropriate selection of an upper reference point for biomass (Bbuf) for 3LNO American plaice and 3NO cod. SC is also asked to review the stock recruit relationship for 3NO cod and the historical productivity regime used in setting the Blim value of 60kt.* SC is further requested to provide *proposals regarding possible harvest strategies which would move the resource to (or maintain it in) the Safe Zone, including medium term considerations and associated risk or probabilities which will assist the Commission in developing the management strategies described in paragraphs 4 and 5 of Annex II of UNFSA.*

Paragraph 7 of Annex II of UNFSA provides general guidance on implementing the PA: "*The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points. For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield* [Fmsy], *and that the biomass does not fall below a predefined threshold* [Bbuf?]*. For overfished stocks, the biomass which would produce maximum sustainable yield* [Bmsy] *can serve as a building target.*

Analyses reported here attempt to address some of the current requests from FC related to reference points and harvest strategies in a manner consistent with the UNFSA guidance. Stock-recruit models are fit to VPA estimates of spawning stock biomass and recruitment, SSB and F reference points are estimated, and an initial evaluation of a rebuilding strategy is carried out.

Fitting stock-recruit models

Recruitment in relation to SSB in 3LNO plaice has previously been examined visually to determine a limit reference point (NAFO, 2003) and through segmented regression by Dwyer et al. (2005) to estimate PA reference points. In relation to the Dwyer et al. study, STACFIS expressed concern about the sensitivity of estimated reference points to the stock-recruit model chosen and to the choice of current partial recruitment (PR) in the fishery. More recently, Morgan and Shelton (2009) estimated Fmsy for 3LNO American plaice using 4 different stock recruit models (Ricker, Beverton-Holt, segmented regression and Loess smoother) taking into account 3 alternative PR vectors. Estimates were mainly affected by the choice of stock recruit model with only minor influence of choice of PR. A Loess smoother gave the best fit to the data and the best prediction of recruitment.

Recruitment in 3NO cod has previously been modeled by Loess smoother to determine Blim (NAFO, 1996), by randomly drawing past recruitment values with replacement from spawning stock biomass quartile bins in a study of rebuilding (Rivard et al., 1999), using a Cauchy kernel smoother to estimate Blim (NAFO, 2003), and using a Gaussian kernel smoother in an examination of the impact of bycatch mortality (Shelton and Morgan, 2005).

In the present study the stock-recruit analysis for 3LNO plaice and 3NO cod were updated using data from Dwyer et al. (2010) and Power et al. (2010). The S-R models described in Morgan and Shelton (2009) were applied to both stocks. In addition two further models were explored, a generalized additive model (GAM) and a Loess smoother applied to log transformed recruitment values.

Generalized additive models were fit in R using generalized cross validation (GCV) and residual patterns examined. The model was

$$\log(E(recruitment)) = f(SSB)$$

where recruitment has gamma error and the link function is log. f is a smooth function (thin plate spline) with the degree of smoothness determined by GCV. Other forms (with a log link and Gaussian error and with an identity link and Gaussian error) of the GAM model were also examined, however, for both plaice and cod, log link with gamma error provided the best model fit (determined by GCV score, residual pattern and AIC).

Model fits (Beverton-Holt, Ricker, segemented regression, Loess (on logged and unlogged data), and GAM) were compared by assessing the mean absolute error (MAE).

$$MAE = \frac{\sum_{i=1}^{n} abs(Y_i - \hat{Y})}{n},$$

where Y_i is the observed recruitment value and $\hat{Y}$ is the model predicted value.

A "best practice" set of methods for modeling the stock-recruit relationship within NAFO has yet to emerge. In the current application (Fig. 1) the best fits based on MAE were the GAM for 3LNO plaice and the Loess (data not log transformed) for 3NO cod (Table 1), although the differences in MAE between models was relatively small. Clearly the parametric functions do not describe the data particularly well suggesting other approaches should be explored.

Smoothers are relatively straightforward to apply and allow the data to determine the shape of the fit. They have been widely applied in previous studies on fisheries reference points (e.g. Cook 1998, O'Brien 1999) and are proposed here as the method to be used for both stocks. In Morgan and Shelton (2009) the recruitment data for 3LNO plaice were not log-transformed before applying the Loess smoother. Following Cook (1998), we now apply the smoother to log-transformed data and carry out the conventional bias correction in back-transforming the resulting recruitment estimates. The correction for transformation bias is $\exp(\frac{s^2}{2})$ where s^2 is the estimated error variance or residual variance ($\sum (Y_i - \hat{Y})^2 / 2$) of the regression under log-transformation (MacCall and Ralston, 2002).

For 3LNO plaice the smoothing parameter selected by the GCV score (subject to the constraint that there is no decrease in R with increasing SSB) is 0.54 and the bias correction factor is 1.103. For 3NO cod the optimum smoothing window is 0.6 and the bias correction is 2.069. The estimated relationships for the two stocks are somewhat similar (Fig. 1). There is a cluster of recent data points near the origin. With increasing biomass there is a slightly depensatory bow to the curve up to an intermediate SSB where there is a slight compensatory hummock, followed by a second slight depensatory dip before the relationship straightens out to a near linear increase in recruitment with increasing SSB. For the purpose of estimating reference points and evaluating harvest control rules, it is assumed that beyond the highest SSB value, recruitment is assumed constant at the predicted value for the highest SSB (i.e. the S-R relationship has a flat-top). Similarly, below the lowest SSB value recruitment is assumed constant at the predicted value from the smoother for the lowest SSB. Plots of the residuals against year show strong temporal patterns for both stocks prior to the early 1990s (Fig. 2). Residuals plotted against SSB do not show strong patterns but tend to be small at low stock size.

In response to the FC request for a review of the S-R relationship for 3NO cod, we conclude that, while no S-R approach is strongly supported by the data, the Loess smoother fitted to log recruitment provides a general description of the past response of recruitment to SSB and can be used as a basis for deriving reference points and examining harvest control rules.

Although no further review of the 3LNO plaice S-R relationship was requested by SC, we consider that the updated Loess fitted to log recruitment data should be used in further consideration of reference points and harvest control rules for this stock in place of the Loess fitted to unlogged data presented in Morgan and Shelton (2009) and accepted by SC.

The temporal pattern in the residuals in both stocks requires further consideration. It could be the result of a variety of causes including changes in reproductive potential over time that are not captured solely by mature biomass alone (Morgan et al., 2009; Morgan, 2008). Similar periodicity is seen in the plots of recruitment rates (R/S) prior to 1990 (Fig. 3). There is no indication that recent productivity is impaired with respect to R/S for 3LNO American plaice with four of the last seven years generating above average R/S. For 3NO cod R/S was low from the early 1980s to about the mid 1990s but it has improved since and the last 3 years all have above average R/S suggesting that this aspect of productivity is not impaired.

Estimating reference points

Reference points have typically been estimated directly from S-R data or from production model fits. S-R models can indicate the point at which recruitment becomes impaired or severely impaired, whereas production models can indicate where overall production (recruitment + body growth – natural mortality) becomes impaired.

If reference points are based on an S-R model, the NAFO Study Group on Limit Reference Points (SGLRP) recommended that B50%Rmax (the SSB corresponding to 50% of maximum recruitment) be considered as Blim (NAFO 2004). If a production model is applied, SGLRP recommended that the biomass giving 50%MSY should be considered as Blim. For stocks assessed with the Schaefer model (i.e. a symmetrical function with Bmsy at 0.5*B0) this is 30%Bmsy. Finding the biomass giving 50%MSY can be problematic for stocks with highly asymmetrical production functions such as those estimated for 3LNO plaice and 3NO cod. Instead we advocate simply using 30%Bmsy as Blim and consider 30%Bmsy preferential to B50%Rmax when both reference points can be computed because of the additional information from YPR and SPR incorporated in a production model vs. a S-R model.

NAFO SC has already established Blim for 3LNO plaice and 3NO cod. For 3LNO plaice Blim is set at 50kt SSB based on a visual examination of the stock recruit scatter from the VPA which indicates that there was no good recruitment below this level (Morgan et al.,
2002). Further support for this Blim value was provided by NAFO (2003). For 3NO cod Blim is set at 60kt SSB based on visual inspection that showed a decreased likelihood of obtaining good recruitment below this level (NAFO, 1999), supported by the fit of a Loess smoother to the data. Further support for this Blim value was provided by NAFO (2003).

While the NAFO PA Framework established Flim=Fmsy (NAFO/FC Doc. 04/18), issues related to changing productivity and fishery selectivity over time have complicated the choices of reference levels for 3LNO American plaice and 3NO cod. For 3LNO plaice NAFO (2003) suggested Flim=0.33. Morgan and Shelton (2009) proposed Flim=0.4 based on the estimate of Fmsy from a Loess smoother fit to unlogged recruitment values, together with SPR and YPR data averaged over the last three years (except PR which was the long term average) prior to the assessment year and this was adopted by SC as a preliminary value of Flim. For 3NO cod Fmsy has not recently been estimated and no value has been proposed by SC for Flim.

The NAFO PA Framework (NAFO/FC Doc. 04/18) recognizes the need for a Btarget refrence point. Under UNFSA, for overfished stocks, the biomass that would produce MSY, Bmsy, constitutes a rebuilding target. The 2002 World Summit on Sustainable Development in Johannesburg set the objective of *attempting to maintain stocks at, or restore stocks to, levels that can produce MSY* (i.e. Bmsy), *with the aim of achieving these goals for depleted stocks on an urgent basis and where possible not later than 2015*. In their review of the definitions of sustainability, Shelton and Sinclair (2008) found wide support for Btarget to equal Bmsy or higher. The NAFO PA Framework specifies that Ftarget should be chosen to ensure that there is a low probability (<20%) that F exceeds Flim, and a very low probability (<5-10%) that biomass will decline below Blim within the foreseeable future (5-10 years). No values for Ftarget have been proposed by SC or adopted by FC thus far for these stocks.

In the current analysis we estimate a variety of SSB and F reference points based on the Loess smoother applied to log-transformed recruitment values from the 2010 plaice and cod VPA assessments. Calculations are carried out on both recent average (2007-2009) and long-term average inputs for weights, maturity and PR. Initial computations for plaice under long term average conditions were carried out by averaging the whole 50 year time series (1960-2009). However, following review by SC this was changed to computing a long term average for weights and maturities over a 25 year period for which the maturity at age was relatively stable (1985-2009). PR however was averaged over the whole time series (1960-2009). The logic behind using the average of the last 25 years for biological inputs for plaice is the view expressed in SC that maturities would not revert to a pre-1985 level in the near future. For cod, the long term average for weights, maturities and PR were computed over the whole 51 year time series (1959-2009) for partial recruitment, stock weight, catch weight and maturity vectors (Fig. 4). Natural mortality was taken to be 0.2 in both stocks.

The biggest differences between the 50 year average and recent average inputs in 3LNO plaice are in regard to proportion mature at age and partial recruitment (selectivity) to the fishery (Fig. 4). There is a greater proportion of fish maturing at younger ages in the recent period compared to the average. The 25 year average maturities are, however, much more similar to the recent period. With regard to partial recruitment, fish aged 9-11 are less selected in the recent period and fish aged 12 and older are more selected compared to the long term average. This may be the result of a shift to larger mesh size that occurred in the foreign fishery in the mid to late 1990's. Plaice are accumulating slightly more weight at older ages in the last 25 years compared to the long-term average. In 3NO cod, there is also a shift towards younger ages maturing earlier in the recent period compared to the long-term average, but the change is not as marked as in plaice. Partial recruitment is variable for older ages in the recent period and but appears somewhat lower for ages 8 and older compared to the long-term average. There is a slight change in weight at age, with older fish accumulating slightly less weight in the recent period compared to the long-term average, thus negating some of the compensatory effect of earlier maturation. This change in weight at age is the reverse of what was found in plaice.

In order to determine Fmsy, projections of stock size were carried out to equilibrium at various F levels to determine Fmsy, Bmsy (in terms of SSB), MSY and a variety of other metrics. In addition, SPR and YPR analyses were conducted using the same input data.

Productivity changes related to changes in natural mortality are not examined in these analyses. A change in natural mortality can have a big impact on SPR and YPR, and thus on MSY-based reference points and the whole dynamics of the stock. Although there is no strong evidence for a change in natural mortality from the base level of 0.2 over time in 3NO cod, the SC assessment for 3LNO plaice applies a natural mortality (M) value of 0.53 (instead of the base level of 0.2) on all ages for 1989-1996 (Dwyer et al. 2008). Should natural mortality (or more accurately, unaccounted for deaths) revert to this level again in the future it would have a major impact on the dynamics of the plaice stock.

The estimates of a variety of reference points based on the Loess smoother applied to log recruit with SPR and YPR calculated from both recent average (2007-2009) and long-term average (1960-2009 for plaice and 1959-2009 for cod inputs), are presented in Table 2 and Figure 5. Only some of the results are highlighted here.

Firstly, the current adopted Blim values continue to look reasonable, if slightly low, under the current analysis. For both stocks, 30%Bmsy provides somewhat higher estimates of Blim and could be argued to be a better approach because it incorporates information on YPR and SPR in addition to S-R. B50%Rmax estimates are also higher than the adopted Blim value for plaice but very close to the adopted Blim for cod. The Blim estimates for plaice and cod are 5% to 6% of the estimated virgin biomass B0, somewhat lower than might be preferred under the PA, providing an added argument for using higher Blim estimates than the current ones.

The Bmsy estimates are relatively robust to the time period over which inputs are averaged for calculating YPR and SPR. Fmsy on the other hand is twice as high for plaice when calculated using recent averages compared to long-term averages (50 years). Fmsy calculated using the average YPR and SPR for the last 25 years is intermediate. In contrast, Fmsy is similar over both short term and the 51 year time period in 3NO cod. Of some concern are the substantial differences between F35%SPR and Fmsy, particularly in the case of plaice. Fmsy is therefore associated with a high level of SPR depletion suggesting that Ftarget should be substantially lower than Fmsy. Also of concern is that Fcrash is only slightly higher than Fmsy in both stocks, again suggesting that Ftarget should be substantially lower than Fmsy.

Table 2 indicates the substantial difference in the population dynamics of the two stocks. In plaice an age 1 recruit produces about 1.3 kg of SSB over its lifetime whereas in cod an age 1 recruit produces 5.8 to 6 kg SSB. The exponential growth rate of plaice (rmax, instantaneous rate) at low stock sizes is between 0.13 and 0.16 whereas for cod it is 0.24. Based on the 2010 assessment, plaice are at about 67% of Blim and 14% Bmsy whereas cod are only at 21%Blim and 5% Bmsy. Thus although plaice have a much lower potential recovery rate than cod, they are closer to Blim and Bmsy than cod. The production function is more skewed in the case of cod than plaice with Bmsy/B0 at about 20% B0 for cod and at about 30% for plaice implying greater resilience to fishing in cod.

In order to determine which of the input parameters is producing the difference in Fmsy estimates in plaice when using inputs averaged over different time periods, calculations were repeated a number of times using long-term average (50 year) inputs but replacing one of the vectors with recent (2007-2009) averages each time. For example, Fmsy was estimated using long term stock weights, catch weights and maturities but with recent selectivity. In addition, estimates were made using recent average inputs but in one case replacing recent average maturity with long-term average maturity and in the other replacing recent average PR with long-term average PR. The results of these permutations are given in Table 3. The largest impact comes from the maturity at age vector. Using recent average maturities along with other long-term average inputs results in an increase in Fmsy from 0.21 to 0.29, while using long term maturities with other recent inputs results in a decrease in Fmsy from 0.42 to 0.27. Selectivity and stock weights also have some impact, but note that while older plaice accumulate more weight in the recent period, older cod accumulate less weight, negating some of the impact of earlier maturation.

Results can also change substantially in the short term. Table 4 shows the results of projections using parameters averaged over different 3 year periods from the most recent (2007-2009) to averages over the 2004-2006 period. If the convention was to use 3 year averages these periods would correspond to what would be used in the advice provided in 2007 through 2010. Estimates of Fmsy would vary substantially over that short period from a low of 0.36 in 2007 to 0.47 in 2009 and back down to 0.42 in 2010. This is a variation of 23% in the reference point in only 3 years

Proposed reference points

We propose that Blim = 30%Bmsy for both stocks based on long-term average inputs. This has the advantage over the current Blim values in that the calculation takes in to account both the S-R data and the YPR and SPR information. It also has the advantage of being consistent with other proposed MSY based reference points.

Further we propose setting Flim = Fmsy calculated based on long-term average biological values and partial recruitment, the logic being that recent values associated with compensatory biological changes, particularly the shift to earlier maturation, which have resulted in increased stock productivity, are likely to be reversed as the stock recovers. An argument could possibly be made for using recent average partial recruitment values in the Fmsy calculation. For plaice this would shift Flim only slightly higher (see Table 3). However it should be noted that in both plaice and cod fishing mortality over the moratorium period has come from bycatches only and may have a very different selectivity from a directed fishery. If estimation of Fmsy were based on recent averages of all inputs this would necessitate the frequent recalculation of Fmsy. This could potentially lead to large changes in TAC.

Consistent with UNFSA, NAFO should formally adopt Btarget = Bmsy for both stocks, calculated using long-term average inputs. SSB is currently estimated (2010) to be at 14%Bmsy in plaice and at 5%Bmsy in cod indicating that substantial rebuilding is still required in both stocks.

We propose setting Ftarget = 3/4xFmsy. In recent years SC has advised on F0.1 as a target fishing mortality for some stocks. When it comes to considering management strategies and harvest control rules (see below), there is some advantage in keeping reference points consistent with the MSY approach. For example, Ftarget calculated on the basis of YPR may not be consistent with an Flim calculated on the basis of the production function incorporating S-R, YPR and SPR. 3/4Fmsy based on long-term average data is reasonably close, but slightly above, F0.1 for both stocks.

We propose setting Bbuf = 80%Bmsy to provide very low risk (<5-10%) of the actual biomass falling below Blim (see NAFO/FC Doc. 04/18) and at a point below which the stock is in more urgent need of rebuilding to the target. 80% Bmsy is used as a reference point in US fisheries sustainability index (FSSI) and is the default biomass reference point demarcating the boundary between the Healthy and Cautious Zones in the Canadian PA framework.

We propose setting Fbuf = 0.5xFmsy to ensure that there is a low risk (<20%) that any fishing mortality rate estimated to be below Fbuf will actually be above Flim as described in NAFO/FC Doc. 04/18.

These proposed reference points are summarized in Table 5. Note that all these values may change slowly over time as the long-term average values for maturity, weight and partial recruitment evolve.

Evaluation of rebuilding strategies and harvest control rules

There can be little doubt that concerted effort is required to rebuild 3LNO plaice and 3NO cod to the target biomass levels. Although both stocks have been under moratorium since 1994 they have remained below their respective Blim values and well below Bmsy. SC is requested by FC to provide proposals on possible harvest strategies for rebuilding these stocks, given that past measures have failed. We first briefly review the current strategies adopted by FC and then propose an alternative MSY-based strategy that is simple and consistent across both stocks.

Review of FC plaice and cod strategies

The FC "Interim 3LNO American Plaice Conservation Plan and Rebuilding Strategy" (NAFO/FC Doc. 10/13) has the objective of rebuilding and maintaining the SSB at or above Bmsy, which is consistent with UNFSA and with what we proposed above. The Blim of 50kt is adopted but Bbuf is set at an arbitrary value of 100kt, substantially lower than 196kt as proposed here based on 80%Bmsy. Flim is set less than Fmsy which is taken to be 0.4, consistent with the value proposed in Morgan and Shelton (2009). However this estimate was based on the recent average weight and maturity values and SC now advocates using the last 25 year average values which gives a lower Flim estimate of 0.31. The FC rebuilding strategy assumes Bmsy = 175kt whereas Bmsy is estimated here to be substantially higher at 242kt. Under the FC strategy a directed fishery reopens when the SSB is above Blim. F is set at <0.15 to allow continued recovery and low probability of falling below Blim when SSB is between 50 and 100kt. This corresponds to either the NAFO PA Cautionary F or Danger Zone, depending on the level of fishing mortality. The FC strategy allows that when SSB is above Bbuf, F can increase but should be <0.2 to allow continued growth subject to natural fluctuations, i.e. when the stock is in the Safe Zone or the Overfishing Zone, depending on the level of F. When SSB is above Bmsy the F should be set at <3/4xFmsy.

While some elements of the FC rebuilding strategy for plaice seem reasonable, and are partly consistent with the reference points proposed here (e.g. Ftarget = 3/4xFmsy; see below), other elements are vague and somewhat arbitrary and not easily transposable to other stocks. The strategy combines MSY based F reference points with arbitrary values. Although risk is touched on, it is not fully addressed and there is no attempt to be consistent with the NAFO PA policy risk management requirements. The harvest control rules in the FC strategy have conditional components (e.g. *When SSB is above Bbuf TAC levels should be set to allow for continued growth, subject to natural fluctuations that may be expected to occur, with F not to exceed 0.2 (F0.1)*). These vague conditional components are not easily transcribed into mathematical notation or computer code for simulation testing of the robustness of the strategy.

The FC “Cod Recovery Strategy for Division 3NO” (NAFO/FC Doc. 07/8) is, in comparison with the plaice rebuilding strategy, less detailed. The strategy aims at attaining Blim = 60kt SSB rather than a Btarget. This is to be accomplished by reducing bycatch by 40% from the average over the 2004-2006 period. Because of its importance as a forage species, continuation of the moratorium on 3NO capelin is part of the strategy. Before Blim is reached, FC expects to develop a management strategy based on the PA. SC is requested to do a detailed review of PA reference points for the stock when SSB reaches 30kt.

Proposed management strategy

We propose a simple alternative to the FC management strategies for plaice and cod that can be applied to most groundfish stocks for which production can be modeled, either through a stock-recruit relationship together with YPR and SPR, or through an age-aggregated surplus production model (Fig. 4). Our strategy attempts to be as consistent as possible with the NAFO PA framework and to meet UNFSA criteria. All reference points are MSY-based. Two new reference points are introduced, Brebuild = 50%Bmsy and Frebuild = 1/4xFmsy. This recognizes the need to further reduce fishing mortality when SSB falls below 50% Bmsy. Fmin represents minimum bycatch mortality, which clearly has to be much lower than it presently is to promote rapid rebuilding.

Initial robustness tests of the proposed strategy

Methods

Stochastic simulations of the plaice and cod stocks under the application of the proposed management strategy were carried out in an initial determination of the robustness of the strategy. Simulations were run forward for 50 years, repeated 1000 times. The harvest control rule incorporated in the management strategy was applied in each year to generate the TAC based on the SSB at the beginning of that year. Three sources of error were introduced: error in recruitment, error in natural mortality (both are process error) and error in the F that is applied (assessment or observation error). Recruitment comes from the Loess smoothers fit to log recruitment with error introduced by resampling the residuals with replacement and adding them to the predicted recruitment in each year. Natural mortality (M) is modeled by multiplying the base M of 0.2 by a random multiplier drawn from a uniform distribution, U[0.8,2]. F is generated from the HCR depending on the value of SSB. The F from the HCR is multiplied by lognormal assessment error with CV=30% before it is applied to the simulated population.

Projection inputs in the simulation were recent average values (2007-2009) as applied in the 2010 assessment for each stock. So, while the reference points are based on long-term average inputs, the robustness simulation uses recent average inputs for weights, maturity and partial recruitment. The logic behind this is that at present the stock is expected to respond as per the recent average but the rebuilding target is the long-term MSY level.

In a full management strategy evaluation (MSE) the uncertainties or errors would be modeled in more detail. For example, here we do not consider uncertainty in the maturities at age, weights or PR and we don’t track both the true and the perceived population over time, applying the HCR to the perceived population and determining the performance based on the true (simulated) population.

We consider only a limited set of performance statistics related to recovery:

(i) risk that Blim will not be acheived by 2020
(ii) median date to achieve Blim
(iii) risk that Bmsy will not be achieved by 2030
(iv) median data to achieve Bmsy
(v) risk of F>Flim within each run
(vi) median catch in year 10 across runs
(vii) median catch in year 20 across runs
(viii) median catch in year 30 across runs

The risk of falling below Blim is not computed because SSB is already below Blim in both stocks.

Results and Discussion of Robustness Tests

The results are summarized in Table 6 and Figs. 5 and 6. The risk, under the management strategy, of not achieving Blim by 2020 is 87% for plaice and 34% for cod under the assumed assessment error, variability in M and recruitment uncertainty. However, the median date to reach Blim is 2024 for plaice and 2019 for cod. The risk of not achieving Bmsy by 2030 is 100% for plaice and 67% for cod. The median date for reaching Bmsy is longer than the time horizon of 50 years for plaice (>2060) and 2033 for cod.

The risk of F>Flim at least once over the 50 year time horizon is 48% r plaice and 99% for cod. It should be noted from the scatter plots in Figs 5 and 6 that this occurs mainly when the stock is above Brebuild and mostly when the stock is above Bbuff. This risk is entirely dependent on the CV assumed for log-normal assessment error (30%) in the present simulations.

The median catches across 1000 runs after 10 years is relatively low because of the low Fmin imposed below Blim. Higher Fmin, representing minimum bycatch, could be considered, but this would further lengthen the time to get to Blim. Median catch after 20 years is only about 7kt for plaice, indicating the low surplus production in this stock, but will reach nearly 60kt for cod. After 30 years the median catch for plaice under the management strategy will still be relatively modest at 18kt but will have reached about 70kt for cod.

The results are sensitive to the assumed values for assessment uncertainty and variation in natural mortality. American plaice are particularly sensitive to the variability in M and given evidence of higher M's in the past this is an important consideration in terms of testing the robustness of management strategies.

While the proposed management strategy is slow to rebuild the stock and the catches generated in the initial period are low, the trajectories are positive and the F is reasonably well controlled below Flim at lower stock sizes. Steps with higher F values could be contemplated but this would further slow down the recovery and would have a higher risk of F>Flim. The current strategy only partially meets the risk criteria outlined in the NAFO PA framework and an even more conservative strategy may be considered necessary.

The current set of simulations apply the recent average weights, maturities and partial recruitment (selectivity) against reference points that are computed using long-term (last 25 years for plaice and last 51 years for cod) average inputs. This seems a reasonable approach. As rebuilding evolves, new recent average biological inputs could be applied to update the times to rebuild and risks.

The proposed management strategy is MSY based and this has the advantage that all the reference points are internally consistent, rather than a mixture of reference points based on YPR, S-R and arbitrary values. Alternative MSY based reference points could be proposed and examined.

The same management strategy was tested with all reference points the same except that Blim was replaced with the existing Blim for each stock i.e. 50 000 t of SSB for 3LNO American plaice and 60 000 t of SSB for 3NO cod. This framework has the disadvantage that the reference points do not all have the same basis. Table 7 shows the results. The main difference is that the risk of not achieving Blim by 2020 and the median date of reaching Blim are lower in this framework, because Blim is lower. There is not much difference in the medium to long term development of the stocks.

Any future management strategy proposed for NAFO stocks should have clear harvest control rules that, like the ones applied here, can easily be turned into mathematical notation and computer code for robustness testing. It is also important for NAFO to translate its management objective for stocks into measurable performance statistics in order to be able to evaluate the merits of alternative strategies.

The initial testing applied here is only a first step, but should be considered a necessary first step for any management strategy that is proposed. A much more thorough approach using management strategy evaluation (MSE) should be pursued. Under a full MSE two broad approaches become available: the management strategy could be based on harvest control rules that respond directly to model estimates of SSB and F relative to reference points as is the case here, or they could be much simpler TAC adjustment rules based on trends in surveys, but tuned to have acceptable risks of achieving the reference points. Simple survey based rules may outperform more complex assessment based rules. Under both approaches, risk is evaluated in the form of performance statistics, rather than coded directly into the rule.

Conclusions

Formal management strategies that address the NAFO PA framework should be put in place to rebuild the 3LNO American plaice and 3NO cod stocks and to manage them in a sustainable manner once rebuilt. It is suggested that these strategies be based initially on MSY derived reference points based on long-term average biological inputs (weights and maturity). The performance of these management strategies should undergo initial robustness testing through stochastic simulation. In these simulations stock dynamics should be determined by recent average biological inputs. Risk should not be built into the harvest control rule but should instead be evaluated in the form of performance statistics, taking into account the risk tolerance requirements of the adopted NAFO PA Framework. Eventually proposed management strategies should be subject to formal MSE. At this point it may be determined that simple feedback harvest control rules perform as well or better than more complicated harvest control rules based on the PA framework as proposed here.

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Table 1. Mean absolute error for different S/R models fit to data for 3LNOAmerican plaice and 3NO cod.

	Beverton-Holt	Ricker	Segmented	Loess	Loess Logs	GAM
American plaice	45.1	44.6	44.8	41.2	41.5	40.6
Cod	32.1	32.1	32.3	31.1	33.7	32.8

Table 2. Reference points for 3LNO American plaice and 3NO cod based on Loess smoother fitted to log-recruitment. Reference points are calculated based on recent average and long term average weights, maturity and partial recruitment at age. Biomass values represent SSB. F values are average for fully recruited ages. Per recruit values are in kg and are relative to an age 1 recruit. Long term averages for 3LNO American plaice are based on 1985-2009 for maturities and weights and 1960-2009 for partial recruitment. Long term averages for all inputs for 3NO cod are based on 1959-2009.

	3LNO Plaice		3NO Cod	
Reference point	**Recent ave**	**Long-term ave**	**Recent ave**	**Long-term ave**
F0.1	0.15	0.16	0.22	0.20
Fmax	0.61	0.53	0.34	0.30
Max YPR	0.11	0.10	0.58	0.63
Yield ratio	0.86	0.90	0.95	0.95
SPR at F=0	1.24	1.33	5.81	5.95
F35%SPR	0.07	0.07	0.18	0.14
MSY	70,767	69,667	109,462	119,148
Fmsy	0.42	0.31	0.34	0.30
Fcrash	0.50	0.25	0.35	0.33
1/4xFmsy	0.11	0.08	0.09	0.08
1/2xFmsy	0.21	0.16	0.17	0.15
3/4XFmsy	0.32	0.23	0.26	0.23
Bmsy	240,920	241,639	232,515	247,681
30%Bmsy	72,276	72,492	69,755	74,304
50%Bmsy	120,460	120,820	116,258	123,841
80%Bmsy	192,736	193,311	186,012	198,145
B0	837,962	896,130	1,098,768	1,123,878
Bmsy/B0	0.29	0.27	0.21	0.22
rmax	0.16	0.13	0.24	0.24
B50%Rmax	77,218	77,218	59,968	59,968
Current Blim	50,000	50,000	60,000	60,000
Blim/B0	0.06	0.06	0.05	0.05
SSB in 2010	33,377	33,377	12,730	12,730
SSB2010/Blim	0.67	0.67	0.21	0.21
SSB2010/Bmsy	0.14	0.14	0.05	0.05
F in 2009	0.13	0.13	0.05	0.05
F2009/Fmsy	0.31	0.42	0.15	0.17
F2009/F0.1	0.87	0.81	0.23	0.25
Catch2009	3,015	3,015	1,083	1,083
Catch2009/MSY	0.04	0.04	0.01	0.01
Yrs averaged				
Wts and mats	2007-2009	1985-2009	2007-2009	1959-2009
Partial recruitiment	2007-2009	1960-2009	2007-2009	1959-2009

Table 3 Comparison of results using different input parameters. Biomass and catch are in '000 tons. Recent refers to averages from 2007-2009 and long term refers to averages over the entire time period 1960-2009.

	Fmsy	SSBmsy	KSSB	Bmsy/K	1/3Bmsy	Blim/K	MSY
recent	0.42	240	780	0.31	72	0.064	70.8
Longterm (LT)	0.21	245	686	0.36	73	0.073	62.0
LT, recent maturity	0.29	244	762	0.32	73	0.066	64.9
LT, recent PR	0.24	246	683	0.36	73.8	0.073	64.6
LT, recent stock weight	0.23	244	699	0.35	73.1	0.071	63.0
LT, recent catch weight	0.21	245	686	0.36	73.5	0.073	64.0
Recent, LT maturity	0.27	245	697	0.35	73.5	0.072	68.1
Recent, LT PR	0.33	242	783	0.31	72.7	0.064	68.6

Table 4. Comparison of results using different input paramaters averaged over different time periods. Biomass and catch are in '000 tons.

Advice year	Averaging period	Fmsy	SSBmsy	KSSB	Bmsy/K	1/3Bmsy	Blim/K	MSY
2010	2007-2009	0.42	240	780	0.31	72	0.064	70.8
2009	2006-2008	0.47	242	826	0.29	72.5	0.061	74.2
2008	2005-2007	0.43	243	864	0.28	72.9	0.057	75.1
2007	2004-2006	0.36	242	896	0.27	72.5	0.056	74.8

Table 5. Propsosed reference points for 3LNO American plaice and 3NO cod.

MSY Basis	Ref	3LNO Plaice	3NO cod
30%Bmsy	**Blim**	73kt	74kt
50%Bmsy	**Brebuild**	121kt	124kt
80%Bmsy	**Bbuf**	193kt	198kt
Bmsy	**Btarget**	242kt	248kt
~0	**Fmin**	0.01	0.01
1/4xFmsy	**Frebuild**	0.08	0.08
1/2xFmsy	**Fbuf**	0.16	0.15
3/4xFmsy	**Ftarget**	0.23	0.23
Fmsy	**Flim**	0.31	0.30

Table 6. Performance statistics from the proposed management strategy based on 1,000 runs of the simulation model.

Performance statistic	3LNO Am plaice	3NO cod
Risk Blim not achieved by 2020	87%	34%
Median date to reach Blim	2024	2019
Risk that Bmsy not achieved by 2030	100%	67%
Median date to achieve Bmsy	>2060	2033
Risk of F>Flim in each run	48%	99%
Median catch year 10	545	1,804
Median catch year 20	6,674	58,558
Median catch year 30	17,602	69,203

Table 7. Performance statistics from the proposed management strategy but with Blim being the current adopted Blim for each stock. Results are based on 1,000 runs of the simulation model.

Performance statistic	3LNO Am plaice	3NO cod
Risk Blim not achieved by 2020	20%	16%
Median date to reach Blim	2017	2018
Risk that Bmsy not achieved by 2030	100%	69%
Median date to achieve Bmsy	>2060	2033
Risk of F>Flim in each run	47%	100%
Median catch year 10	937	7,305
Median catch year 20	5,887	59,225
Median catch year 30	15,453	70,954

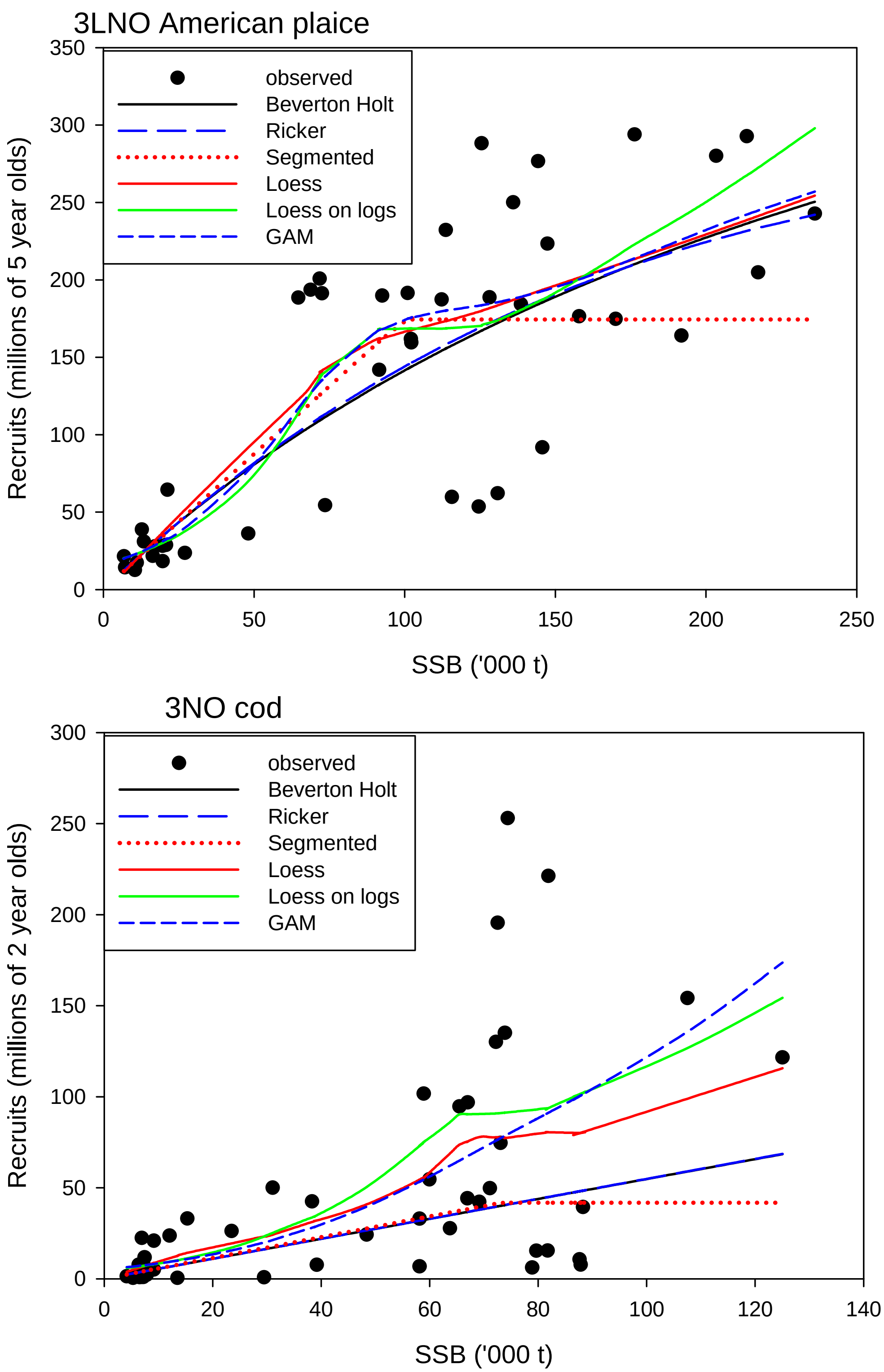
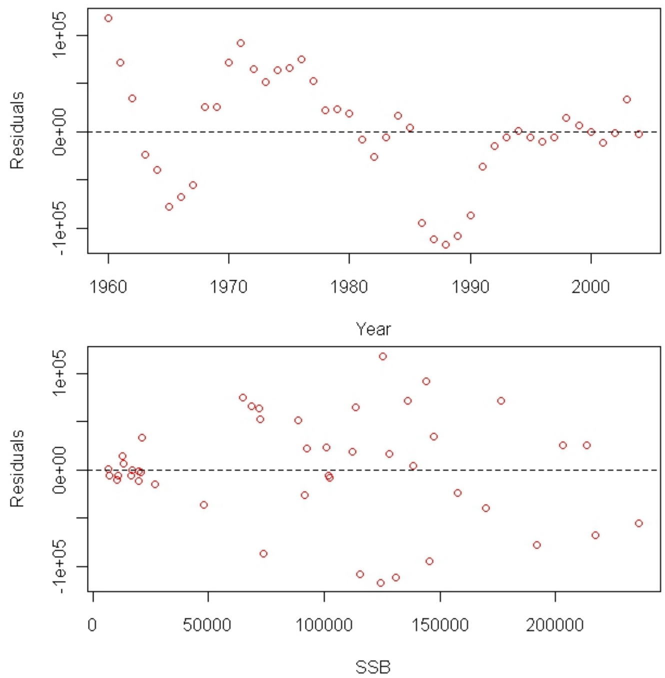


Fig. 1. Fit of alternative stock-recruit models to 3LNO plaice and 3NO cod VPA estimates from the 2010 NAFO SC stock assessments.

3LNO American plaice



3NO Cod

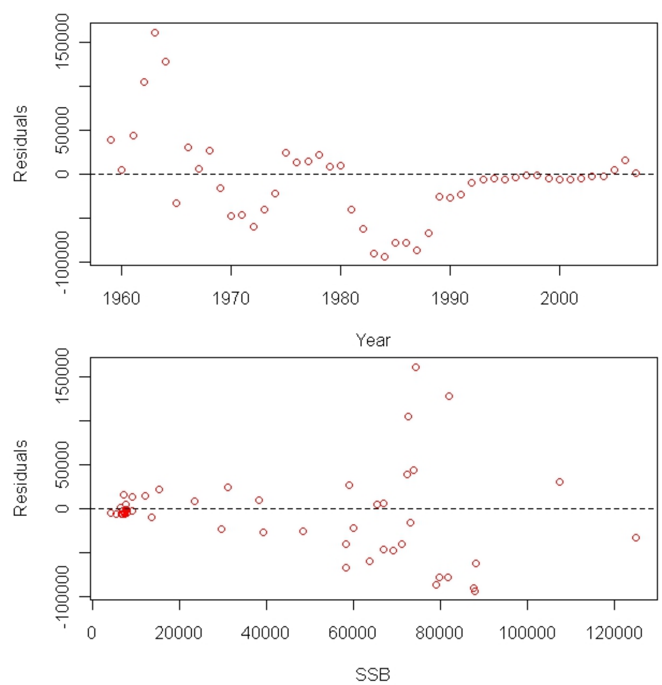
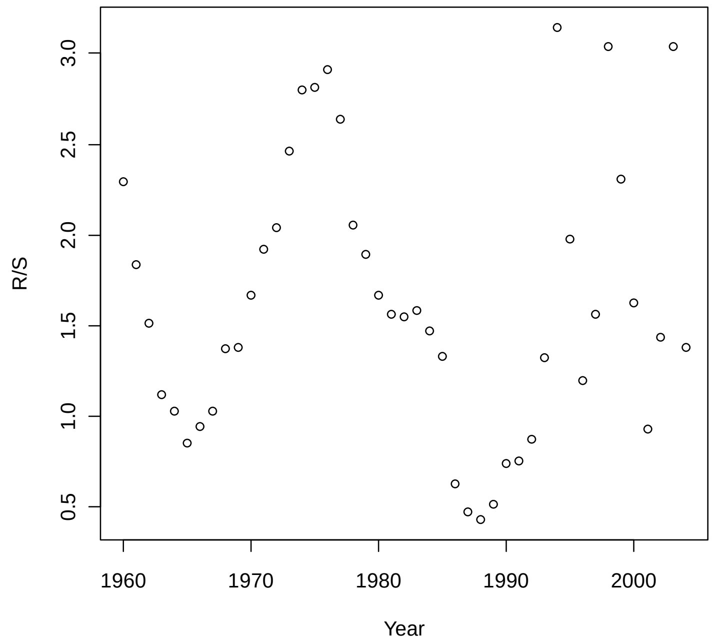


Fig. 2. Residuals from the Loess fit to log recruitment values.

3LNO American plaice



3NO cod

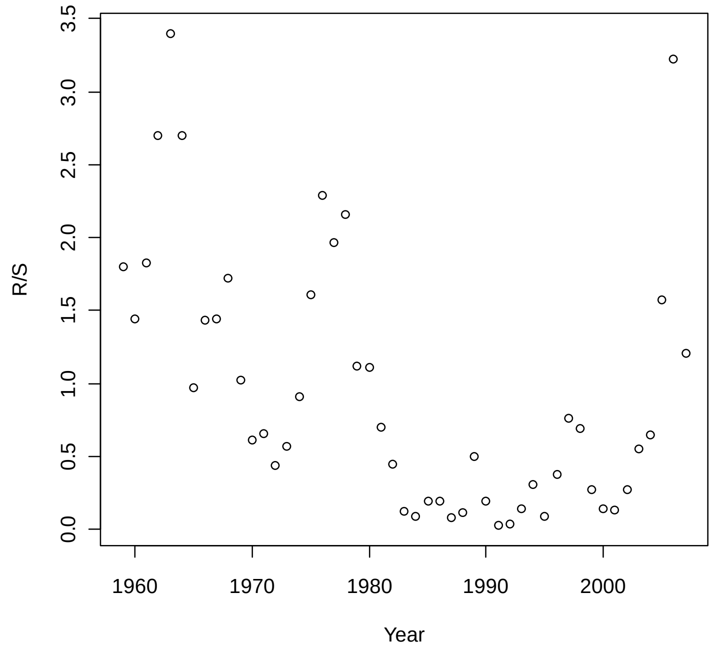


Fig. 3 Recruits per spawner for 3LNO American plaice and 3NO cod.

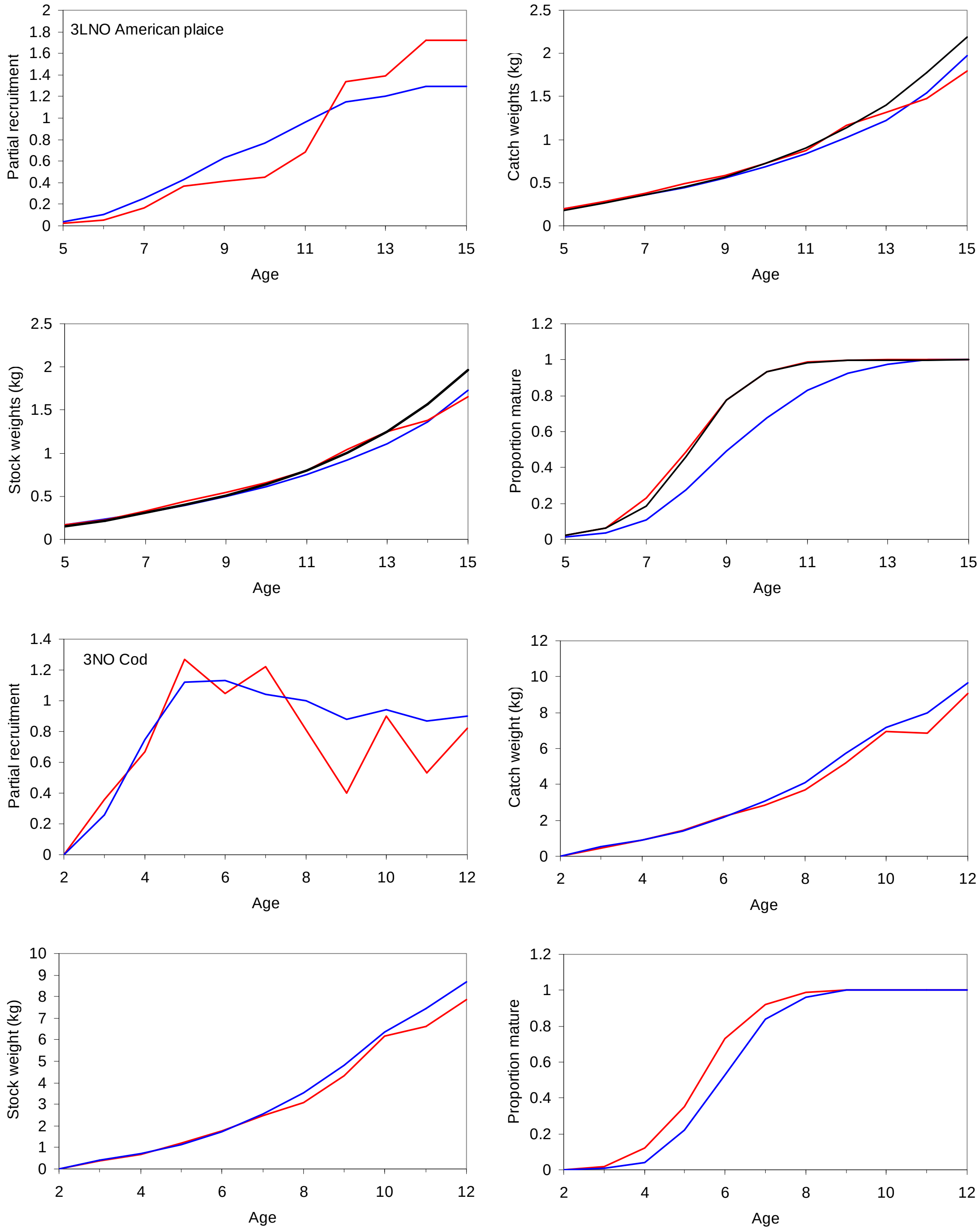
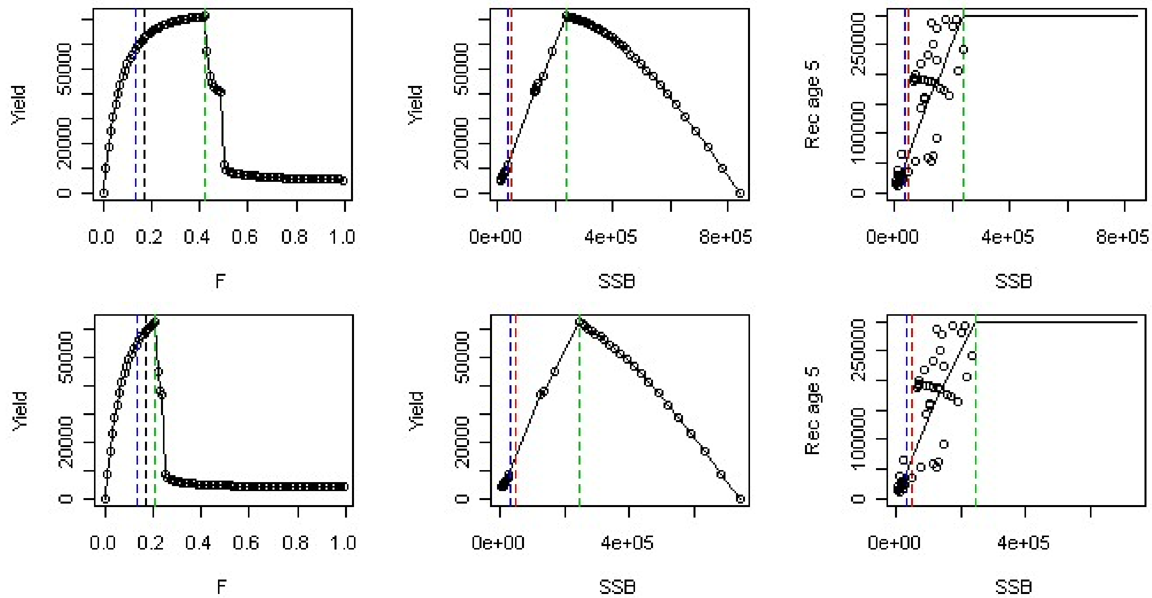


Fig. 4. Input vectors of biological parameters for 3LNO American plaice and 3NO Cod. Blue line is the long-term average (range of years in the VPA) and red line is the recent average (2007-2009). The black line in the 3LNO American plaice plots is the average for the last 25 years as advised by NAFO SC.

3LNO American plaice



3NO Cod

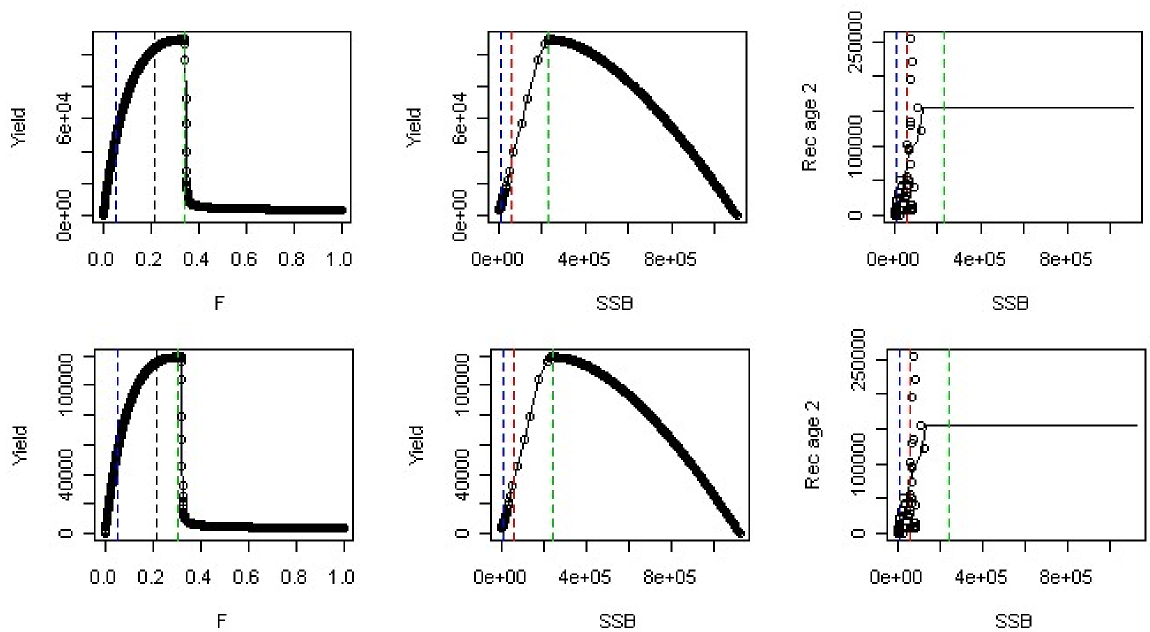


Fig. 5. Equilibrium yield and reference points for 3LNO plaice and 3NO cod obtained using the Loess smoother fit to the stock recruit plots together with YPR and SPR data. The top row for each species uses the recent average YPR and SPR and the bottom row uses the long-term average. The vertical lines denote Bmsy and Fmsy (green), Blim (red) and current value (blue).

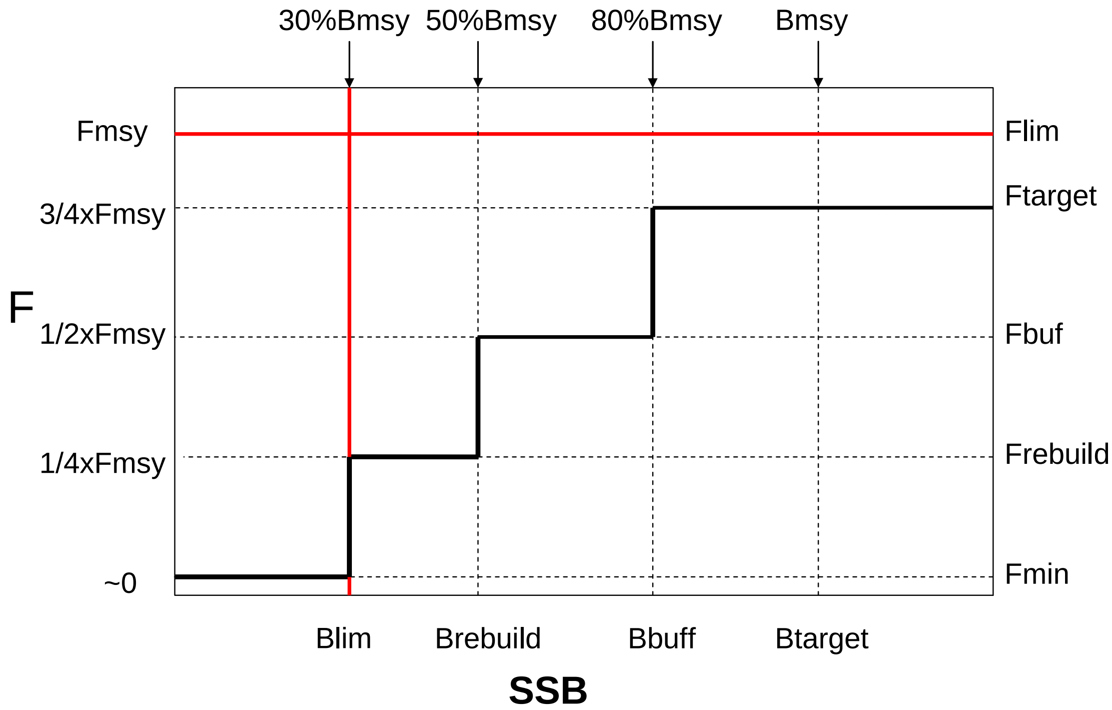


Fig. 6. Proposed PA framework for the management of 3LNO plaice and 3NO cod.

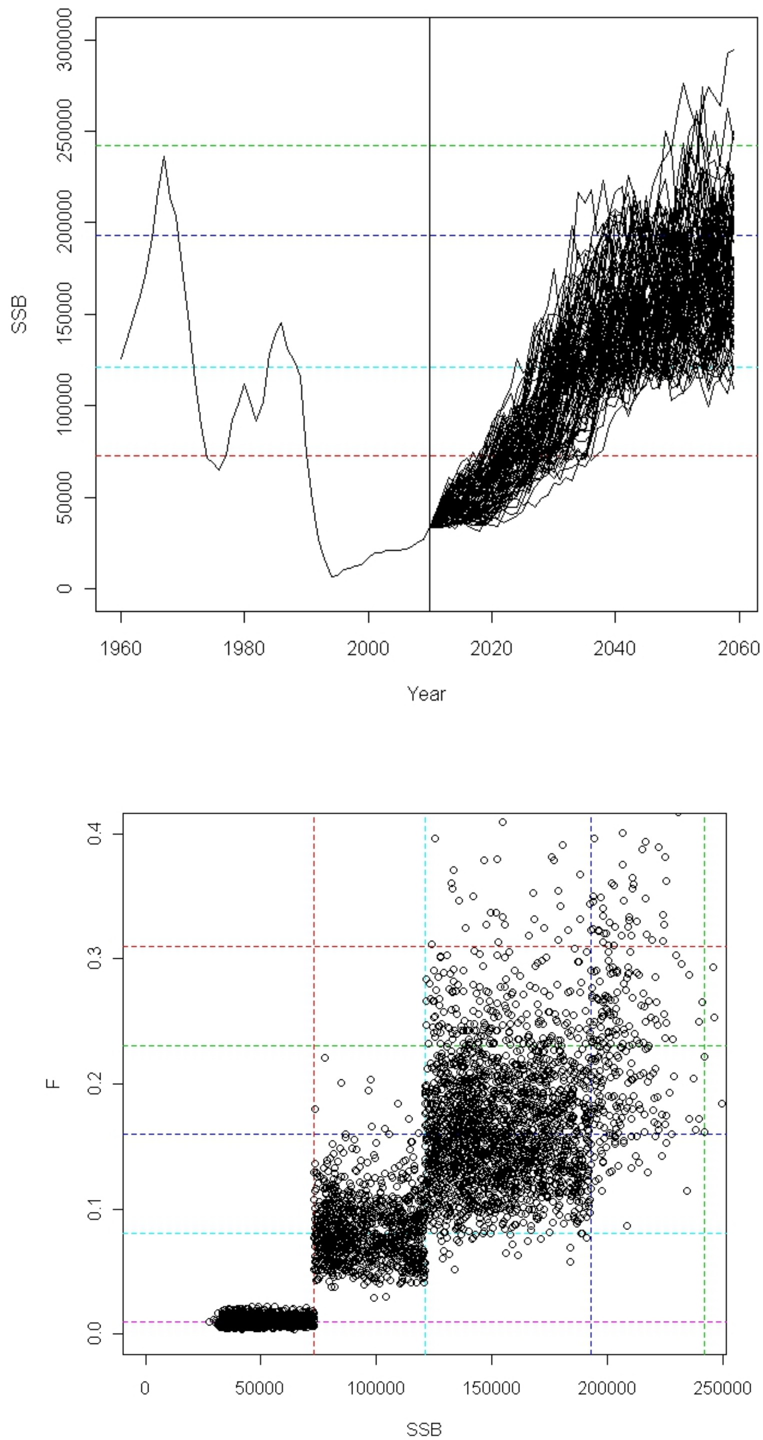


Fig. 5. Simulation results from 100 runs of the proposed management strategy applied to 3LNO American plaice. Reference lines correspond to Fig. 4.

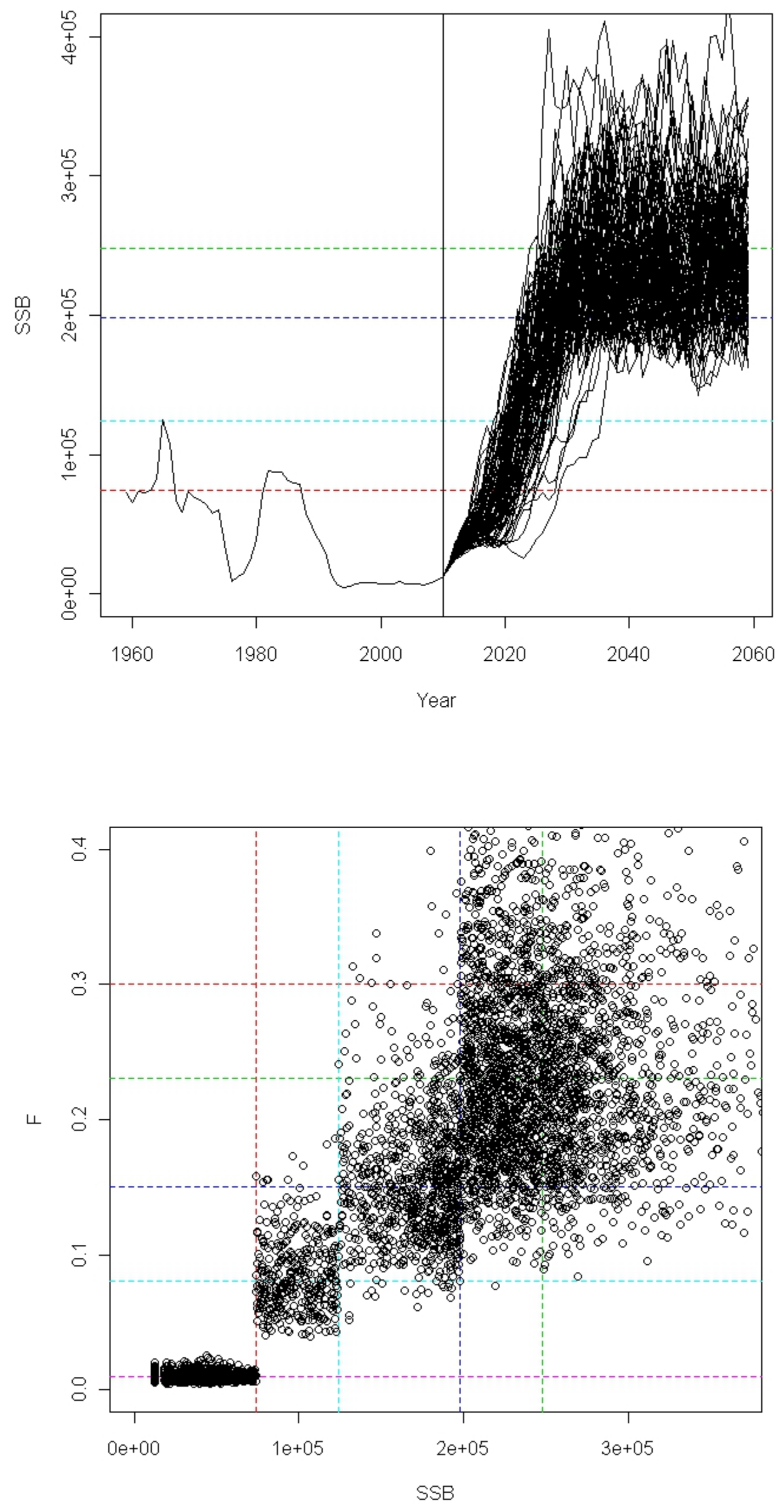


Fig. 6. Simulation results from 100 runs of the proposed management strategy applied to 3NO Cod. Reference lines correspond to Fig. 4.