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Working Paper 4.2

Setting SSBmsy via Stochastic Simulation Ensures Consistency with Rebuilding Projections

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Summary

Current approaches to setting biological reference points and conducting projections contain an inconsistency. Specifically, fishing at the Fmsy rate for many generations does not produce the SSBmsy with 50% probability. This inconsistency arises whether a parametric or empirical approach is used due to the variance in projected recruitment causing the stock to be more or less productive than assumed in the deterministic calculations of the reference points. The proposed solution is to utilize the available projection software to make the SSBmsy value an emergent property of fishing at Fmsy for many generations. This approach ensures consistency between the reference points and the projections used to determine fishing levels necessary to rebuild overfished stocks to the SSBmsy level. This paper provides a demonstration of large the inconsistency can be in a typical situation and discusses a number of related issues including an extension of this approach to solve for Fmsy, the standard approach to deal with lognormal error distributions, historical significance of this inconsistency, biologic and fishery vectors used in the calculations, and Fmsy relative to its proxies.

Introduction

Biological reference points for age-based stock assessments have been determined for GARM species using per recruit calculations and two approaches for estimating recruitment associated with the reference points: parametric and empirical. The parametric approach uses a stock-recruitment curve to determine equilibrium levels of catch and spawning stock biomass (SSB) for a range of fishing mortality rates. The F corresponding to the highest catch is the Fmsy, and the associated catch and SSB are the MSY and SSBmsy, respectively. The empirical approach uses a proxy for Fmsy, typically F40%SPR, the fishing mortality rate that produces 40% of the spawning stock biomass relative to an unfished cohort. This fishing mortality rate has associated spawning stock biomass per recruit (SSB/R) and yield per recruit (Y/R). The SSB/R and Y/R are multiplied by a recruitment level assumed to be representative of the stock at MSY conditions to generate the SSBmsy and MSY proxies.

The F and SSB reference points are used to make determinations relative to overfishing and overfished status by comparing the current year estimates to the reference points. If a stock is determined to be overfished, it must be rebuilt to the SSBmsy level within a given timeframe with at least 50% probability. These projections in the Northeast are stochastic both both in terms of the starting population abundance at age as well as the future recruitments.

An inconsistency has been noted in the past between the biological reference points and the rebuilding projections. Namely, fishing at Fmsy for many years does not cause the median SSB to be equal to the SSBmsy reference point. The time frames involved and large amount of rebuilding between current SSB and the reference point meant that this inconsistency was relatively minor. However, as the timeframes have become shorter, this inconsistency has become more apparent and now needs to be addressed. This paper demonstrates how the inconsistency arises and provides a simple approach to ensure consistency between the SSB reference point and the rebuilding projections.

Demonstration

Consider a stock with the yellowtail flounder-like biological and fishery characteristics defined in Table 1 and an estimated time series of spawning stock biomass and resulting recruitment defined in Table 2. Assuming a Beverton and Holt stock recruitment relationship, the parametric biological reference points using these data were determined by the NOAA Fisheries Toolbox (NFT) program SRFIT to be

Fmsy = 0.435
SSBmsy = 27.70 thousand mt
MSY = 9.27 thousand mt
BH alpha = 40.2366
BH beta = 4.96331
BH sigma = 0.558234

The SRFIT program also provides equilibrium calculations for a range of F values which can be used to determine F40%SPR = Fmsy proxy = 0.27. The equilibrium calculations also provide the SSB per recruit and yield per recruit at this F, SSB/R = 1.111848 and Y/R = 0.246908. If the geometric mean of the recruitment observations are used as a proxy for the recruitment associated with MSY, R=19.42 million fish, then the empirical biological reference points are SSBmsy proxy = 21.59 thousand mt and MSY proxy = 4.80 thousand mt.

The NFT program AgePro was used to project the stock for 50 years for the two cases. A bootstrapped VPA produced 1000 vectors of numbers at age to begin the projections, and each initial stock abundance vector was projected 100 times, resulting in 100,000 trajectories. The median SSB in each year from these trajectories is typically used in rebuilding scenarios to determine if a given fishing mortality rate will achieve the SSB target by a specific year.

As a first test of the parametric approach, the Beverton and Holt stock recruitment parameters alpha and beta were used in AgePro, but the variance about the stock recruitment curve was set to zero. The median SSB after 50 years fishing at Fmsy=0.435 matched exactly the SSBmsy predicted from SRFIT. However, as sigma increased from zero to the value from SRFIT (0.558234) and beyond, the median SSB after 50 years of fishing at Fmsy=0.435 increased at an increasing rate (Table 3 and Figure 1).

For the empirical approach, observed recruitment values were used to create a cumulative distribution function from which future recruitments were sampled randomly, the AgePro option 14 for recruitment. In this case, F40%SPR=0.27 was projected for 50 years and the resulting median SSB was 24.8 thousand mt, approximately 15% larger than the non-parametric calculations using the geometric mean recruitment.

Thus, in both parametric and empirical approaches to estimate biological reference points there is an inconsistency between the deterministic biological reference points and the projections due to the variability about the stock recruitment curve. This variability arises from the use of the lognormal distribution in the parametric case and arises due to the observed recruitment not following a specific distribution in the empirical case. The parametric case will always have projected median SSB larger than the deterministic value when the lognormal distribution sigma is greater than zero. The empirical distribution median SSB could be either larger or smaller than the product of Y/R at F40%SPR and recruitment at MSY, depending on how the recruitment value is chosen and the actual distribution of observed recruitment values.

This inconsistency between SSBmsy reference point and long-term median projection when fished at Fmsy is important in both cases because the fishing mortality rate for rebuilding will be too high when projected mediam SSB is greater than the SSBmsy reference point. For example, if the biological reference point SSBmsy is set using the parametric deterministic approach (27.7 thousand mt), then the fishing mortality rate necessary in years 2008-2014 to achieve this SSB in 2014 with 50% probability (Frebuild) increases with increasing sigma (Table 4). As per standard practice, the catch in 2007 was fixed in all runs at that year's quota (1,250 mt). This increase in Frebuild as sigma increases means that the stock is more productive when recruitment variability is higher, as seen in the higher median SSB when Fmsy was projected for 50 years. This change in productivity relative to the deterministic case means that rebuilding strategies will be too optimistic in this example, allowing more catch due to the uncertainty in recruitment in the projections.

A Solution to Ensure Consistency

To ensure consistency between the biomass reference point and the projections used in rebuilding evaluations, the projection software can be applied for many generations into the future and the median spawning stock biomass that results declared the SSBmsy proxy. This ensures complete consistency between the reference point and the projections because the biomass reference point is an emergent property of the projections. This approach can be applied using either parametric or empirical stock recruitment relationships. The basis for Fmsy remains in the deterministic calculations as either the Fmsy value derived from a parametric stock recruitment relationship or the F%SPR used as a proxy in the empirical case. This means that Fmsy will remain the same regardless of the variance in the stock recruitment relationship, while SSBmsy will change with changes in this variance. As described above, the SSBmsy from this approach is approximately 15% greater than the deterministic calculations for both the parametric and empirical cases. The similarity in the amount of change for the parametric and empirical approaches is a coincidence and is not expected to occur in most cases. This change in how SSBmsy is calculated will also change the value used for overfished status determination.

Discussion

This approach could be taken one step further by defining the Fmsy based on a search over a range of F values in stochastic projections. However, this approach will produce higher F values due to the variability in R supporting larger catches on average than the deterministic calculations. Under extreme variability in recruitment, this search in stochastic projections could result in very high F because there is always the possibility of a strong cohort saving the stock. This seems anti-precautionary to me, and I do not recommend it as an approach for determining reference points.

One common method to address this inconsistency between reference points and projections for parametric cases is to use the standard bias-correction for lognormal error distributions: subtracting half the variance. However, this adjustment is for the mean, not the median. Since the median is always less than the mean for a lognormal distribution, using this adjustment will cause the median SSBmsy from projections to be lower than the reference point, meaning the projected stock is now less productive than the stock assumed when setting the reference points. Since the median of projected SSB does not have a closed form solution, it is unlikely that an analytic formula can be found that will allow direct estimation of an SSBmsy that is consistent with the projected median SSB when fished at Fmsy for many generations.

This inconsistency between reference point and projections has probably not been highly influential in the past because the time frames for the rebuilding scenarios were long enough that the difference was damped. However, now that rebuilding time frames for many New England groundfish stocks are approaching five years, this inconsistency will become much more important. Furthermore, previous management regulations have focused on effort controls which can be difficult to relate to small changes in F. Implementation of hard quotas due to either sector management or annual catch limits would make this inconsistency more consequential as well.

A separate issue of consistency which is not addressed in this paper is the maturity, weight at age, and fishing selectivity vectors to use in projections and reference points relative to those in the stock assessment model. While it is easy to ensure consistency between the reference points and projections, it is not always easy to determine whether to use an average of only recent years from the stock assessment or an average of the entire assessment time period when the values are changing. For the purposes of the GARM3 Biological Reference Points meeting, the decision was made by members of the Population Dynamics Branch at NEFSC to use recent averages for the fishery selectivity, maturity, and weight at age vectors in both the reference point calculations and projections. This allows recent changes in these vectors to be expressed in the reference points. As stocks rebuild, these vectors may change, requiring further change in the reference points. Of particular note is the weight at age for the plus group. Since many stocks are overfished, the age structure in the plus group is truncated relative to the rebuilt conditions. Since the reference points are being used for short-term management, the change in age structure of the plus group causing a change in weight at age is ignored in these calculations. As the stock rebuilds, the largest changes in the weight at age vector are expected in the plus group due to expansion of the age structure. However, density dependence could arise at some point, limiting the increase in weight of the plus group. Thus, until expansion of the age structure in the plus group causing an increase in the weight at age is observed, the current estimates of weight at age for the plus group are considered the most appropriate for use in the reference point calculation and projections.

Similarly, there may be reasons for using different recruitment scenarios for short-term and long-term projections. This could be due to a recent period of poor recruitment thought to be associated with an environmental change, for example. One way to deal with this situation would be to use low recruitment values for short-term projections but all recruitment values for long-term projections, assuming the environmental conditions will eventually change back to "normal." One should take care when using different recruitment scenarios for short-term projections because it may be impossible to rebuild the stock to the biomass reference point from the long-term projections using lower recruitment. Searching for Frebuild values is not recommended when using different recruitment scenarios for short-term and long-term projections.

Finally, another topic not addressed in this paper is whether Fmsy should be limited by F%SPR levels. In the example provided in this paper, the Fmsy from the parametric case was 61% higher than the F40%SPR used as a proxy for Fmsy. Either this stock is much more resilient than the typical groundfish stock, meaning that F40%SPR is too conservative, or else the stock recruitment relationship is artificially steep allowing too high a fishing mortality rate because it is limited to a period of observation when the stock has been overfished. Any large discrepancy between the Fmsy and F%SPR thought to be an appropriate proxy for Fmsy should be evaluated on a case-by-case basis to determine if one is too optimistic or the other is too pessimistic. One option is to use a mixed approach whereby the stock recruitment relationship is utilized but the F reference point is the F%SPR.

Table 1. Biological and fishery characteristics of a stock used for demonstration, based on yellowtail flounder like conditions. M denotes natural mortality rate, WAA denotes weight at age (kg) used for both catch and spawning stock biomass, Mat denotes maturity, Sel denotes selectivity, and FracZ denotes the proportion of total mortality that occurs within a year prior to spawning.

Variable	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
M	0.2	0.2	0.2	0.2	0.2	0.2
WAA	0.1443	0.3193	0.4340	0.5790	0.7493	0.9807
Mat	0	0.52	0.86	1	1	1
Sel	0.0029	0.1174	0.5495	1	1	1
FracZ	0.4167	0.4167	0.4167	0.4167	0.4167	0.4167

Table 2. Spawning stock biomass (SSB) in thousand metric tons and resulting recruitment (R) in millions of fish for a yellowtail flounder like stock.

Obs	SSB	R
1	21.8990250	52.186380
2	14.7715280	70.632020
3	8.9672447	24.730860
4	9.9495671	17.280330
5	8.3533725	54.436470
6	6.1599829	25.510690
7	8.4240317	24.033690
8	10.9024618	62.998650
9	10.4106119	22.847090
10	13.4120665	6.581807
11	11.3467909	10.842200
12	4.2685951	16.748350
13	3.5055674	8.472905
14	4.6079955	9.198605
15	3.4859022	22.877490
16	3.0443120	9.731976
17	6.6465026	11.541570
18	5.7165389	22.787140
19	4.5186161	18.341110
20	4.5966527	13.958050
21	4.2390869	10.659220
22	2.9074393	11.123520
23	2.6483545	13.179330
24	4.3401933	18.432290
25	5.6654100	23.897190
26	6.9822737	25.540210
27	9.5465901	21.028900
28	10.4513363	23.780260
29	9.4621606	16.168740
30	10.5150128	12.200490
31	10.4819520	12.494980
32	5.9502183	14.926990
33	4.4376633	62.932190

Table 3. Median spawning stock biomass (thousand mt) after 50 year projections fishing at Fmsy=0.435 for different levels of variability about the stock recruitment relationship (sigma).

Sigma	median SSB
0	27.7
0.2	28.2
0.4	29.7
0.558234	31.7
0.8	36.2
1.0	41.5

Table 4. Fishing mortality rate (Frebuild) required in years 2008-2014 to achieve the deterministic SSBmsy value of 27.7 thousand mt with 50% probability for different values of sigma in the Beverton Holt stock recruitment relationship.

sigma	Frebuild
0.2	0.39
0.4	0.42
0.558234	0.45
0.8	0.53
1.0	0.61

Figure 1. Median spawning stock biomass (thousand mt) after 50 year projections fishing at Fmsy=0.435 for different levels of variability about the stock recruitment relationship (sigma). The fit line is just to indicate the rate of change in SSB as a function of sigma.