Spawning Stock Biomass-per-Recruit Analysis: A Timely Substitute for Stock Recruitment Analysis

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Abstract

Relative biomass per recruit of adult (i.e., sexually mature) fin- or shellfish is shown to help in identifying levels of fishing mortality likely to lead to recruitment overfishing. This is illustrated with data from a Malaysian penaeid shrimp fishery.

Introduction

Although relatively easy to carry out when traditional age-based assessments are used (Le Guen 1971; Lee and Al-Baz 1989) or when using the size-based assessment methodologies that are more applicable to tropical fisheries (Mathews et al. 1987), spawning biomass-per-recruit assessments are rarely carried out in practice. Thus, management of stocks and fisheries rarely if ever relies on this type of analysis. This is because spawning biomass-per-recruit analysis was to date not associated with any simple criterion, readily acceptable to managers and scientists, for determining whether a proposed management measure is likely to increase recruitment and hence landings. This article presents a recent example of spawning biomass-per-recruit assessment of prawn stocks based on contributions to be published in Mathews and Lui (in press). Then, the suggestion is made that spawning biomass-per-recruit analyses should be carried out more frequently and used as input for fisheries management.

Materials and Methods

The analytical technique used here is described in the manual of the Compleat ELEFAN software (Gayanilo et al, 1988), which shows how the yield-per-recruit and biomass-per-recruit analyses are carried out, using standard definitions of these concepts. Herein, biomass (B) per recruit (R) is calculated as relative biomass per recruit (B'/R). The analyses provide estimates of B /R for specified values of the exploitation ratio (E = F/Z) and size at entry to the fishery (Lc) in % of B'/R in the unfished population; thus a value of (B'/R) = 100% implies that the population is unfished. Values of B'/R < 100% imply that the biomass per recruit has decreased because of fishing.

In addition, the relation between cumulative sexual maturation (in per cent) and body size was used to adjust the estimated B'/R so that an estimate of the relative biomass per recruit of *sexually mature* fish or prawns (B_m'/R) can be obtained (and expressed in % of the unfished B_m'/R). This was obtained by multiplying B'/R values, for each size at entry and exploitation ratio, by the fraction of biomass consisting of sexually mature animals (SM) at a particular size at entry to the fishery:

$$B_m'/R = B'/R * SM.$$

Assessments

Fig. 1 shows a yield-per-recruit analysis for trawl-caught *Metapenaeus affinis* off the West Coast of Malaysia (Taupek, in press); this species provides the most valuable and important component of the Pukat Kenka (Danish seine) fishery of Perak State, Malaysia. Taken by itself, and without information on the reproductive biology of *M. affinis*, this analysis suggests that yield per recruit could be increased by 9% if size at entry were reduced from about 95 to 65 mm TL at the current exploitation rate (E = 0.55). Fig. 2 shows the relation between cumulative maturation of female *M. affinis* and body size: 50% are mature at about 125 mm TL. Taken jointly, Fig. 1 and Fig. 2 show that sexual maturation occurs at a rather large size at entry (about 78% of L_∞), and well above the size at which harvesting occurs (under 60% of L_∞), i.e., most of *M. affinis* caught are immature.

Fig. 3 shows the biomass per recruit isopleths (continuous lines) and the spawning biomass-per-recruit isopleths (broken lines). The fishery is situated at a B_m'/R of about 1% of the unfished biomass: any reduction in size at entry will lead to a reduction in the spawning biomass to levels well below 1% of the

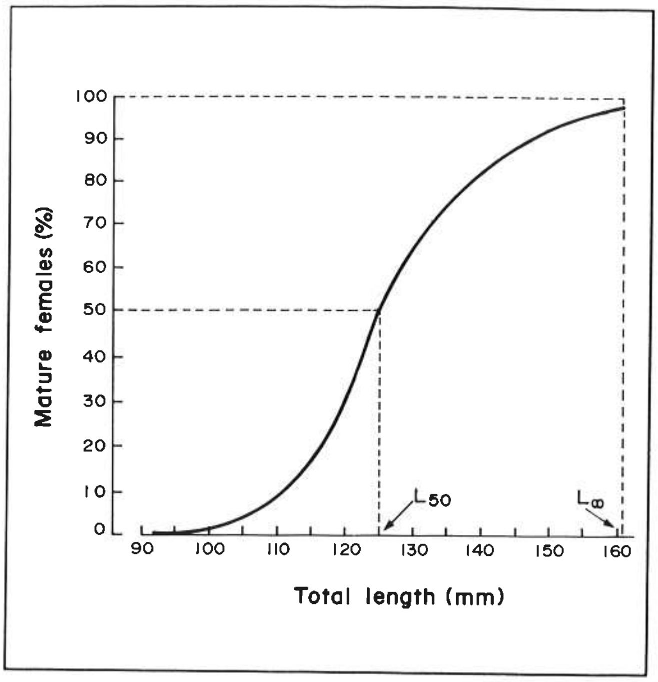

Fig. 1. Yield-per-recruit isopleths for female *Metapenaeus affinis* (TL_∞ = 162 mm), including the position of the fishery (after Taupek, in press). Lines were interpolated by eye: the large dot shows the current position of the fishery.

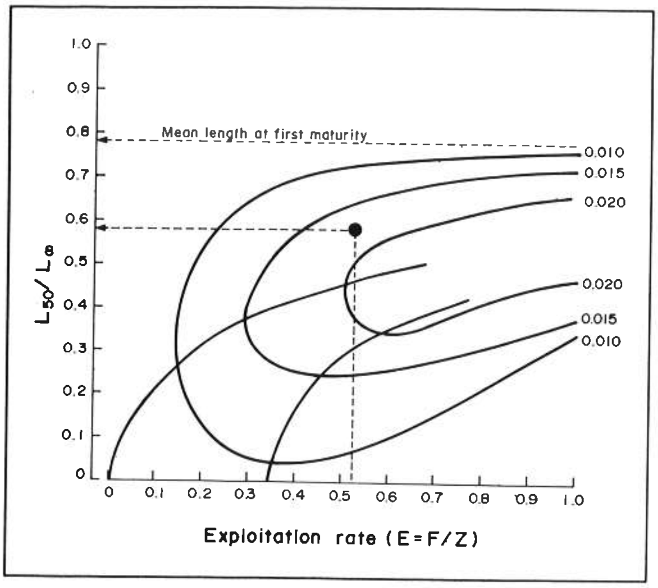

Fig. 2. Relation between the proportion of sexually mature female *Metapenaeus affinis* (cumulative % mature) and body size.

unfished biomass. Alias and Mathews (in press) obtained similar results when assessing the West Coast stock of *Penaeus merguiensis*, Perak State.

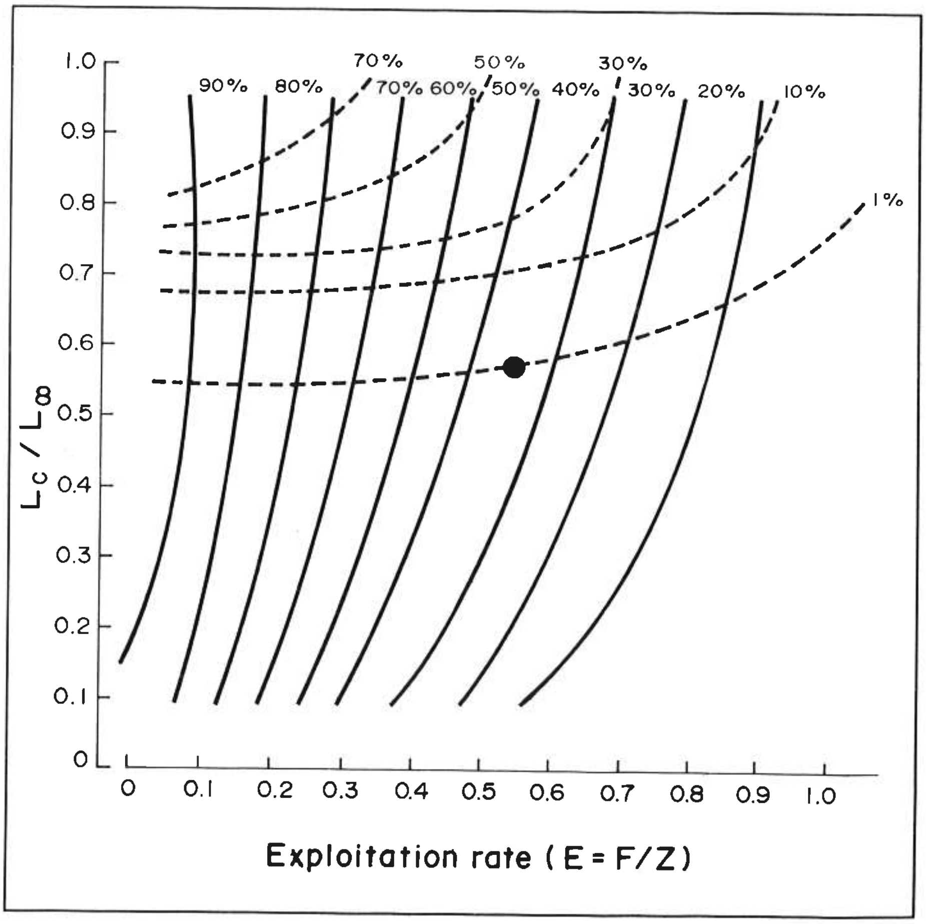

Fig. 3. Relation between B'/R (solid lines, %), B_m'/R (broken lines, %), size at entry to the fishery (mm TL and L_{50}/L_∞) and exploitation ratio (E) for *Metapenaeus affinis*.

Abu Talib and Taupek (in press) provided catch rates for important prawn species from surveys carried out over the last decade, covering the whole West Coast of Malaysia. Their data suggest that there may have been a greater decrease in catch rates of the larger species of prawn than of the smaller species: Table 1 shows that for *P. merguiensis* and *M. affinis*, which are larger than the other species fished, there may have been a decline in the catch rates from 1981 to 1988, while for *P. hardwickii* (one of the most abundant smaller species) no such trend can be seen; for *P. gracillima* (one of the smallest species), the catch rates even increased. Although the data are insufficient to allow a more rigorous test of this idea, it is possible that it is mainly the larger species which have been reduced by high exploitation rates and that these larger species may have been replaced by smaller species which mature at smaller sizes and are less vulnerable to the gear used. The low estimated B_m'/R obtained for the *M. affinis* and *P. merguiensis* stocks may be caused by recruitment overfishing, which reduced the

Table 1. Data on some Malaysian West Coast prawn stocks, relating mean catch rate (kg fresh whole prawn per hour's fishing) and date of the survey. Surveys were carried out on the Fisheries Research Institute's research vessel, KK Pelaling, using standardized fishing and analytical techniques (Abu Talib, in press).

Species	Catch rate 1981	1984	1987	1988	L_∞ (mm TL)
Penaeus merguiensis	0.187	0.075	0.131	0.060	168-208[a]
Metapenaeus affinis	0.186	0.024	0.144	0.129	145-162[b]
Parapenaeopsis hardwickii	0.798	0.185	1.016	0.776	122-148[c]
Penaeus gracillima	0.062	n.a.	0.055	0.262	104-138[c]

[a]For males and females, respectively.
[b]West Coast stock (after Taupek, in press; Alias and Mathews, in press).
[c]Sarawak stock (after Yong et al., in press).

spawning biomass. This is likely for *P. merguiensis*, a very large species now occurring in trawls with rates ranging from a few individuals to 20, rarely more, per one hour trawled.

Some Difficulties in Applying B_m'/R Analysis in Assessments

There are several reasons why B_m'/R is not often used in assessments:

1) Although it is easy to estimate B_m'/R, it has not been possible until recently to relate its specific value to any clear quantitative criterion of the state of the stock. While it may be possible to show that a stock will, under a proposed new regime, experience a sharp reduction in B'/R and in B_m'/R, it has generally not been possible to decide whether such a reduction is likely to reduce recruitment to the fishable population and therefore to reduce landings.

A skeptical manager would find it hard to accept conservative management recommendations, implying a significant economic impact (e.g., new closed seasons, new quotas) on the basis of evidence that B_m'/R will be reduced to any particular level, without strong evidence that this reduction will lead to a stock collapse;

2) Another reason why estimates of B_m'/R are rarely used in practical assessments is that biomass-per-recruit estimates assume implicitly that a stock recruitment curve for the stock studied does exist. Such relations are difficult to identify in practice with any precision and many, perhaps most, fisheries scientists are therefore reluctant to accept their existence in most stocks (especially for penaeids, at least until recently);

3) Where stock recruitment curves are thought to exist, scientists are often reluctant to use them because they usually display considerable noise. This is often related to environmental variation, which is difficult to predict and expensive to measure and model. Environmental variations are also difficult to distinguish in practice from sampling errors.

These difficulties all tend to turn attention away from B_m'/R analysis as a practical tool, although I think that the first difficulty has been the most serious one.

A Simple Criterion for Detecting Recruitment Overfishing

Goodyear (1989) addressed these problems and showed that there is a relation between the B_m'/R (as defined above) observed in a fished population and a critical level of B_m'/R which he showed was likely to be no less than 20% of the unfished B'/R. He defined the spawning potential ratio (SPR):

$$SPR = (SSBR_{fished}) \;/\; (SSBR_{unfished})$$

where SSBR is the spawning stock biomass per recruit and SPR is equal to B_m'/R as defined above.

For any level of SPR, Goodyear defined a compensation ratio, (CR), where "CR value of 100 means that in order for the population to persist at the corresponding level of fishing mortality, the mean survival probability of an average recruit must increase a hundredfold over the level existing in the unfished condition". Fig. 4 shows his estimate of the effects on CR of increasing F in a population of the seabass *Morone saxatilis*: very high CR values are needed for F = 0.4-0.8 $year^{-1}$. There will be an analogous relation for every exploited stock.

Fig. 5 shows the relation between a given level of SPR and the CR value required per unit change in SPR, in any exploited species. At a level of SPR = 0.2, a unit change in SPR requires a compensatory increase in

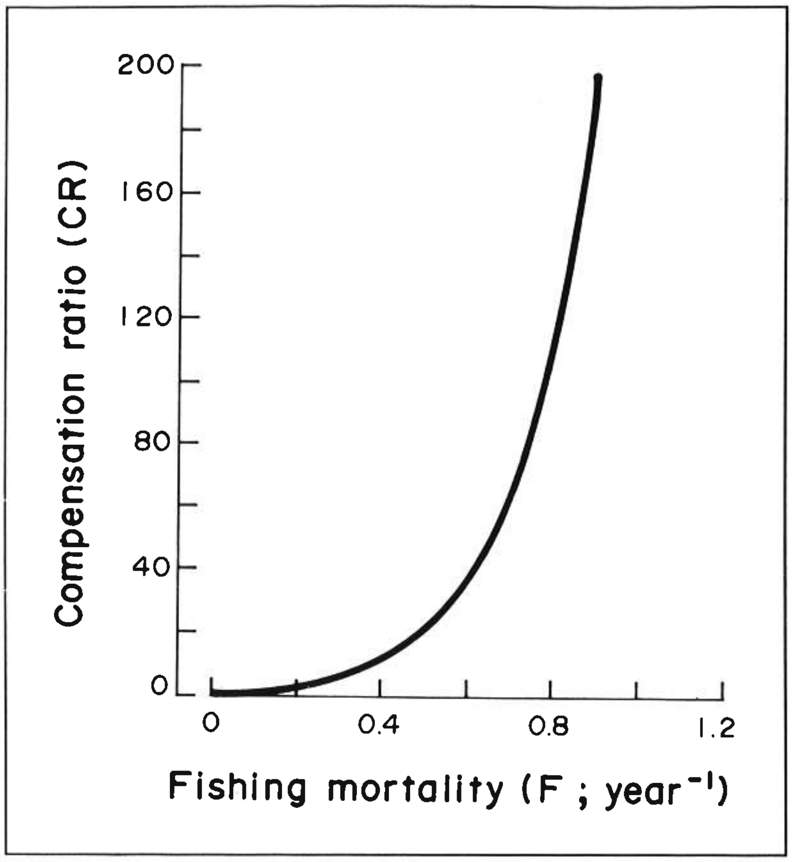

Fig. 4. Effect of fishing on the compensation that must occur for population persistence in striped bass (*Morone saxatilis*) as a function of fishing mortality (from Goodyear 1989).

survival from egg to recruitment of x25, compared to the value (x1) needed at SPR = 1.0. Goodyear suggested that "SPR should not be set below 0.2 without considerable justification, and 0.3 might be a more reasonable choice". Fig. 5 shows that the change in SPR needed to maintain a population increases markedly at about SPR = 0.20-0.30 (i.e., for values of B_m'/R = 2-3%).

Goodyear (1989) evaluated the reliability of the 20-30% level in B'_m/R based on data from several temperate demersal populations, and noted declines in recruitment at levels of B_m'/R < 20% (i.e., of SPR < 0.20).

Finally, he also showed that there is a relation between the slope at the origin of the stock recruitment curve and the relative change in SPR. He demonstrated, for 33 populations of fish with well-documented stock recruitment relationships, that likely values of the SPR needed for maintenance of recruitment were between 0.5 and 0.7 (B_m'/R = 50-70%). Therefore, the value of 0.2-0.3 may be lower than is needed to protect the spawning biomass per recruit of most fish populations. No similar analysis has been carried out for tropical fishes or for penaeids.

Discussion

Fisheries scientists who assume (explicitly or implicitly) that stock-recruitment relation

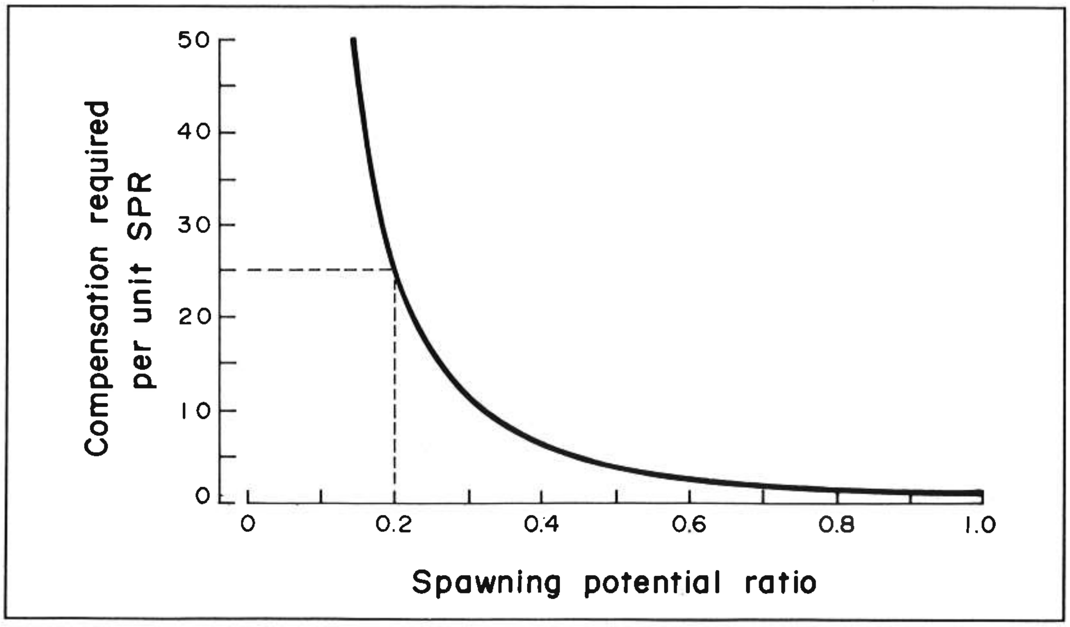

Fig. 5. Increase of compensation required for persistence as SPR declines. Ordinate values are ratios of the compensatory change in mortality required to offset a reduction in SPR relative to that required at SPR = 1.0 (from Goodyear 1989).

can be ignored may successfully manage their stocks over particular ranges of mortality, catch rates and population density. Nevertheless, erroneous assessments may be made if important density, mortality, recruitment and/or fecundity changes occur below some (unknown) threshold level. Indeed, it is often argued that the collapse of fisheries is usually caused by such decrease in spawning biomass. Practical difficulties in quantifying a stock recruitment relationship should therefore not cause scientists to assume that no relation exists.

The estimation of B_m'/R, together with the results of Goodyear (1989), may be combined to provide a provisional rule of thumb for assessing the possible effects of any proposed management measure on the reproductive capability a stock and of the fishery it supports (Table 2).

The criteria suggested in Table 2 need to be applied with caution; errors made in using the proposed criteria are likely to lead to insufficient protection. Moreover, if the criteria proposed in Table 2 are to be applied routinely, it is necessary for B_m'/R assessments to be carried out on a wide variety of penaeid and fish stocks and for assessments of this type to be compared with results of other types of assessments.

Assessments based on B_m'/R are easy to carry out but involve accurate determination of the relation between sexual maturation and body size (i.e., obtaining the information displayed in Fig. 2) for the stock studied.

The related technique applied by Le Guen (1971) in West Africa was based on estimating fecundity per recruit and was costly and laborious. The variant developed for Malaysian shrimp stocks is not expensive and will be most useful where timeliness is more important than accuracy; perhaps this will also lead to a more adequate set of criteria. I expect that appropriate modifications to Table 2 will then result.

Table 2. Mature biomass per recruit (B_m'/R) as an index of stock condition, and for determining the effects of proposed management measures for the fisheries.

A B_m'/R (% unfished B'/R) observed in the stock studied	B Likely effect on sexually mature stock	C Likely effect on landings	D Likely effect on catch rates
20-30%	Possible decrease	Possible reduction	Possible reduction
5-10%	Likely decrease reduction possible	Some reduction likely, substantial	Same as (C)
< 1-1%	High probability of decrease	High probability of a moderate decrease, substantial possibility of a large decrease	Same as (C)

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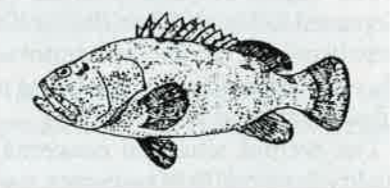

[a]Interested readers should contact Mr. Y.P. Lui, Fisheries Research Institute, 11700 Glugor, Penang, Malaysia, for details about this publication.