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The steepness stock-recruit parameter for red snapper in the Gulf of Mexico (*Lutjanus campechanus*): What can be learned from other fish stocks?

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Executive Summary

1. It is well known that the value assumed for the steepness stock-recruit parameter strongly determines fisheries management reference points and the potential rate of stock-rebuilding. Due to the relatively few years and low range of stock abundances observed for Gulf of Mexico red snapper (*Lutjanus campechanus*), there is very little empirical basis to estimate steepness and identify with confidence the functional form of the stock-recruit function for Gulf of Mexico red snapper (*Lutjanus campechanus*). In the 1999 stock assessment some strong assumptions were required to attempt to estimate stock-recruit parameters for Gulf of Mexico red snapper and very high estimates of steepness were obtained. However, given the various assumptions made in the estimation of stock recruit parameters, the estimated values obtained for steepness must be treated as highly uncertain.

2. Because the values for the steepness parameter assumed for the 1999 stock assessment and reference point computation are highly uncertain, it may be useful to compile additional information to identify a range of values that might be plausible for the steepness parameter for Gulf of Mexico red snapper. This paper investigates what might be learned from information from other fish stocks that are approximately similar in life history characteristics to Gulf of Mexico red snapper.

3. The FISHBASE website contains information for a few dozen different Lutjanid species but indicates stock-recruit data are available for only two populations, the Gulf of Mexico red snapper population and the *L. synagris* population. These stock-recruit data for Lutjanids are insufficient to provide any potentially useful information about a plausible range of steepness values for Lutjanid species. There are only two stock-recruit datasets (at least a half dozen would be required) and both datasets are very small and uninformative about the potential functional form of the underlying stock-recruit relationships for these two population.

4. The FISHBASE website classifies *L. campechanus* as having low resilience to exploitation. Of eight other Lutjanids with similar life history characteristics, five are classified as having low resilience to exploitation and three are classified as having moderate resilience to exploitation. This classification appears to be made based on the estimated stock doubling times of these populations.

5. A paper by Myers et al. (1999) provides estimates of steepness for several dozen fish species. The estimates of steepness for marine demersal species that are moderately long-lived to long-lived were compiled and tabulated. The mean, median and standard deviation from the tabulated values are 0.67, 0.75 and 0.21. The modal value (most frequent value) was approximately 0.82. The approximate 10^{th} and 90^{th} percentiles are 0.35 and 0.85. The steepness values used in Amendment 22, NOAA (2003), 0.90 and 0.95 are much larger than the mean, median and modal values for demersal stocks and higher than the 90^{th} percentile for demersal stocks.

6. The range of estimates for steepness for demersal stocks and the high uncertainty in the estimated values for steepness for Gulf of Mexico red snapper, suggest that the steepness value assumed in Amendment 22 may be too high and lower values appear to be more plausible. Also given that *L. campechanus* is considered to be a stock with low resilience to exploitation in comparison to other Lutjanids, it could be argued that the most plausible values for steepness for *L. campechanus* should be not be chosen from the uppermost range of estimated values for steepness for demersal stocks.

Introduction

It is well known that the parameter values and functional form of a stock-recruit function can strongly influence computations of reference points for fisheries management (e.g., Myers and Mertz 1998; Myers et al. 1999; Michielsens and McAllister 2004). Problematically, it is rare for the stock-recruit dataset for the stock of interest to be sufficiently informative for the functional form to be undisputable and for accurate and precise estimates model parameters to be obtained (Barrowman and Myers 2000). Therefore if uncertainty is to be taken into account in stock assessment and the computation of management reference points, then the uncertainty in the functional form of the stock-recruit function and parameter estimates should be taken into account in the stock assessment.

Due to there often being a paucity of data available to support stock-recruit parameter estimation, values for some key quantities such as the rate of natural mortality and values for recruitment at unfished stock sizes may be applied but with little empirical support (ICCAT 2002; Schirripa and Legault 1999). When uncertainty is taken into account, it is common to undertake additional evaluations that utilize alternative plausible assumptions and to seek additional sources of information to evaluate the sensitivity of results to initial assumptions (McAllister et al. 1994; Boyer et al. 2001). The 1999 assessment of Gulf of Mexico red snapper (Schirripa and Legault 1999) contain a number of assumptions that may be questioned and thus may lead to the adoption of alternative sources of information to evaluate the sensitivity of estimates to the assumptions. This paper reviews some of these assumptions and formulates some alternative approaches that could be considered for stock-recruit model choice and parameter estimation.

In NOAA (2003), two alternative values for steepness (h) in the Beverton-Holt stock recruit function for Gulf of Mexico Red snapper are applied to compute biological reference points. These are 0.90 and 0.95. It is mentioned that the high value (0.95) provided the best fit between the model and the observed data. "The low value … (0.90) better approximated the steepness values of species with life history characteristics that are similar to those of red snapper. It is important to note that the steepness value defining the low end of the range is high relative to that defined for other species (Myers et al. 1999). As a result, estimates of MSY, B_{MSY}, and F_{MSY} derived from model runs that used the "low" steepness value still represent a highly productive stock" (NOAA 2003). This note thus also reviews available sources of information external to the stock assessment (Schirripa and Legault 1999) that provide indications of the plausible range of values for steepness and provides suggestions for a range of values that might serve as a prior probability distribution for steepness in the upcoming stock assessment.

Review of Some Assumptions Affecting Stock-Recruit Parameter Estimates

Data for years in only the last few decades (1984-1998) are utilized in the 1999 stock assessment (Schirripa and Legault 1999) and only very low spawning stock biomass values are available for estimation of stock-recruit parameters. In the 1999 assessment, it is recognized that "All analyses estimate current conditions to be near the origin relative to the virgin conditions and to the left of the bend in the assumed Beverton and Holt curve. None of the plots show a reasonable regression range for estimating the stock recruitment relationship." To facilitate the estimation of stock-recruit parameters, the value for the maximum average unfished recruitment parameter is fixed at two alternative values, a high value (245 million age 0 recruits) and a low value (163 million age 0 recruits). "The 245 million recruits comes from previous assessments where the SEAMAP time series was used to estimate the maximum recruitment based on the relationship between the number of recruits estimated in years 1984-1994 and the index. The 163 value is 2/3 of this maximum, under the assumption that the maximum index value was not representative of the maximum recruitment, but rather the average value from the early part of the index time series is representative of the maximum recruitment." (p. 27, Schirripa and Legault 1999).

There are a few critical assumptions made in the use of SEAMAP proxy for maximum recruitment and that have been outlined in McAllister (2003). One assumption is that the regression relationship between the SEAMAP index and estimated recruitment for the period 1984-1994 holds for years outside of this range, for example, for 1972-1976. This might not necessarily hold if the range of the area covered and / or survey gear, vessels or skippers employed in the SEAMAP survey changed between the 1970s and 1980s. It is common for the catchability of a survey abundance index to change when any one of these conditions change (Gunderson 1993).

A second assumption is that the recruitment estimate from the 1970s reflects the long-run average unfished recruitment. The catch per unit effort (cpue) value for 1972 is much higher than the rest in the series and is used to formulate the high average unfished recruitment value. This is the first year of the SEAMAP survey in the time series and often in surveys of abundance the initial survey value obtained is imprecise and not as reliable because the survey crew are only just learning to implement the survey. The recruitment values from the period 1972-1976 have a higher average value compared to later values. However, this does not necessarily imply that the values reflect the average unfished recruitment values. The 1999 estimate of stock biomass was at less than 6% of the biomass at MSY (B_{msy}), the fishery has been ongoing for over 100 years and the stock has been subjected to substantial overfishing (NOAA 2003, p. 18). Thus, it is possible that the 1970s recruitment values might not reflect the average unfished stock size but could be lower than the average unfished recruitment.

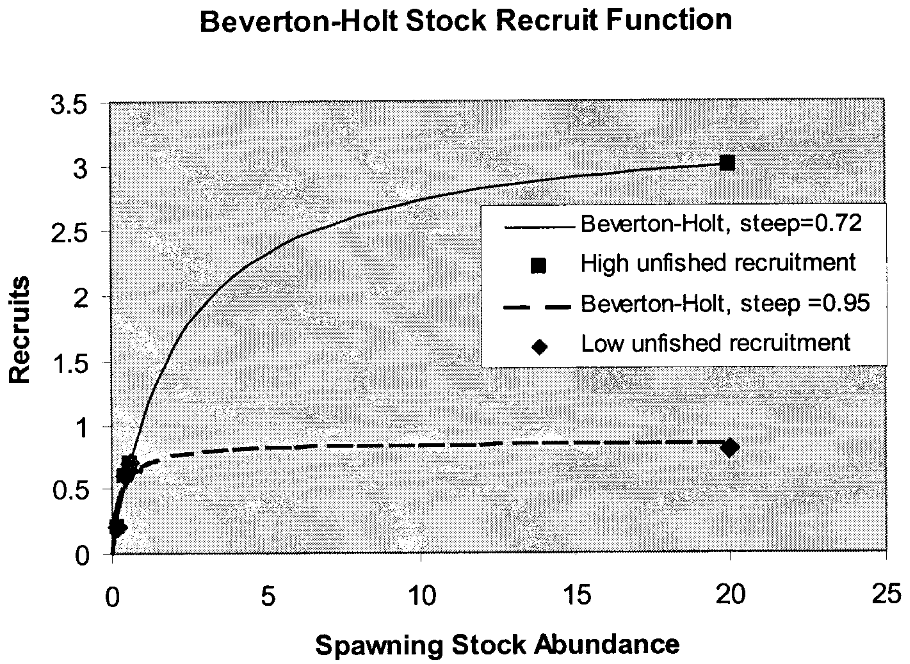
If the value assumed for maximum recruitment is in fact considerably less than the actual value, then this would tend to lead to a positive bias in the value for steepness. This is because the stock-recruit function starting from very low spawner abundance would have to bend down very quickly in order for the curve to go through a low average unfished recruitment value. Figure 1 provides a hypothetical illustration of the effects of an assumed high versus low unfished recruitment value on steepness when datapoints are centred over very low spawning stock sizes. If average unfished recruitment values were higher than the value assumed, the associated steepness estimates could be expected to be lower than the maximum likelihood value of 0.95.

The 1999 assessment thus used only two alternative assumed values for maximum recruitment, a high value based on the 1972 SEAMAP index and a value 2/3 of this. Other potentially higher values for maximum recruitment were not considered, though higher values also could also be plausible.

Review of databases for stock-recruit data for Lutjanids

One approach to estimation of stock-recruit parameters is to analyse stock-recruit datasets for other similar populations (Myers et al. 1999). Reviewing estimates of, for example, steepness, for other similar populations can give an indication of the range of values plausible for some newly studied population. Additionally, some recently developed methods of hierarchical modelling can be applied to estimate posterior predictive distributions for the steepness parameter. This predictive distribution could then be used as probabilistic input to the stock assessment for the species of interest.

Figure 1. A hypothetical illustration of the effect of assuming high or low unfished recruitment on the estimate of steepness when datapoints are only for very low values for spawning stock size. The high spawning size point is inserted by assumption, just as in the Schirripa and Legault (1999) assessment, except that a much higher value for unfished recruitment is inserted as an alternative to the low unfished recruitment scenario. The term "steep" in the legend denotes steepness.



FISHBASE (www. fishbase.org) was explored to investigate the information available on Lutjanids that might have bearing on identifying a plausible range of values for steepness for Gulf of Mexico red snapper (*L. campechanus*). FISHBASE had information available for several dozen Lutjanid species. However, the website indicated that stock-recruit data were available for only two different populations of Lutjanids and that these were obtainable for Ram Myers' database (see below). In all, eight other Lutjanids were listed that had similar growth and mortality characteristics to Gulf of Mexico red snapper. In FISHBASE, Gulf of Mexico red snapper was characterized as having a low resilience to exploitation possibly because the population's doubling time was listed to be between 4.5 and 14 years (Table 1). Of the eight other Lutjanids, five were listed to have low resilience to exploitation with similar population doubling times and three were listed to have moderate resilience to exploitation with lower doubling times (between 1.4 and 4 years) (Table 1). The precise basis for the estimated doubling time and categorization of resilience to exploitation was not available on the FISHBASE website. However, it is arguable that a fish with low resilience to exploitation generally might not be expected to have very high steepness (e.g., > 0.8) in the stock-recruit function. The use of steepness parameters of 0.90 and 0.95which are reported to indicate a stock with high resilience to exploitation (NOAA 2003), appear to be inconsistent with the FISHBASE categorization of *L. campechanus* to have low resilience to exploitation.

Table 1. Biological characteristics of large-sized (> 80 cm maximum length) Lutjanids in FISHBASE

Latin name	Resilience to exploitation	Maximum reported age (yr)	Maximum size (cm)	Growth parameter K	Fecundity	Doubling time (yr)
Ocyurus chryurus	low	14	86.3	0.1-0.16	--	4.5-14
L. peru	moderate	--	95	0.26	--	1.4-4.4
L. purpureus	low	18	100	0.09-0.12	--	4.5-14
L. rivulatus	moderate	--	80	0.22	--	1.4-4.4
L. sanguineaus	low	13	100	0.24	--	4.5-14
L. sebae	moderate	35	116	0.13-0.38	5 million	1.4-4.4
L. vivanus	low	--	83	0.09-0.32	--	4.5-14
L. malabricus	low	31	100	0.12-0.18	5 million	4.5-14
L. campechanus	low	57	100	0.12-0.2	>1 million	4.5-14

The Ram Myers' database (http://fish.dal.ca/welcome.html) on stock-recruit (S/R) data was inspected for the availability of stock-recruit data on Lutjanids. Only two datasets were found. These included dataset for the Gulf of Mexico Red snapper (*L. campechanus*) and the Carribean Sea species *L. synagris*. Both datasets are fairly short and uninformative. For example, the range of abundances is relatively small (e.g., about 15-45 hundred tonnes, n=17, for L. synagris and about 12-16 thousand billion eggs, n = 8, for *L. campechanus*), the CV in recruitment is high (about 0.5) and no functional form for a stock-recruit function is readily discernable for either dataset. Due to the few datapoints in either dataset and low contrast in the range of spawner estimates, it could be concluded that there exists no reliable basis to undertake a meta-analysis to identify an appropriate functional form and to estimate the parameters for stock-recruit functions for Gulf of Mexico Red snapper based on available stock-recruit data for Lutjanids.

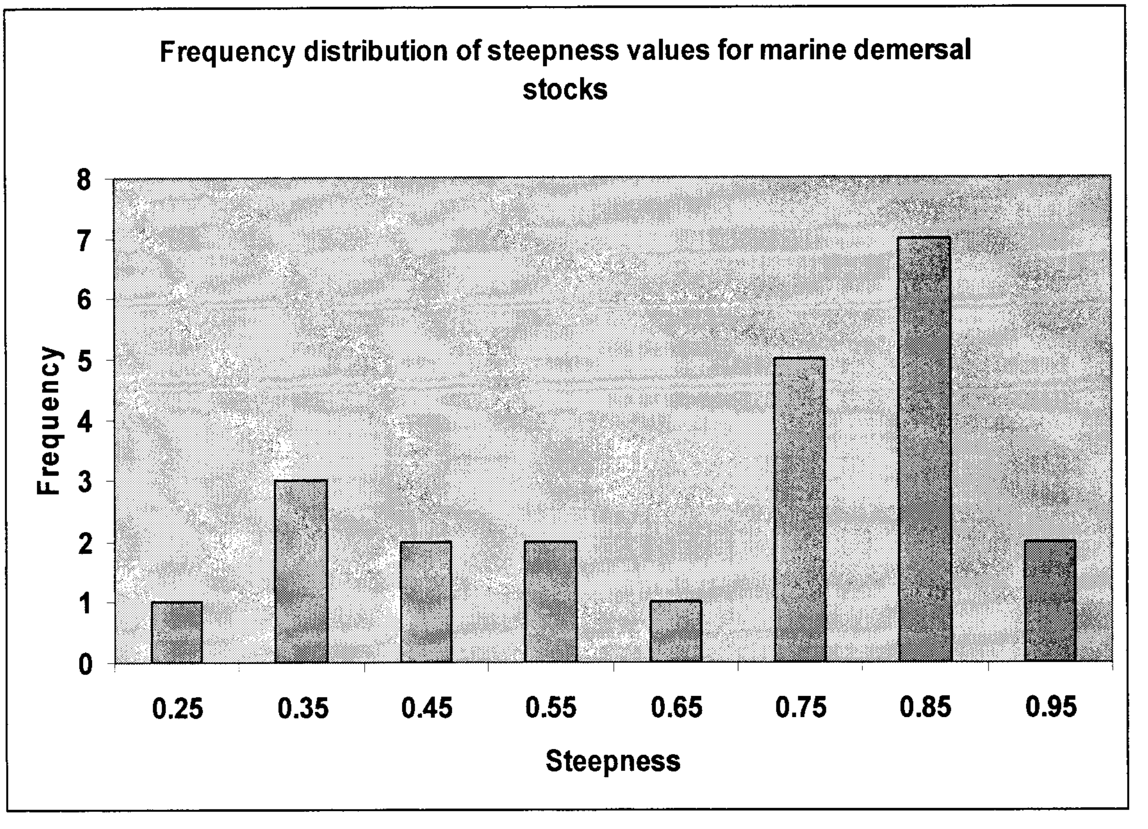
Although there are insufficient datasets to undertake a quantitative meta-analysis of stock-recruit parameters for Lutjanids, it might be possible to identify other species that have sufficient ecological and life history similarities to Gulf of Mexico Red snapper to be able to consider these datasets and parameter estimates. Myers et al. (1999) provide estimates of steepness from a meta analysis of a large number of stock recruit datasets. According to probabilistic meta-analysis (Gelman et al. 1995), the value for steepness for *L. campechanus* could be considered to be a random draw of a value for steepness from a large number of populations with similar life history characteristics.

Table 2. Estimates of steepness (z) for several different demersal species. n indicates the number of populations (stock-recruit datasets) used to estimate the distribution of steepness values for a given species, z_{20}, z_{med} and z_{80} indicates the 20th, 50th and 80th percentiles in the estimated distribution for z for a particular species.

Species	Latin Name	n	z_{20}	z_{med}	z_{80}
Gadiformes					
Gadidae		49	0.67	0.79	0.87
blue whiting	*Micromesistius poutassou*	2		0.71	
Atlantic cod	*Gadus morhua*	21	0.76	0.84	0.9
Haddock	*Melanogrammus aeglefinus*	9	0.64	0.74	0.82
Hake	*Mercluccius hubbsi*	1		0.82	
Pacific hake	*Merluccius productus*	1		0.32	
Pollock or Saith	*Pollachius virens*	5	0.78	0.81	0.84
Silver hake	*Merluccius bilinearis*	3	0.31	0.39	0.47
Walleye pollock	*Theragra chalcogramma*	2	0.53	0.55	0.58
Whiting	*Merlangius merlangus*	5	0.64	0.81	0.91
Lophiiformes					
Lophiidae		1		0.64	
Black angler fish	*Lophius budegassa*	1		0.63	
Perciformes					
Sparidae		3		0.95	
New Zealand snapper	*Pagrus auratus*	2		0.94	
Scup	*Stenotomus chryops*	1		0.95	
Plueronectiformes					
Plueronectidae		14	0.71	0.8	0.87
European flounder	*Platichthys flesus*	1		0.57	
Greenland halibut	*Reinhardtius hippoglossoides*	3	0.59	0.79	0.91
Plaice	*Plueronectes platessa*	8	0.83	0.86	0.88
Yellowtail flounder	*Plueronectes ferrugineus*	2	0.69	0.75	0.81
Solidae		7	0.72	0.84	0.91
Sole		7	0.72	0.84	0.91
Scorpaeniformes					
Anoplopomatidae		1		0.28	
Sablefish	*Anoplopoma fimbria*	1		0.26	
Hexagrammidae		1		0.77	
Atka mackerel	*Pleurogrammus monopterygius*	1		0.75	
Scorpaenidae		4	0.31	0.39	0.48
Chillipepper	*Sebastes goodie*	1		0.35	
Pacific ocean perch	*Sebastes alutus*	3		0.43	
Deepwater redfish	*Sebastes mentella*	1		0.47	

To identify a plausible set of values for the steepness for *L. campechanus* based on estimated values for other populations, a number of species of demersal fishes were selected from Table 1 in Myers et al. (1999). The species whose steepness values were considered to be plausible candidates for that of *L. campechanus* include species that are non-anadromous, non-pelagic, moderately long-lived, and have relatively slow growth rates. The estimated values for steepness for these populations are listed in Table 2. Where available, the 20th and 80th percentiles for the estimates of steepness for a given species are also listed. A histogram was formed using the estimated values for 23 species (Figure 2). The mean (average value), median (50^{th} percentile or middle value), mode (most common value) and standard deviation from the tabulated values are approximately 0.67, 0.75, 0.82 and 0.21. The approximate 10^{th} and 90^{th} percentiles are 0.35 and 0.85. The steepness values used in Amendment 22, NOAA (2003), 0.90 and 0.95 are much larger than the mean, median and modal estimated values for demersal stocks and also higher than 90^{th} percentile of estimated steepness values for demersal stocks.

Figure 2. The frequency distribution of steepness values for marine demersal stocks taken from Myers et al. (1999).



Conclusions

Because the time series of stock-recruit data for Gulf of Mexico red snapper is relatively short and span only a very short range of values for spawner abundance, they are uninformative for the choice of a functional form for the stock-recruit function and uninformative for the estimation of stock recruit parameters. In the 1999 assessment, estimation of stock-recruit function parameters was attempted by assuming a fixed value for the average unfished recruitment. This was a value obtained from the SEAMAP survey index values in the 1970s. The two main assumptions used, i.e., that the constant of proportionality from the mid-1980s also applies to the 1970s and that the recruitment in the 1970s approximated the average unfished recruitment may be questionable. Therefore, other approaches to formulating plausible values for the stock-recruit function should be considered.

A consideration of the relative resilience to exploitation of various Lutjanid species suggested that *L. campechanus* is in the group of Lutjanids that have low resilience to exploitation. Unfortunately there are no stock-recruit datasets for other Lutjanids that could be used to formulate a frequency distribution of plausible values for the steepness of this family. However, in a recent study by Myers et al. (1999), steepness values have been estimated for a large number of demersal and other fish species. Taking the steepness estimates for demersal species, the mean and median values across stocks are much lower than the values for steepness utilized in NOAA (2003). The values utilized in NOAA (2003) were at the extreme upper range of values for values estimated for demersal species. This indicates that given the high uncertainty in the estimated values for steepness for Gulf of Mexico red snapper and the frequency distribution of values for other demersal stocks, the steepness value assumed in NOAA (2003) may be too high and lower values may be more plausible. Also given that *L. campechanus* is considered to be a stock with low resilience to exploitation in comparison to other Lutjanids, it could be argued that the most plausible values for steepness for *L. campechanus* should not be chosen from the very upper range of estimated values for the steepness of demeral fish stocks.

Given that stock-recruit data and spawner biomass per recruit estimates are available for these various stocks, it is recommended that a hierarchical analysis (Michielsens and McAllister 2004) of these data be carried out to produce a predictive distribution for the steepness parameter. This distribution could be entered into the upcoming stock assessment as a prior probability distribution for steepness and help to constrain estimates of steepness when the steepness and average unfished recruitment are both assumed to be estimated parameters (rather than fixing the averaged unfished recruitment at some value from the 1970s).

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