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A step-by-step illustration of the basis for the monthly depletion estimator in a Stock Synthesis model for dorado

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1. INTRODUCTION

In order to explain the basis of the monthly depletion estimator in the Stock Synthesis model for dorado, we present four progressively more complex models. We start with a simple log-linear regression of within-year monthly CPUE similar to catch-curve analysis, and end with a monthly depletion estimator that has several modifications similar to those used in the full Stock Synthesis model.

2. METHODS

2.1. Catch rate analysis ("catch-rate")

A linear regression is applied to the logarithm of the monthly CPUE within a year[1], and the analysis is repeated independently for each year. The CPUE represents the relative abundance, in numbers, of the cohort in that month. This analysis, which is similar to catch-curve analysis, measures the relative abundance of a cohort as it ages throughout its first year of life, using the CPUE rather than the proportion-at-age in the catch. Only the CPUEs from October through April are used, in order to eliminate months in which the fishery is not principally targeting dorado. To make the regression model more like a population dynamics model, a simple exponential model is used to model the change in relative abundance from one month to the next:

$$\hat{I}_{y,1} = \alpha_y$$

$$\hat{I}_{y,m+1} = \hat{I}_{y,m} e^{-Z_y}$$

where $\hat{I}_{y,m}$ is the relative abundance, in numbers, in year y and month m, α_y is the initial relative abundance in year y, and Z_y is the instantaneous rate of total mortality.

The model is fitted to the monthly CPUE data using a lognormal likelihood function (with the variability parameter fixed at σ_I = 0.2 and ignoring constants):

$$\sum_{y,m} \frac{\left(ln[I_{y,m}] - ln[\hat{I}_{y,m}]\right)^2}{2\sigma_I^2}$$

Where $\hat{I}_{y,m}$ is the observed CPUE-based relative abundance in year y and month m.

The parameters to estimate are α and Z for each year.

[1] The year used in the model starts on 1 July and finishes on 30 June

2.2. Depletion estimator ("depletion")

The catch-rate model can be converted into a monthly depletion estimator by fitting to the monthly total catch data. The amount of depletion, as measured by the monthly CPUE and caused by the catch, provides information on absolute abundance. The model has to be converted into absolute abundance and the predicted CPUE scaled by an estimated catchability parameter (q). The population dynamics model is essentially the same as that used for the catch-rate analysis.

$$N_{y,1} = \alpha_y$$

$$N_{y,m+1} = N_{y,m} e^{-Z_y}$$

The model is fitted to both the monthly CPUE and total catch data (as with CPUE, catch data for October through April only are used) using a lognormal likelihood function (given σ_I = 0.2 and σ_C = 0.2 and ignoring constants):

$$\sum_{y,m} \frac{\left(ln[I_{y,m}] - ln[qN_{y,m}]\right)^2}{2\sigma_I^2} + \sum_{y,m} \frac{\left(ln[C_{y,m}] - ln[\hat{C}_{y,m}]\right)^2}{2\sigma_C^2}$$

where $\hat{C}_{y,m} = \frac{F_y}{Z_y} N_{y,m}(1 - e^{-Z_y}) w_m$, $F_y = Z_y - M$ is the fishing mortality in year y, M is natural mortality, and w_m is the average weight of a dorado in month m.

The parameters to estimate are α and Z for each year and q.

2.3. Including selectivity ("selectivity")

Not all the dorado may be in the fishing area during the early months or the last months of the year, or the fishing effort may be targeting other species. This can be taken into account by including a month-specific catchability (or equivalently, an age-in-months-based selectivity). A variety of approaches has been used to model the shape of the selectivity curve. For simplicity, we illustrate the addition of a selectivity curve by assuming that dorado selectivity by monthly age increments (s_m) follows a logistic curve. The changes to the model are:

$$N_{y,m+1} = N_{y,m} e^{-s_m F_y - M}$$

$$s_m = \left(1 + exp\left[-ln[19] \frac{a - a_{50}}{a_{95} - a_{50}}\right]\right)^{-1}$$

$$\hat{C}_{y,m} = \frac{s_m F_y}{s_m F_y + M} N_{y,m}(1 - e^{-s_m F_y - M}) w_m$$

where a_{50} and a_{95} are the ages at 50% and 95% selectivity, respectively.

To simplify the calculations we estimate F_y rather than Z_y. The parameters to estimate are α and F for each year and q, a_{50}, and a_{95}.

2.4. Adding fishing mortality deviations ("*F*-deviations")

The monthly catch varies depending on a number of factors, including the abundance of dorado and the fishing mortality (F). The previous three models assume that F is constant throughout the year except for the early months of the year that are modeled by selectivity in model 2.3. The fishing mortality is dependent on the effort by the fishery, and may change both during a year and between years. Assuming a constant F throughout the year probably overestimates F for the months whose catch data are not fitted, resulting in overestimates of depletion levels. To accommodate this variable F, we add monthly deviations in fishing mortality, penalized by an arbitrary distributional assumption. The standard deviation of the catch likelihood function is set to the lower value of σ_C = 0.05, in order to ensure that the model fits the catch data well. In addition, we now fit the model to catch data for all months, not just October-April. The changes to the model include the following:

$$N_{y,m+1} = N_{y,m} e^{-F_{y,m}-M}$$

$$\hat{C}_{y,m} = \frac{F_{y,m}}{F_{y,m}+M} N_{y,m}(1-e^{-F_{y,m}-M}) w_m$$

$$F_{y,m} = s_m F_y e^{\varepsilon_{y,m}}$$

s_m stays the same as the previous model and the following penalty is added to the objective function:

$$\sum_{y,m} \frac{\varepsilon_{y,m}^2}{2\sigma_\varepsilon^2}$$

3. RESULTS

The catch-rate model fits the index of relative abundance well, but the estimates of monthly fishing mortality are high. The estimates for 2008 and 2013 are less reliable because they are based on fewer months of data. The level of depletion is calculated by assuming that there was no fishing mortality in months for which the index of relative abundance was not fitted, which should underestimate the depletion. The stock is estimated to be highly depleted by the end of the year compared to an unfished stock.

The depletion model fits the index of relative abundance (CPUE) much worse than the catch-rate model, and neither does it fit the catch data well. The model estimates that the stock is even more depleted at the end of the year than does the catch-rate model.

The selectivity model fits the catch data much better than the depletion model, but fits the index of relative abundance slightly worse. The (total) fishing mortality is estimated to be higher, but the stock is estimated to be less, but still highly, depleted. The model estimates that dorado are not fully selected until around month 8 of the year (*i.e.* January).

The fit of the *F*-deviate model to the index of relative abundance is similar to that of the selectivity model, and it fits the catch data very well (note that the standard deviation for the catch likelihood is set much smaller than in the other models). The estimates of fishing mortality are substantially lower than those estimated by the depletion and selectivity models, and much closer to those of the catch-rate model. The estimated depletion of the stock is less than that estimated by the depletion and selectivity models, but the stock is still highly depleted at the end of each year.

4. DISCUSSION

We have illustrated how monthly CPUE for dorado, in combination with total catch, can be used in a depletion-based estimator to estimate the absolute abundance of the stock. The approach is similar to that used in a standard integrated stock assessment (*e.g*. Stock Synthesis) configured with a single recruitment per year and a seasonal dynamic based on months. In a standard integrated stock assessment model we found the following differences from the models proposed here (a) modelling of dorado older than one model year, (b) using Pope's approximation to analytically remove catch rather than using the catch equation together with an estimated *F*, (c) linking the recruits with the previous year's adult abundance through a stock-recruitment relationship, (d) extending the recruitment process to more than one month, and (e) using length-composition data to estimate length-based selectivity.

Several extensions could be added to the proposed models to improve them or make them more similar to a standard integrated stock assessment model. For example, the selectivity curve could be dome-shaped to account for a change in targeting to other species at the end of the year, or a stock-recruitment curve with annual deviates could be used to link recruitment with the previous year's abundance.

Selectivity was used to model the incomplete recruitment to the fishery at the start of the proposed model year, and only one recruitment was estimated per year. Alternatively, recruitment could be modeled for multiple months within a year and selectivity held constant. In the above models except the first, the weight of a dorado is related only to the month of the year, but in Stock Synthesis it would also be related to the month in which the recruitment occurred, and would differ among dorado spawned in different months.

The catch-rate and *F*-deviate models estimate similar fishing mortalities. The former uses only CPUE data that are assumed to be reliable because they correspond to the main fishing season for dorado. Therefore, the consistency in the estimates of *F* between these two methods lends support to the results of the *F*-deviate model, which also fits to catch for all seasons. The analysis shows promise, but further investigation, using the most recent data, is needed. The success of the *F*-deviate approach is encouraging, and suggests that a full integrated stock assessment model with a seasonal structure in Stock Synthesis could also be successfully implemented; however, these analyses are only preliminary, and should not be used as a basis for management advice.