

A new search approach to improve Stock Synthesis assessment forecasts when considering allocations

Need to account for fleet allocations in forecasting benchmark targets:

Stock assessment forecasting is a critical component of successful fisheries management. In order to achieve appropriate forecasts of future stock structure and quantify current stock status, it is essential that the forecasts achieve target stock abundance benchmarks, target annual fishing intensity (F_{OFL} , F_{ABC} , $F_{REBUILD}$), and the expected aggregate fishery selectivity. Future fishery selectivity is important because fishery benchmarks are inherently dependent on this selectivity. This dependence occurs because each size/age class is able to support its own unique MSY and F_{MSY} if harvested exclusively (i.e., a single cohort slot fishery), which forms the rationale for global MSY analyses (Figure 1). The global MSY results presented in figure 1 show the MSY and F_{MSY} that are estimated when fishing exclusively on a single age class ranging from age 1 to 9 such that each point represents an independent simulation outcome. In realistic fishing scenarios, a number of fleets with differing selectivity across ages will be exploiting a fish population simultaneously (Figure 2). Given the influence of the age of harvest on MSY and F_{MSY} , it is important that fixed sector catch allocations are represented in forecasts. This is particularly important in scenarios where stock rebuilding is expected to cause the age composition of landings to change throughout the projection period.

The motivation for the new forecast search approach was to enable multiple fishery intensity and composition targets to be achieved simultaneously in order to achieve management goals and reflect the expected future fishery dynamics. To achieve this, we identified four primary targets that need to be achieved when performing forecasts:

- 1) Achieve MSY or MSY proxy (i.e. SPR30% or SSB30%) at equilibrium (~100yrs)
- 2) Achieve an equal total fishery harvest rate F_{OFL} in every year of the forecast.
- 3) Achieve fixed catch allocations in pounds between sectors in every year of the forecast.
- 4) Maintain annual relative effort between fleets, within a sector, at the average of recent years.

Previous approaches to calculating fleet/year specific projection F_s have each focused on some of the above targets in isolation at the expense of violating others.

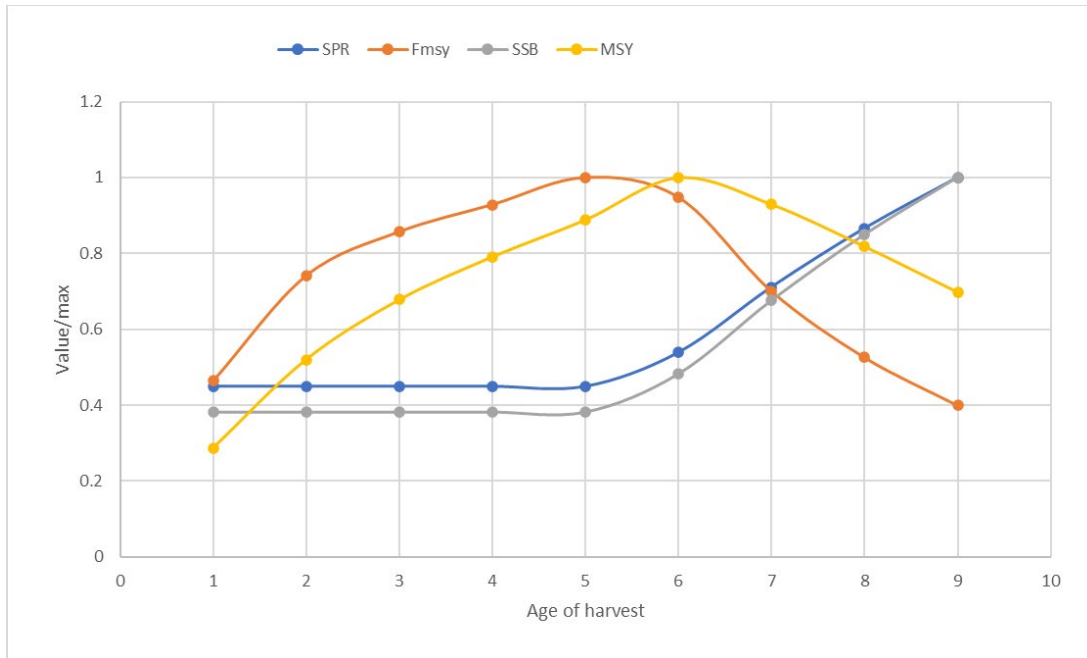


Figure 1: Global MSY search results displaying SPR, F_{MSY} , SSB_{MSY} , and MSY for different ages of harvest scaled relative to each of their maximum values.

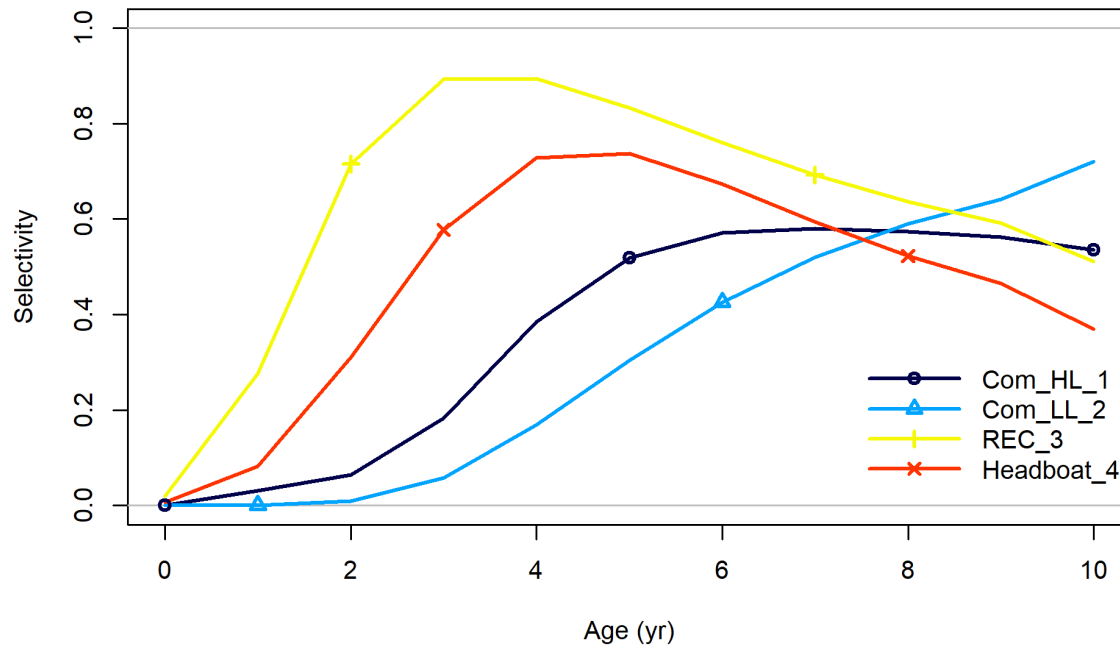


Figure 2: Age-specific selectivity of individual fleets in the Greater Amberjack fishery.

Overview of previous approaches:

The traditional baseline approach for fishery forecasting has been to assume the relative effort between fleets remains fixed at the average of recent years and adjusting the total annual fishing intensity to achieve the desired yield or stock status benchmark and annual total fishing mortality rate. This approach makes no direct consideration of sector allocations in the projection process, allowing the determined OFL to be apportioned between fleets as desired after the fact. As shown by the Global MSY analyses this can have negative outcomes, either causing overfishing or leaving potential yield unrealized, depending on the fishery in question and allocation decisions.

To better reflect actual management practices, SEFSC stock assessment projections for Gulf of Mexico fisheries have to the extent possible incorporated fixed catch allocations into their projections over the last decade. The first attempt to directly integrate allocations was implemented directly within stock synthesis (SS). To achieve allocations SS proceeds sequentially by

- 1) Estimating the equilibrium F required to achieve the benchmark target (SPR30%, MSY, etc.) under the assumption of constant relative effort between all fleets.
- 2) Adjusting total effort in each year to achieve the same equilibrium F in every year.
- 3) Shifting effort between sectors in each year to achieve target allocation fractions.

These default SS projections with sector allocations were found by SEFSC to sometimes diverge from the input benchmark target at equilibrium due to the impacts of changing the aggregate fishery selectivity through fixed catch allocations. In order to overcome this, an approach was developed by the SEFSC to iteratively adjust the input benchmark target value until the achieved equilibrium result matched the true target. This approach provided a large improvement over the available alternatives of either not accounting for allocations in forecasts or using the default SS implementation.

Recently, two remaining issues in the allocation projections being produced by SS using the improved SEFSC approach were identified:

- 1) The forecast results using SS were found to not achieve the target F_{OFL} in every year, specifically trending in F was often observed in the early forecast years.
- 2) The existing SEFSC approach to correct benchmark target errors was unable to be extended to MSY or F_{max} calculations.

The trending F deviation in early forecast years was of greatest concern as it could potentially produce annual harvest rates that exceed F_{OFL} or alternative targets (see vermilion snapper, SEDAR 67, SSC presentation and discussion). The deviations also occur primarily in the first years of projection which are the most important for management, as they will be implemented prior to subsequent assessment updates. The magnitude of F divergence from F_{OFL} has also generally been larger in scenarios where significant stock recovery is needed, thereby compounding risks to the fishery. This pattern is due to the fact that recovering stocks will exhibit changing length/age structure in the population causing constant F vs constant catch allocations to diverge. The MSY limitation had not been previously considered due to the lack of assessments with estimable steepness; as data series grow and improve, it is hoped that more assessments will seek to implement MSY projections increasing the need for this capability.

New approach:

Given the above issues regarding existing projection approaches, a new projection optimization has been developed to enable more fishery targets to be achieved simultaneously. This new approach improves the efficiency and transparency of current forecasting efforts and will provide the software capacity needed to achieve future forecasting objectives such as directly estimating MSY. While developing the new software, additional features were also added to allow SEFSC analysts to simultaneously produce OFL, ABC, and F_{REBUILD} projections. The bulk of the inputs needed to parameterize the forecasts are extracted from the existing forecast.ss file (Figure 3):

- 1) Forecast period biology, selectivity, and recruitment dynamics,
- 2) Forecast benchmark targets (B_{ratio} , SPR, MSY),
- 3) Allocation fractions, and
- 4) Fixed catch inputs for recent years and bycatch fleets.

In addition to these forecast file values, the new forecast function accepts an $F_{\text{ABC}}/F_{\text{OFL}}$ ratio to perform ABC projections if desired, a rebuilding target year if rebuilding projections are desired, and an F_{MAX} designator if F_{max} (rather than MSY) projections are desired (lines 46-57 of code).

The new search approach utilizes the SS ability to input fixed fleet-specific F landings for up to 100 years of projection. By simultaneously iterating every fleet /year specific F using a custom search algorithm the new code is able to achieve multiple interdependent targets simultaneously. This approach works by:

- 1) Defining a starting F for every Fleet/Year to initialize the search. This is defined as the average F for each fleet in the year range specified in the forecast file for relative F. This initialization begins the search with all fleets fishing at the desired relative effort.
- 2) Running an SS projection with these initial Fs.
- 3) Comparing the achieved projection results to the target values and adjusting Fs as needed to achieve the target values.
- 4) Repeating steps 2 and 3 until the difference between all achieved and target values is less than an analyst-specified threshold of convergence (default 0.1%)

In order to update the F guesses in each round of iteration, the search routine uses three multiplicative scalars to compare achieved outcomes with target outcomes and then iteratively adjust the Fleet/Year specific F values until all targets are achieved.

The first scaling function is designed to achieve the desired equilibrium benchmark target. To achieve this, the median benchmark value achieved in the last 30 years of the projection is compared to the target benchmark value to calculate a scalar multiplier which is then applied to every Fleet/Year F. This will ensure the average F achieves the desired benchmark but does not address annual needs for constant F_{OFL} or achieve allocation targets (lines 338-432 of code).

The second scaling function is designed to achieve a constant total fishery F every year. To do this the median total fishery annual F over the final 90 years of the projection is selected as the target F and each annual F achieved is compared to this to calculate a scalar multiplier for each year of the

projection. Every Fleet-specific F in each year is then multiplied by this scalar. As the equilibrium benchmark achieved approaches the target benchmark the median F will approach F_{OFL} . The combination of these two scalars ensures that benchmark targets will be achieved and that projected catches will reflect F_{OFL} every year, however, they do not achieve target allocations (lines 454-468 of code).

The third scaling function is designed to ensure that sector allocations are achieved every year. First, the achieved catch of each sector and all fleets combined is calculated for each year. These values are used to calculate the achieved allocation fractions in each year. The ratio of target to achieved allocation fraction is then used to scale all fleet F s within an allocation group. This multiplier ensures that allocation fractions are correct while also maintaining relative fleet effort levels within a fishery sector (lines 546-561 of code).

Once all three multipliers have been calculated, the Fleet/Year specific F s are adjusted and SS is rerun with new input F s and the results are again compared to the targets and adjusted until achieved = target for all objectives within a user-specified error tolerance (lines 563-568, 597-614 of code).

For the SSB and SPR benchmark targets, this search routine is straightforward as the benchmark target is known (i.e. SPR 30%) allowing the search to directly iterate to the target (lines 338-350, 424-432 of code). However, this becomes more complicated for the MSY/F_{max} optimization goal as while achieved catch can be calculated the value of MSY or catch at F_{max} is unknown. In order to effectively search for MSY , a dome-shaped relationship is assumed between equilibrium SSB/SSB_0 and equilibrium yield, with MSY occurring at some unknown intermediate SSB/SSB_0 value. This relationship is used to develop a two-stage optimization algorithm to estimate MSY (lines 351-423 of code).

- 1) A projection is first run with the recent average F s.
- 2) From this the median SSB/SSB_0 achieved is identified and set as an SSB/SSB_0 target.
- 3) Search loops are then run until this SSB/SSB_0 , annual F , and allocation targets are all achieved
- 4) The equilibrium catch achieved is calculated and the SSB/SSB_0 and catch pair are saved.
- 5) The SSB/SSB_0 target is then rounded to one decimal place (i.e. 0.1, 0.3, etc).
- 6) A new round of search loops is undertaken until all targets are again achieved and the catch is again calculated and stored as an SSB/SSB_0 and catch pair.
- 7) A meta-search is then implemented by incrementing the target SSB/SSB_0 by fixed step values starting at 0.1, performing a search loop and saving an SSB/SSB_0 and catch pair.
- 8) Each time a search loop is completed for a given SSB/SSB_0 target the change in total catch achieved is used to calculate the next change in target SSB/SSB_0 :
 - a) If the achieved catch is larger than all previous catches the SSB/SSB_0 target is adjusted by one step (step size starts at 0.1).
 - b) If the achieved catch is less than the previous catch, the step size is multiplied by -0.5 and SSB/SSB_0 is adjusted by the new step (i.e. steps slowly reduce in size from 0.1, -0.05, 0.025, -0.0125)
 - c) This meta-search continues until step size is less than the user-specified convergence threshold (default = 0.001) identifying that MSY has been achieved.

The first search round for benchmarks represents the OFL search which is saved for the user (lines 616-639 of code). If an ABC ratio has been input a second ABC search round will be implemented. This search round will fix the first benchmark scalar at 0 as no stock status level is being targeted. The

annual F target will then be set at the specified ratio of the OFL F estimate. From here iterations will progress until the F_{OFL} ratio and allocation fractions are achieved which represents an ABC projection. These results are then also saved for the user (lines 433-436, 640-655 of code). If an additional Rebuild year has been specified, a third search will be run where the F target for years up to the rebuilding year are scaled by the ratio of achieved target benchmark ratio, and the years after the rebuilding year are targeted at F_{OFL} . Iterations are then run until these two targets are achieved and the results are saved for the user (lines 437-449, 466-468, 656-664 of code).

Validating results: This new projection approach represents an attempt to better achieve our desired forecasting objectives simultaneously. All aspects of the new approach have been and can always be vetted against the reported results directly out of SS. In the case of greater amberjack, we can directly observe the SPR, SSB/SSB0, annual F, and catch fractions achieved to ensure that the search algorithms correctly obtained our intended goals. This direct result testing has now been performed using this code for red grouper, gag grouper, and greater amberjack. Future proposed additions to the code include automated documentation of the input targets and output results for the most important forecasting assumptions and reference points in order to further streamline the review process.

```
#C forecast file written by R function SS_writeforecast
#C rerun model to get more complete formatting in forecast.ss_new
#C should work with SS version: 3.3
#C file write time: 2021-09-14 14:45:16
#
1 # benchmarks
1 # MSY
0.3 # SPRtarget
0.3 # Btarget
# Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF, end_relF, be
0 0 0 2016 2018 2009 2018 0 0
1 # Bmark_relF_Basis
1 # Forecast
100 # Nforecastyrs
1 # F_scalar
# Fcast_years: beg_selex, end_selex, beg_relF, end_relF, beg_recruits, end_re
2016 2018 2016 2018 1984 2018
0 # Fcast_selex
0 # ControlRuleMethod
0.04 # BforconstantF
0.01 # BfornoF
1 # Flimitfraction
3 # N_forecast_loops
3 # First_forecast_loop_with_stochastic_recruitment
3 # Forecast_loop_control_3
1 # Forecast_loop_control_4
0 # Forecast_loop_control_5
2119 # FirstYear_for_caps_and_allocations
0 # stddev_of_log_catch_ratio
0 # Do_West_Coast_gfish_rebuilder_output
2022 # Ydecl
2019 # Yinit
1 # fleet_relative_F
# Note that fleet allocation is used directly as average F if Do_Forecast=4
3 # basis_for_fcast_catch_tuning
# enter list of fleet number and max for fleets with max annual catch; termina
-9999 -1
# enter list of area ID and max annual catch; terminate with area=-9999
-9999 -1
# enter list of fleet number and allocation group assignment, if any; termina
#_Fleet Group
1 1
2 1
3 2
4 2
-9999 -1
#_Year Group 1 Group 2
2019 20 80
-9999 -1 -1
-1 # InputBasis
#_Year Seas Fleet Catch or F Basis
2019 1 1 156.90700000 3
2019 1 2 14.51000000 3
2019 1 3 22.97900000 3
2019 1 4 0.99000000 3
```

Figure 3: Example SS forecast input file.