Impact on Yield from Density Dependence of Red Snapper Juvenile Life Stages

By

W.J. Gazey, R.P.Bio.
W.J. Gazey Research
1214 Camas Court
Victoria, BC V8X 4R1
Canada

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A key question that should be addressed is that if juvenile (age-0 or age-1) red snappers are saved from shrimp trawls then do sufficient numbers live to become adults? Up until 1989, the Gulf Council believed that bycatch restrictions would result in very few additional recruits to the adult population. By 1990, a paradigm shift occurred and the Gulf Council and NMFS now believe that if survivors from trawls double then adult recruitment will double (i.e., density independent). To the best of our knowledge, this belief is not based on research nor has the presence/absence of density dependent mortality been acknowledged as a research need. Presently, the assessment assumes the sole population control occurs at a life history stage prior to when red snapper become vulnerable to trawling (at about 5 cm). The extreme reproductive potential and low natural mortality for red snapper argues that several life stages may actually experience density dependence. For example, age-0 fish could be displaced or denied residence by age-1 fish on benthic micro-relief habitat. Similarly, the population may be limited by reef habitat (or juveniles displaced or denied residence on the reef by older fish). There is a substantive literature foundation (***literature search and review required – hundreds of potential citations)*** pointing out the importance of reefs with respect to red snapper life history and population limitation. Perhaps older snapper (age-8+), which disperse from the reefs, are significant predators of age-0 and age-1 red snapper. In any case, reef fish populations are often modeled (e.g., Mapstone et al. 1996) with density dependent mechanisms upon both settlement and reef residence.

The 1999 assessment (Schirripa and Legault 1999) assumption that reefs play no role in the population dynamics of red snapper is not defensible. A better, possibly oversimplified, assumption is that red snapper are reef limited upon taking residence at age-2. The purpose of this note is to explore the impact on fishery yield calculations of these two approaches. All parameter values are taken from Schirripa and Legault with adult instantaneous natural mortality set at 0.1, recruit maximum set at 245 million age-0 recruits and steepness set at 0.95. Schirripa and Legault chose this parameter set to illustrate most of the tuning indices and termed it the “baseline situation” because it fit the data best. Figure 1 provides the likelihood profile of the steepness recruitment parameter with maximum age-0 recruitment set to 245 million. While the steepness set at 0.95 is not actually the best fit to the data (Schirripa and Legault used a coarse grid at 0.025 intervals) it is sufficiently close to be included in any reasonable confidence region.

In order to make comparisons with and without compensation of juvenile snapper, recruitment must be expressed in terms of age-2 fish where both approaches assume age-2 and older fish are subject to density independent mortalities. Mathematically, Schirripa and Legault assume recruitment of age-0 is projected with a Beverton-Holt stock recruitment (S-R) function (an equivalent mathematical development can found in Appendix 1 of Schirripa and Legault):

$$R = \frac{E}{\alpha E + \beta}$$

where R is age-0 recruits, E is eggs and α and β are parameters with $1/\alpha$ the asymptotic recruitment (carrying capacity) and $1/\beta$ the slope at the origin. Because they assume that all mortality is density independent for age-0 and age-1, recruitment at age-2 can be expressed simply as:

(1) $$R'_{Benthic} = \frac{E \cdot e^{-Z}}{\alpha E + \beta}$$

where $R'_{Benthic}$ is the age-2 recruits and Z is the cumulative instantaneous natural and fishing mortalities to age-2. The term "benthic" is used because population control is assumed to be at settlement. Assuming that reef limited recruitment is also a Beverton-Holt function with a carrying capacity at the without fishing (virgin) level and initial slope equivalent to the benthic condition then implies:

(2) $$R'_{\mathrm{Reef}} = \frac{E}{\alpha E \cdot e^{M} + \beta \cdot e^{Z}}$$

where M is the cumulative instantaneous natural mortality to age-2.

Recruitment (now age-2), based on alternative compensatory mortality assumptions, is explored in Fig. 2. A line on these S-R plots emulates a specific juvenile mortality. The top panel (benthic limited) depicts the relationship (equation 1) in which all compensatory mortality occurs prior to capture by shrimp trawls. They were computed by simply multiplying the original (age-0) S-R relationship by the associated survival to age-2. The three illustrated S-R functions are as follows: (1) the "No Shrimping" line represents the S-R function if there were no shrimping; (2) the "Historical" line assumes the mean 1984-1989 bycatch mortality; and, (3) the "50% Reduc" line assumes a 50% reduction in the instantaneous bycatch fishing mortality. Conversely, the lower panel of Fig. 2 (reef limited, equation 2) depicts the same bycatch mortality scenarios but with all compensatory mortality acting when red snapper take up residence on the reefs at age-2. The recruit steepness is the same as the benthic limited plots but the recruit maximum is set to the no shimping value. The number of age-2 recruits at any given stock size is larger for the reef limited scenarios (of course, the no shrimping S-R lines are identical).

The following five bycatch scenarios were used for yield calculations using the same methodologies as Schirripa and Legault:

1) Linked. A common selectivity curve was used for both directed snapper and shrimp trawl. This implies that fishing effort for the two fisheries track each other (i.e., if directed effort on snapper is halved then shrimp trawl effort is halved). Since the yield calculations are in weight of red snapper only, the linkage also implies that the allowance for bycatch of red snapper in the pursuit of shrimp is of no value to the shrimp industry. In other words, this procedure is policy-driven.
2) Current. The mean bycatch instantaneous fishing mortality for 1995 to 1995 was used as a constant for the yield calculations. In other words, yield was calculated conditional on bycatch mortality.
3) 27% Reduction. Reduce the instantaneous current bycatch mortality by 27%.
4) 50% Reduction. Reduce the instantaneous current bycatch mortality by 50%.
5) No Shrimping. Reduce the instantaneous bycatch mortality to zero.

The yield under various bycatch scenarios under the benthic limited assumption are plotted as a function of the retained directed instantaneous fishing mortality in Fig. 3. All sources of mortality (natural, directed, non-directed and discard) have been included with the exception of directed and non-directed mortality of age-1 which was ignored (about 0.0007 out of 1.7 total for the 1995-1997 mean). MSY, F_{MSY} , B_{MSY} and other estimates essentially duplicate those reported by Schirripa and Legault (Tables 28 and 29). In general, the yield curves are flat with small gains in yield from reducing directed fishing. The foregone catch from shrimp trawls (the difference between the yield at No Shrimping and the yield for the scenario of interest) is large. By far, the largest gains in yield are made by controlling bycatch. This was the scientific advice provided to the Council by the Schirripa and Legault assessment and is the same as that provided by the previous assessment (Goodyear 1995).

Similar yield plots are provided under the reef limited assumption (Fig. 4). The F_{MSY} and B_{MSY} estimates are identical to the benthic limited assumption where constant bycatch mortalities are used. However, the yields are substantially different. These yield curves are more domed shape with large gains to be made through reduction of directed fishing. If stocks were allowed to rebuild to near B_{MSY} then the relative amount of foregone catch (the difference between the yield at No Shrimping and the yield for the scenario of interest) is much smaller.

The yield estimates that flow from a benthic or reef limited assumption are dramatically different. The issue of what life stages are subject to density dependent processes is key to providing long term scientific advice for the management of red snapper. This conclusion is opposite to that reached by Schirripa and Legault in their Appendix 1. They used a similar set of recruitment curves but failed to compute the yield under a no shrimping scenario and thus made their conclusions without knowledge of foregone yield. Instead, Schirripa and Legault relied on faulty and misleading logic. Their statements and conclusions (in italics) were as follows:

1) *A higher slope (age-2 recruitment) from decreased bycatch results in larger MSY; therefore, juvenile compensation (reef limited) does not limit the importance of bycatch reduction.* It is certainly true that if bycatch is reduced then a higher yield is produced regardless of benthic or reef limited recruitment. However, the foregone catch is substantially reduced under reef limited recruitment (compare Figs. 3 and 4). In other words, juvenile compensation *does* limit the importance of bycatch reduction.
2) *There is more yield to gain under juvenile compensation (reef limited); therefore, it argues even stronger for reduction in bycatch.* Again, it is certainly true that the yields are higher under reef limited recruitment. However, the foregone catch has been reduced because the yield curve without any shrimping is the same under benthic or reef limited recruitment. In other words, bycatch reduction *is not as effective* under a reef limited regime.

In both of the above statement-inference parings by Schirripa and Legault the statement was true but the inference was false as demonstrated in Figs. 3 and 4.

Our yield calculations were made using a particular set of parameter values that are likely not the most plausible. While compensatory mortality of juveniles will reduce foregone catch because of shrimp trawling, the magnitude of the impact could be amended by the following considerations among others:

1) Natural mortality of juveniles. The values to use are currently under debate. If higher rates are used as suggested by recent field experimental studies then foregone catch will be reduced. Offsetting a possible increase in age-0 natural mortality is an error made by Schirripa and Legault in the assessment. They assumed a full year (12 months) of age-0 mortality whereas only seven months (June to December) should have been applied.
2) Bycatch estimates. The bycatch estimates used by Schirripa and Legault were obtained through general linear model (GLM) procedures. These estimates are not credible because of the large number of trawl hauls with zero red snapper caught and unbalanced sampling. A Bayes negative binomial model has been adopted. The bycatch estimates will be substantially less than were used previously; thus, foregone catch will be reduced.
3) The age composition of the bycatch data (proportion of age-0 and age-1) has been adjusted such that the bycatch consists of a higher proportion of age-0. The adjustment will reduce foregone catch.
4) Recruitment parameters. An increase in steepness and a decrease in maximum recruitment will serve to reduce foregone catch. Smaller bycatch estimates will reduce the steepness counteracting to some extent the effects of reduced bycatch mortality.

Alternative yields under other parameter values should be calculated in order to investigate the sensitivity of reef limited recruitment. One approach would be the generation of posterior recruitment parameter distributions based on the uncertainties listed above and others mentioned in the CEDAR 7 Report and then calculate the associated yields. In addition, recovery trajectories need to be examined because the impacts from reef limited recruitment will be minor for small stock size but will become more of a factor as the stock size builds.

Literature Cited

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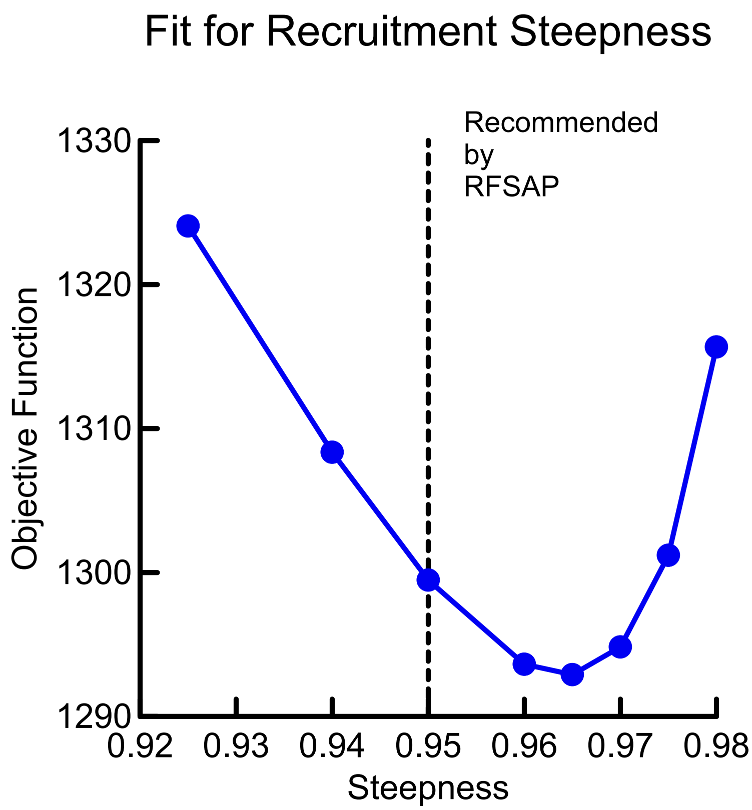
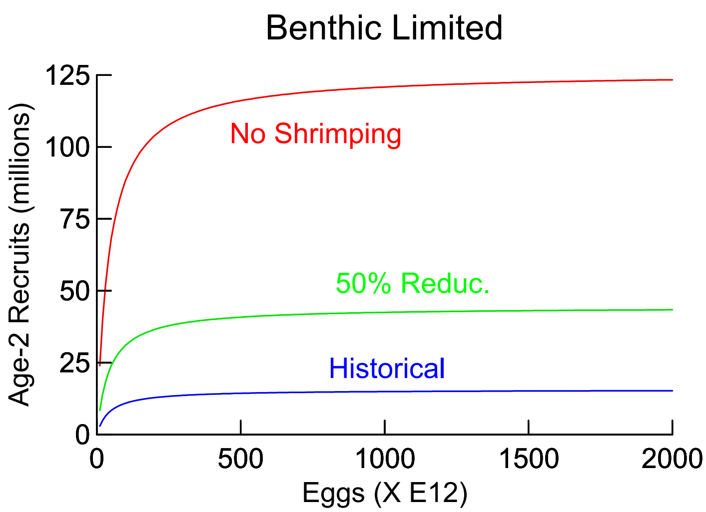


Figure 1. Steepness likelihood profile from the 1999 assessment model with maximum recruitment fixed at 245 million recruits.



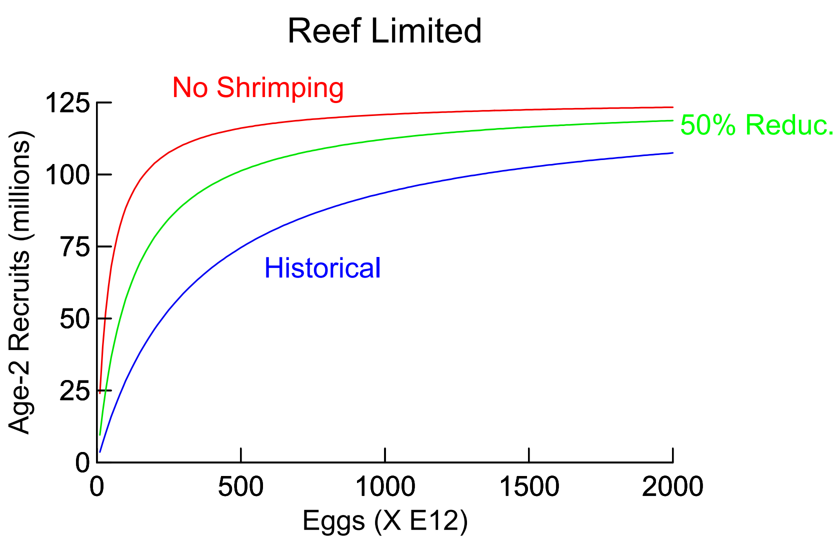


Figure 2. Stock recruitment functions under benthic and reef limited scenarios. The "historical" scenario is based on the 1984-1989 mean bycatch mortality and the "50% Reduc." scenario assumes a 50% reduction in the historical instantaneous bycatch mortality.

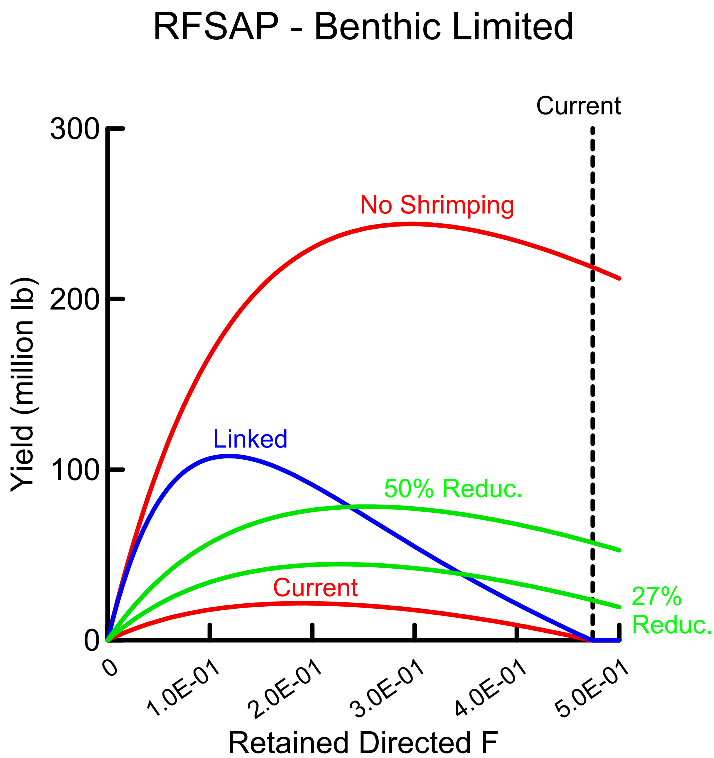


Figure 3. Yield of red snapper as a function of retained directed fishing mortality (F) under various bycatch scenarios using the benthic limited stock recruitment function. The “current” designation was defined as the 1995-1997 mean mortality.

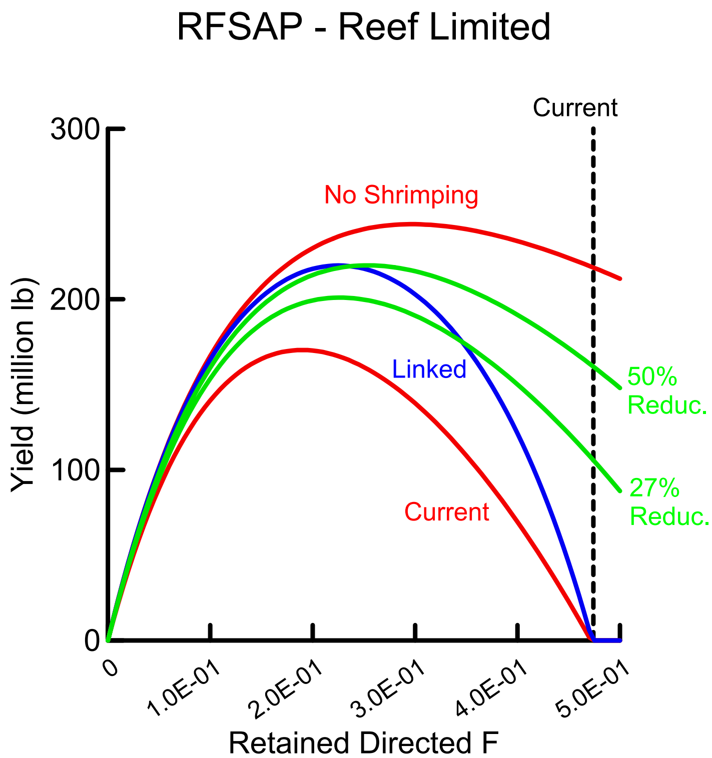


Figure 4. Yield of red snapper as a function of retained directed fishing mortality (F) under various bycatch scenarios using the reef limited stock recruitment function. The “current” designation was defined as the 1995-1997 mean mortality.