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A *priori* estimates of natural mortality rates and stock-recruitment curve steepness for Gulf of Mexico red snapper (2nd draft)

by

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Natural mortality (M)

The estimate of natural mortality rate may strongly influence the perceived status of a resource. It is also one of the most difficult parameters to estimate because it is usually inferred from other data, which themselves are strongly influenced by variability in and measurability of recruitment, fishing mortality, and natural mortality itself (Quinn and Deriso 1999). Typical techniques to infer natural mortality rates relatively directly include catch curve analysis, length frequency analysis, and mark-recapture experiments. Alternatively, inferences can be made based on fitting population models to observed data or from life history attributes.

The most direct inferential techniques do not appear to be feasible for Gulf of Mexico red snapper at present. Catch curve analysis, length frequency analyses, and mark-recapture are most useful in estimating natural mortality rates when fishing mortality rates are low or when they can at least be measured independently and factored out. Red snapper faces high fishing mortality rates from an early age (Schirripa and Legault 1999) and the uncertainties surrounding the true stock size make it difficult to factor out the effects of fishing. One recent effort did estimate total mortality using a catch curve analysis from longline-caught fish sampled west of the Mississippi (Henwood et al. 2004). It produced an estimate of $Z = 0.1289$ and suggested that light fishing might make it reasonable to assume this may be an appropriate estimate of the natural mortality rate (discussed further below). Otherwise, short of estimating M in the assessment itself, we have to rely on life history information for inference.

Red snapper life history is suggestive of a species with a low natural mortality rate, at least for adults. Although most red snapper are caught before they reach 5 years old, several old fish have been observed including a 53 year old fish (Wilson and Nieland 2001). These recent occasional sightings of old and large fish fit with the observation that large red snapper used to be relatively common (Camber 1955 as cited in Schirripa and Legault 1999).

Numerous formulaic approaches relate natural or total mortality rates to other life history characteristics. Of several that were calculated in the past assessment (Schirripa and Legault 1999), the lowest point estimate was 0.02 based on a formula which incorporates the von Bertalanffy growth model parameter k, the oldest observed age (assumed in the absence of fishing), and the ratio of the age at which a cohort has its maximum biomass in the absence of fishing mortality to the maximum observed age (Alverson and Carney 1975). The highest point estimate was 0.36 based on a formula that incorporates annual mean water temperature and the von Bertalanffy parameters k and L_8 (Pauly 1980).

Ralston (1987) developed a simple formula that was not examined in the past assessment but could prove useful in estimating natural mortality rates for tropical snappers and groupers (red snapper were among more than a dozen species in the study). He found that an extremely simple relationship of fishing mortality rates approximating twice the von Bertalanffy growth parameter, k. He found that this relationship fit the snapper and grouper data better than the Pauly formula discussed above. With $k = 0.16$ for Gulf of Mexico red snapper, this formula would estimate natural mortality rates at 0.32. By itself, this estimate seems a poor fit for a species that lives beyond 50 y ears old and does not line up well with the total mortality rate estimate from Henwood and colleagues (2004). A better fit comes from an approach developed by Hoenig (1983) and commonly used in the region. It estimates total mortality based on maximum observed age. This approach has two variations, one of which aims to increase accuracy by taking into account the number of fish sampled. However, this approach is problematic for red snapper because the oldest fish are most likely to come from tournaments, which do not represent random sampling. The finfish-specific formula, which does not rely on an assumption of random sampling, estimates a total mortality rate of 0.078 with 95% confidence intervals spanning from 0.02 to 0.3 (Schirripa and Legault 1999). Because these numbers represent total mortality, they set an upper bound on natural mortality.

The past assessment focused on this level of natural mortality for older fish (age-2 and beyond) but set it higher for age-0 ($M = 0.5$) and age-1 ($M = 0.3$) fish because of the likelihood that natural mortality decreases with age (as recommended by Shepherd and Breen 1992 as cited in Quinn and Deriso 1999). An alternate way to address this life history property also offers the potential to find some consistency between the Ralston (1987) and Hoenig (1983) approaches. This alternate proposal seeks to meld these approaches by maintaining a geometric mean equal to the estimate achieved by the Ralston technique (i.e., $M = 0.32$) for the common red snapper age classes (the first five). It would heed the lower estimates from fieldwork (i.e., $M = 0.13$) and from the Hoenig approach (i.e., $M = 0.08$) by specifying age-specific natural mortality rates, which decrease geometrically with age to those levels according to the formula:

$$M_i = 2k(1-p)^{i-2} = 0.32(1-p)^{i-2}$$

Eq. 1

where p is a decay rate and i is an age class index. This formula was derived by assuming that the geometric mean of the first five natural mortality rates would be $2k$, regardless of the decay rate and that the natural mortality rate would decrease by a proportion $(1-p)$ for each of the first five age classes. Using simple algebra, it can be shown that the natural mortality rate for age-class 0 is $2k/(1-p)^2$. Using this formula, one can find a decay parameter, p, which results in the plus group rate equal to the estimate from the Hoenig approach. Table 1 shows the various age-based natural mortality rate estimates using this approach for a range of decay rates. It shows

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that a decay parameter of $p = 0.4$ produces the desired result of a geometric average M of 0.32 but with the plus group (age-4+) having a natural mortality rate equal to approximately 0.13 while a parameter value p = 0.5 would result in a plus group natural mortality rate of approximately 0.08.

Table 1—Age-specific estimates of natural mortality (M) based on an inverse relationship between natural mortality and age in early year classes with different decay rates, *p*. Results are based on Eq. 1.

	$p = 0$	$p = 0.1$	$p = 0.2$	$p = 0.3$	$p = 0.4$	$p = 0.5$
Age-0	0.32	0.40	0.50	0.65	0.89	1.28
Age-1	0.32	0.36	0.40	0.46	0.53	0.64
Age-2	0.32	0.32	0.32	0.32	0.32	0.32
Age-3	0.32	0.29	0.26	0.22	0.19	0.16
Age-4+	0.32	0.26	0.20	0.16	0.12	0.08

This approach could be applied to either a wider or narrower range of ages if it were determined to be more appropriate. Nevertheless, this approach could be problematic in that it assigns higher natural mortality estimates than previously to young fish. This would be inconsistent to some degree with the Hoenig approach, which focuses on total mortality over a lifetime. It would not violate the field findings, which focused on older fish. Conversely, the setting of low natural mortalities for most of the life span of red snapper would go against the Ralston estimate, which was also designed to apply to a lifetime rather than only a few years. The inconsistencies with the Hoenig approach are of greater concern because of the long lifespan of red snapper in the Gulf of Mexico.

Based on the imprecision indicated by these various estimates, and uncertainty about the appropriateness of applying the formulas to a stock with variable recruitment, the most recent stock assessment concluded "[These techniques] result in little guidance about the actual level of natural mortality for the Gulf of Mexico stock of red snapper" (Schirripa and Legault 1999, p. 3). Ultimately, estimates were applied as follows M = 0.5 to year-0 fish, M = 0.3 to year-1 fish, and M = 0.1 to all older fish. These conclusions are still valid and may be preferable. However, it is worth considering the use of Equation 1 with a decay factor $p = 0.4$ or 0.5, which would produce the natural mortality rate estimates indicated in the last two columns of Table 1.

Steepness

The stock-recruitment relationship also has a strong effect on the outcome of an assessment. The most recent assessment concluded "[T]he stock-recruitment relationship could not be well estimated given the short time series, most likely due to the lack of regression range" (Schirripa and Legault 1999, p. 26). Instead of trying to estimate the stock-recruitment parameters, they ran the model with all combinations of six different steepness parameter values (0.8 to 0.99) and two different maximum recruitment parameter values (163 or 245 million age-0 recruits). Their objective function, a measure of the fit of the model to observed data, was maximized at a steepness of 0.95. However, the Reef Fish Stock Assessment Panel (1999) raised a concern that this steepness value did not match those of other similar species, and so recommended focusing analysis on runs using either a steepness of 0.95 or 0.9.

A meta-analysis of steepness parameters (but using a Ricker rather than a Beverton-Holt parameterization) indicated that species with a periodic life history (typified by red snapper) have a stock-recruitment relationship with an average steepness of 0.7 but with the greatest variability scores, which could represent environmental variability, density compensation effects, or both (Rose et al. 2001). In this analysis, the maximum steepness for a fish with a periodic life history was 0.95, with only 10 percent of the distribution falling above a steepness of 0.86 and only 25 percent of it falling above 0.8. While the periodic life history did include a range of species, all were characterized by delayed maturation to achieve higher reproductive output and increased adult survival, especially during periods of poor environmental conditions. This analysis would indicate that, given the uncertainty surrounding red snapper due to observations only covering a narrow range of biomass levels, the actual steepness may be lower than 0.95. It might be reasonable to consider in the assessment a range from 0.7, the mean value for fish with the periodic life history pattern, or lower up to 0.95 or higher.

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