



# Would enhanced fecundity per unit mass for large hake likely have consequences for hake recruitment and for approaches to hake management?

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## Abstract

The hypothesis that increases in spawning frequency for and more viable eggs from larger hake lead to their making a disproportionately large contribution to recruitment is critically examined. The high steepness ( $h$ ) estimated for stock-recruitment relationships for other than short-lived fish species worldwide, together with high  $h$  estimates from assessments for the South African hake populations, are at variance with this hypothesis, and suggest that the effect postulated is more than compensated by other density-dependent effects operative over the egg-to-recruit stage. This conclusion is supported by the relative insensitivity of OMP robustness test performance statistics to variations in underlying resource dynamics to incorporate this effect. Furthermore, even if larger hake off South Africa had been effectively protected from trawling in refugia, their numbers would have fallen as a result of the effects of fishing on younger animals; however no substantial decrease in recruitment is evident in assessments. While these counter-arguments do not exclude the possibility that recruitment is notably influenced by such effects (perhaps under more complex stock structure hypotheses), models fitted to data which demonstrate such behaviour would need to be developed before the hypothesis might be accorded any priority for attention in further research planning.

## Background

Recently arguments have been offered locally that it is important to reduce fishing pressure on large hake in particular (i.e. certainly relative to that on other size-classes). The associated rationale is that spawning frequency increases with size, as does the viability of eggs, so that reproductive output is relatively more dependent on the contribution from larger fish than the conventional assumption of proportionality to spawning biomass ( $B_{sp}$ ) might suggest. This is termed here the “disproportionate large fish contribution” hypothesis.

Since as fishing intensity increases and resource abundance drops, the proportional contribution of older fish to  $B_{sp}$  decreases, it follows that under this argument “viable egg” output ( $E$ ) as a function of  $B_{sp}$  would take the form of a concave curve (II) rather than a linear relationship (I) as illustrated in Fig. 1.

However eventual recruitment ( $R$ ) is dependent not only on  $E$ , but also on other factors that influence survival from the stage of spawning to recruitment (taken here to be “0-year-old fish” for simplicity):

$$R(B_{sp}) = g(B_{sp})E(B_{sp}) \quad (1)$$

where  $g(B_{sp})$  represents the combined effect of these other factors and their dependence on  $B_{sp}$ .

Since there are limits to population growth,  $R(B_{sp})$  must (on average over years) approach some asymptote as  $B_{sp}$  increases (e.g. the Beverton-Holt form), or reach a maximum and then decline (e.g. Ricker form – perhaps a consequence of egg cannibalism).

Thus the resultant recruitment depends on  $g(B_{sp})$  as well as depending on  $E$ .

## Indications from Fisheries Worldwide

Earlier in fisheries management it was frequently argued that in the absence of statistically significant trends in  $R$  with  $B_{sp}$ ,  $R$  should be taken to be a constant independent of  $B_{sp}$ . Note that this implies strong density dependence in the  $g(B_{sp})$  function, and even more so under the “disproportionate large fish contribution” hypothesis (see Fig. 2).

The work of Myers and colleagues in the late 1990s showed that even through statistically significant  $R$  vs  $B_{sp}$  relationships could often not be detected from data for single stocks, clear dependence did emerge from meta-analyses involving the joint evaluation of spawning stock recruitment data for many fish populations. Importantly, recruitment is typically less at lower stock sizes (and naturally must be zero for  $B_{sp} = 0$ ), so that as  $B_{sp}$  decreases the  $g(B_{sp})$  function must reach a finite maximum at a  $B_{sp}$  level that is not negligible compared to pristine (see Fig. 2).

Associated research (specifically Myers *et al.*, 2002) has also investigated the shape of stock-recruitment relationships. Typically these are characterised by the “steepness” parameter ( $h$ ) of a fitted Beverton-Holt form:

$$R(B_{sp}) = \alpha B_{sp} / (\beta + B_{sp}) \quad (2)$$

where  $h$  is defined as the proportion of pristine recruitment  $R^* = R(K_{sp})$  that occurs (in expected value terms) when  $B_{sp}$  is reduced to 20% of its pristine level  $K_{sp}$  (see Fig. 3).

Fig. 4 displays stock-recruitment curves for various values of steepness. The extremes “possible” are  $h=1$  (constant recruitment) and  $h=0.2$  (linear through the origin, and the same as the replacement line, so that there is no surplus production).

Importantly, if there is an appreciable “disproportionate large fish contribution” to eventual recruitment, one would expect recruitment to drop fairly quickly following the onset of fishing as  $B_{sp}$  and particularly the larger fish proportion thereof falls below  $K_{sp}$ ; in other words, a fairly low value of  $h$  would be expected. In contrast, in a situation where  $h$  is high (close to 1), so that recruitment stays high until  $B_{sp}$  drops to rather low levels relative to  $K_{sp}$ , this large fish effect (even though it may be playing some role) would not be seen as one of importance in a management context.

Information on the values of  $h$  for fish stocks worldwide is available from Myers *et al.* (2002) – see Figure 1 thereof. Aside from short lived, early maturing species such as anchovy, the picture is one of high steepness, with distribution modes for various categories of fish ranging from 0.74 to 0.84. Further plots in the paper indicate that steepness tends to increase with reproductive longevity.

These high values of steepness for fish populations elsewhere with biological parameters similar to those for hake are **not** consistent with the hypothesis of a “disproportionate large fish contribution” to recruitment.

Indeed, effectively the reverse inference is being drawn for some rockfish populations off the USA: that use of  $B_{sp}$  rather than egg production for stock-recruitment plots leads to an underestimate of steepness for these resources, thus inappropriately suggesting that they manifest steepnesses lower than that typical for other species (A.E. Punt, pers. commn).

## Indications for South African Hake

The most recent species disaggregated assessment for South African hake (Rademeyer and Butterworth, 2006) estimates steepness at its upper bound for both *M. paradoxus* and *M. capensis*, i.e. despite substantial reductions of the spawning biomass for each species, the assessment finds no indication of any appreciable reduction in recruitment levels.

This result is particularly strong for *M. paradoxus*, for which forced reduction of  $h$  to 0.8 results in a reduction in log likelihood of 7.4. A corresponding reduction of  $h$  to 0.7 for *M. capensis* is less incompatible with the data, but still significant at the 5% level given a decrease in the log likelihood of the fit by 3.1. These assessments comprise fits to 26 data series in combination. Very few of these series provide an improved likelihood contribution when  $h$  is decreased. The series for which the *M. paradoxus* log likelihood decreases the most when  $h$  is forced to be lower is the offshore commercial catch-at-age, and for *M. capensis* the recent CPUE series.

## The Refuge Possibility

A seemingly attractive theory is that once above a certain size, many hake find themselves a refuge from some forms of fishing by preferentially choosing untrawlable habitat (a size specific gear avoidance ability would have the same effect). Then, under the “disproportionate large fish contribution” hypothesis, fish in such a refuge make the primary contribution to recruitment, which consequently is likely to drop if other methods of fishing subsequently fish down the large hake in such refuges.

However, even without exploitation of older (say age  $a+$ ) hake, their numbers will drop over time because reduction of the numbers of age  $(a-1)$  fish through the effects of fishing will induce a proportionate drop in the abundance of large age  $a+$  hake. Thus large hake in any local refugia have seen their numbers decrease substantially over time, even if not themselves subject to fishing, because of the direct impact of fishing on the abundance of younger fish. If such a decrease in large fish abundance has not led to a major drop in recruitment (for which assessments indicate a value of steepness  $h$  close to 1) why should this then be expected as a consequence of a non-excessive level of fishing directed at the argued refugia?

This inference is supported by robustness tests that formed part of the hake OMP-2007 evaluation process; these shows little further reduction in hake abundance compared to reference assessments if it is assumed (test A10d – mat age=7) that only age 7+ hake contribute to recruitment, instead of age 4+ as conventionally assumed when computing hake spawning biomass. Other robustness tests which attempted to investigate the sensitivity of hake projections to possible manifestations of the “disproportionate large fish contribution” hypothesis show even less dependence (Butterworth and Rademeyer, 2007).

## Concluding Remarks

The possible importance of a “disproportionate large hake contribution” effect on recruitment for the management of South African hake populations is **not** supported by:

- a) the typically high steepness of the stock-recruitment functions for similar fish populations worldwide (Myers *et al.*, 2002);
- b) the high steepnesses estimated in assessments of the two South African hake populations themselves;
- c) even if there have in the past been refugia for larger South African hake, abundances in these refugia would have been reduced by the effect of fishing on smaller hake, yet recruitment is not estimated to have declined (as steepness is estimated to be high); and
- d) robustness tests for this effect in the testing of OMP-2007 (used at present to provide TAC recommendations for the South African hake resource) indicating little sensitivity.

This is not to say that the effect is not present at the level of viable egg production; rather that the empirical evidence shows it to be more than compensated by other density dependent effects operative on survival rates over the stages from eggs to recruitment.

The practice of using measured/inferred changes in some biological parameters (such as, here, viable egg production) as a basis for quantitative management recommendations in fisheries has generally now been discontinued for the reason above, *viz.* the net effect on population trends depends also on other parameters which are not measurable (e.g. survival rates of the youngest fish) and those can change concurrently in a compensating manner. Rather, stress is laid on basing management on the net effect of the various biological parameters and their changes in combination, as indicated by trends in indices of resource abundance. Nevertheless, even though quantitative inferences concerning sustainable levels of catches from a measured change in one biological parameter are considered to be unreliable, such results remain seen as valuable indicators of a need for more careful monitoring of abundance trends.

The analyses of this paper do not exclude the possibility that the effect hypothesised could still be of importance for the management of South African hake, perhaps (for example) as a consequence of some multiple stock structure more complex than the single *M. capensis* and *M. paradoxus* stocks assumed for current assessments. However, before such a possibility might be accorded any plausibility in future considerations of approaches to hake management, given the weight of the existing absence of evidence supporting the effect, a pre-requisite should be the construction of a model, conditioned on (fitted to) available data, which suggests that the effect could be of some importance in a management context.

## References

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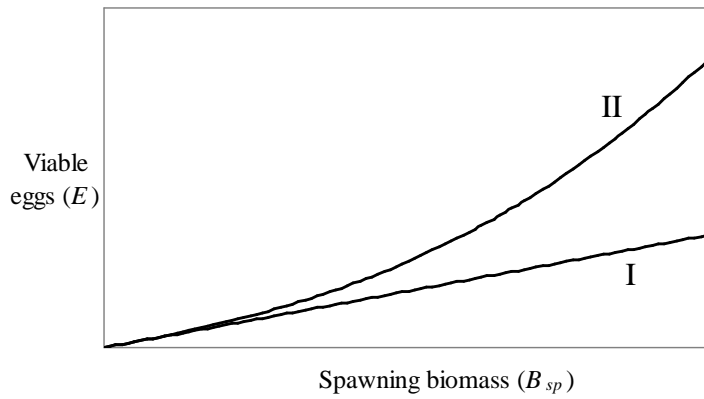


Fig. 1: Schematic illustration of viable egg output as a function of  $B_{sp}$  both with (II) and without (I) an effect where larger fish spawn more frequently and produce more viable eggs.

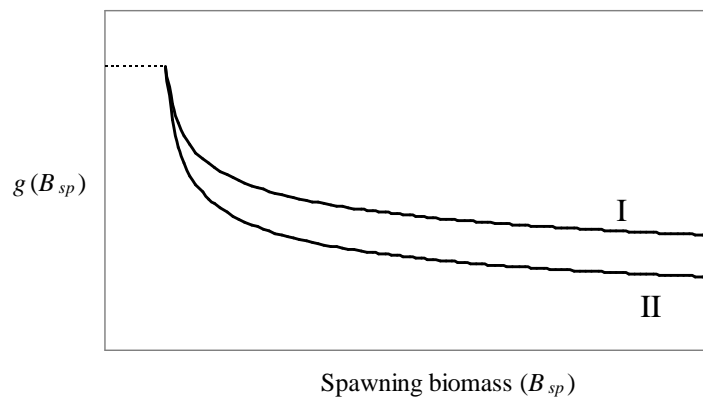


Fig. 2: The multiplicative contribution of factors influencing survival from viable egg to recruited fish in circumstances of recruitment  $R$  being independent of  $B_{sp}$ , for the two relationships of  $E$  to  $B_{sp}$  illustrated in Fig. 1. The dashed line for  $B_{sp}$  close to zero reflects the necessary maximum to the value of  $g(B_{sp})$  implied by the results of Myers and colleagues which confirmed that  $R$  does (eventually) drop as  $B_{sp}$  declines.

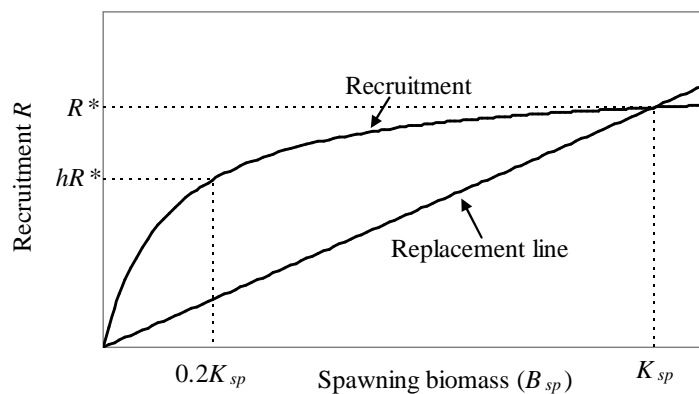


Fig. 3: A stock-recruitment (S-R) relationship shown by the curve, together with a replacement line (the number of recruits required to maintain the population at an unchanged abundance) as a function of  $B_{sp}$ . The S-R curve and replacement line intersect at the pristine spawning stock biomass  $K_{sp}$ . The plot shows how the steepness ( $h$ ) is defined.

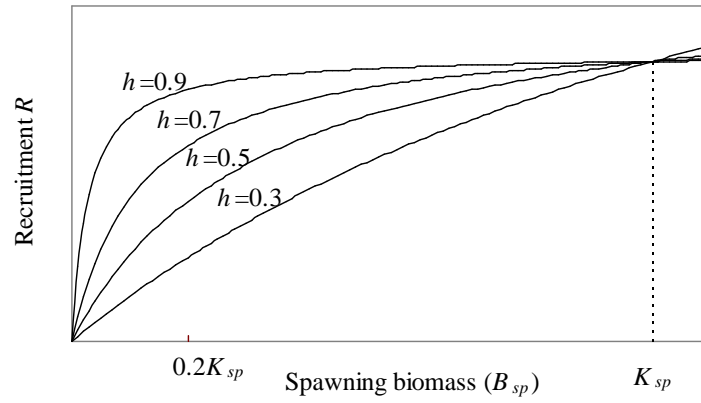


Fig. 4: Beverton-Holt stock-recruitment curves for different values of steepness ( $h$ ).