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# F Limit Reference Points about Preventing Recruitment Overfishing and its Uncertainty

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One of the purposes of reference points (RPs) is to track the state of the fishery relative to those reference points. To prevent recruitment of overfishing, fish stocks should be maintained sufficient spawning biomass to ensure continued high recruitment. Therefore, RPs should be defined to look explicitly at the recruitment process and can be used to set conservation limits for the fishery. These RPs were classed four types by FAO according to the ways to estimate them (Hoggarth et.al, 2006). Firstly, RPs are based on the plots of stock and recruitment (SR) data. Secondly, RPs can be estimated by stock-recruitment relationship (SRP). If there are SR data available, RPs can be based on the spawning stock biomass per recruitment or size of the fish harvest. The details of the four types RPs excerpted from Hoggarth et. al (2006) are as follow:

## RPs from a stock-recruitment plot

The standard SR plot shows the number of recruits that are produced in each year per unit weight of spawning stock biomass. Three lines draw through the point in the SR plot starting from the origin represents a constant ratio of the number of recruits produced per unit of spawning stock biomass (R/SSB). The fishing mortality F corresponding to any given R/SSB ratio can be read off a graph of SSB/R verse F (Fig. 1), and it can be estimated for any R/SSB line through the SR data points. The line cutting the SR plot so that 90 percent of the SR data points are above the line has been termed the $F_{low}$ reference point. The 90$^{th}$ percentile line and the 50$^{th}$ line are the $F_{high}$ and $F_{med}$ reference point respectively. $F_{med}$ can be used as limit reference point (LRP) for avoiding recruitment overfishing, as it an estimate of the fishing mortality that should allow for replacement of successive generations over the observed range of stock and recruitment data. Assuming that recruitment continues at the rates seen in the ST plot , any fishing mortality rate lower than $F_{med}$ should allow the stock size to increase while any F exceeding $F_{med}$ should result in a decline in the stock size. Fhigh has also been proposed as a LRP, but there is a clearly a much higher chance that the stock biomass will decline at this level of fishing.

A problem with the use of $F_{med}$ is that it will only be a reliable reference point if the SR data originate from a time of "good health" in the fishery, e.g. when the biomass has been fluctuating around $B_{MSY}$ levels. If the stock has already been fished down, the available SR data may only indicate the potential spawning available at small stock sizes. If the stock is already reduced below the "Minimum Biologically Acceptable Limit" threshold, the median or 50$^{th}$ percentile line of the data points will not be the true average "replacement" level of the overall stock-recruitment relationship. The use of may therefore be $F_{med}$ dangerously misleading for stocks that have been consistently over-exploited for the period covered by the SR data. Where SR data are available from a wider range of conditions in the fishery, these reference points are potentially less biased and more useful.

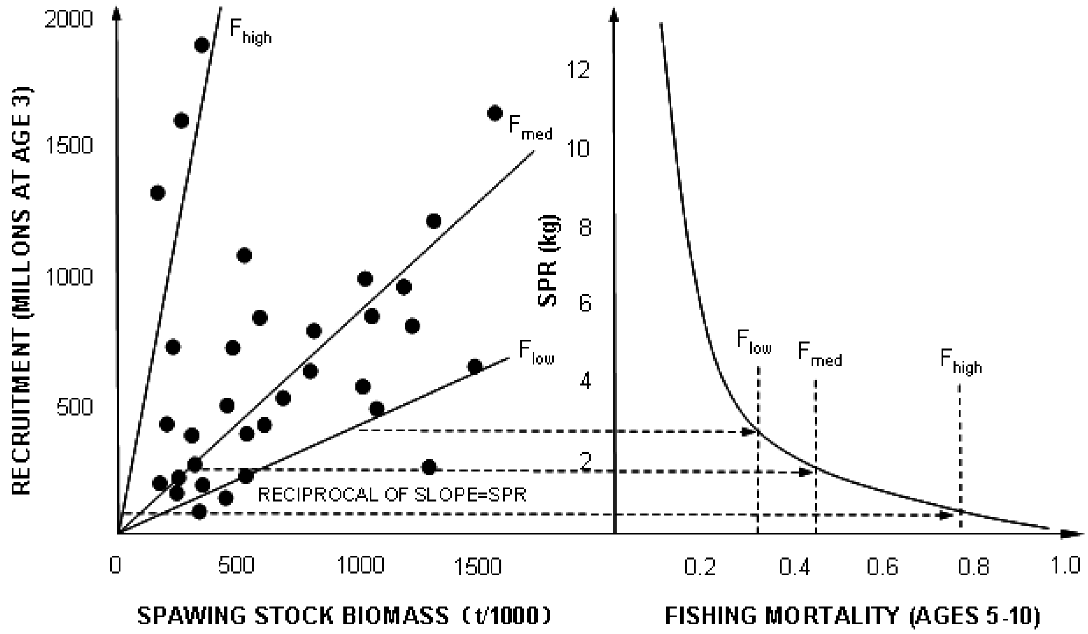


Fig. 1 illustration of the methodology for estimating $F_{low}$, $F_{med}$ and $F_{high}$ by combining SR data with a pre-recruit model (Caddy and Mathon, 1995).

**Reference points from a fitted stock-recruitment relationship (SRR)**

Where SR data plots can be reasonably fitted by stock recruit relationships such as the Beverton-Holt or Ricker, reference points can be calculated from the parameters of the SRR. Where the dome-shaped Richer SRR provides the best fit, an obvious reference point is the spawning stock biomass at which recruitment is highest. This is not appropriate for the Beverton-Holt SRR, however, as its asymptotic form means that the maximum recruitment will be obtained at an infinite biomass.

ICES (2000) used $F_{crash}$ as an extreme LRP for fishing mortality. $F_{crash}$ is the point on an equilibrium yield curve at which both the biomass and the catches are reduced to zero and the stock becomes extinct. This point may be derived either from a biomass dynamic production model or an analytical one. It must clearly be interpreted as an extreme LRP to be avoided by strong precautionary thresholds. Fishing at mortality rate beyond $F_{crash}$ should be expected to leas quickly to extinction of the stock.

**"SRR" Reference points from per recruit models without a SRR**

Where no SR data are available, proxy points for conserving the spawning stock can also be estimated using per recruit models. In this case, standard YPR model is extended to include maturity and fecundity at age or size. This enables the spawning stock biomass per recruit (SSBPR) or more generally the spawning (products) per recruit (SPR) to be estimated at different levels of fishing mortality. Spawning "products" may thus be the biomass of mature fish, the egg production. Such an approach works without the need for SR data or a SRR, and instead proposes to set fishing mortality at a level where the SPR will only be reduced to levels commonly found to be sustainable. Such levels are usually estimated as a percentage of the SPR that would occur in an unfished stock (i.e. with natural mortality, M, but no fishing mortality, F). This indicator, known as the %SPR, always decreases monotonically as fishing mortality increases. With no fishing mortality, 100 percent of a stock's spawning potential is achieved. As F increases, SPR is reduced. The fishing mortality $F_{\%SPR}$ corresponding to any level of %SPR can thus read off the curve or calculated analytically.

The advantage of %SPR reference points is that they do not require a time series of spawning stock sizes and related recruitment data, that can be hard to collect. Where SR data are unavailable and the level of F corresponding to MBAL or $F_{crash}$ ect is unknown, safe values of $F_{\%SPR}$ are instead sought that can be used as proxies. The key question in using %SPR is to decide exactly what percentage reduction in SPR should be allowed in setting a "safe" reference point that will prevent recruitment overfishing. 20-30percent SPR are now commonly used.

Care must clearly be taken over which reference points are selected and for what purpose. The relative proximity of the yield-based and spawning capacity-based reference points is not always clear cut. As should be expected, lower SPR reference points are recommended as proxies for $F_{MSY}$ (i.e. the F that reduces SPR to 30-40 percent of its unexploited level) than for those limit reference points aimed at avoiding recruitment overfishing (20-30 percent SPR). The more extreme spawning capacity reference points such as $F_{crash}$ will also always be above $F_{MSY}$. The fact that $F_{\%SPR}$ reference points in the range 20-30 percent will usually instead be below $F_{max}$ and may also be below $F_{0.1}$, emphasizes the problem with using per recruit models to develop yield-based reference points.

**Size-based reference points**

Where no SR data are available, nor any data for SPR analyses, some protection may still be given to the spawning capacity by the use of size limits. Possible precautionary approaches could be to set size limits to ensure that no (or few) immature fish are caught in the fishery, or to ensure that the average size of fish caught is equal to, or greater than, the average size at maturity. Limit reference points in these cases could either be set as minimum size limits, or as the mean size of fish in the catch. In the latter case, at least 50 percent of individuals should have an opportunity to reproduce at least once. The mean size of fish in the catch will of course depend both on the size limit used and the fishing rate on the stock. If fishing rates increase, it may be necessary to further increase the minimum legal size limit to maintain the stock of mature fish.

Such simple size-based reference points can be useful where full age-based stock assessments are difficult (e.g. for invertebrates or fish species which can not be aged) or where fisheries are not large enough to justify the data needs of the more intensive stock assessments.

**Evaluates uncertainty in the LRP related to fishing mortality**

The status of a fish stock is assessed usually by comparing an estimated current fishing mortality rate $F_{cur}$ with a deterministically estimated LRP related to fishing mortality, e.g. $F_{carsh}$, $F_{20\text{-}30\%SPR}$. There is always uncertainty in both the estimates of $F_{cur}$ and LRP, therefore, lack of consideration of the uncertainty in LRP in the assessment may yield erroneous conclusions about the status of fish stocks. Uncertainty in $F_{cur}$ and $F_{carsh}$ or $F_{20\text{-}30\%SPR}$ can be expressed by using the empirical distributions of these quantities generated from the Monte Carlo simulation.

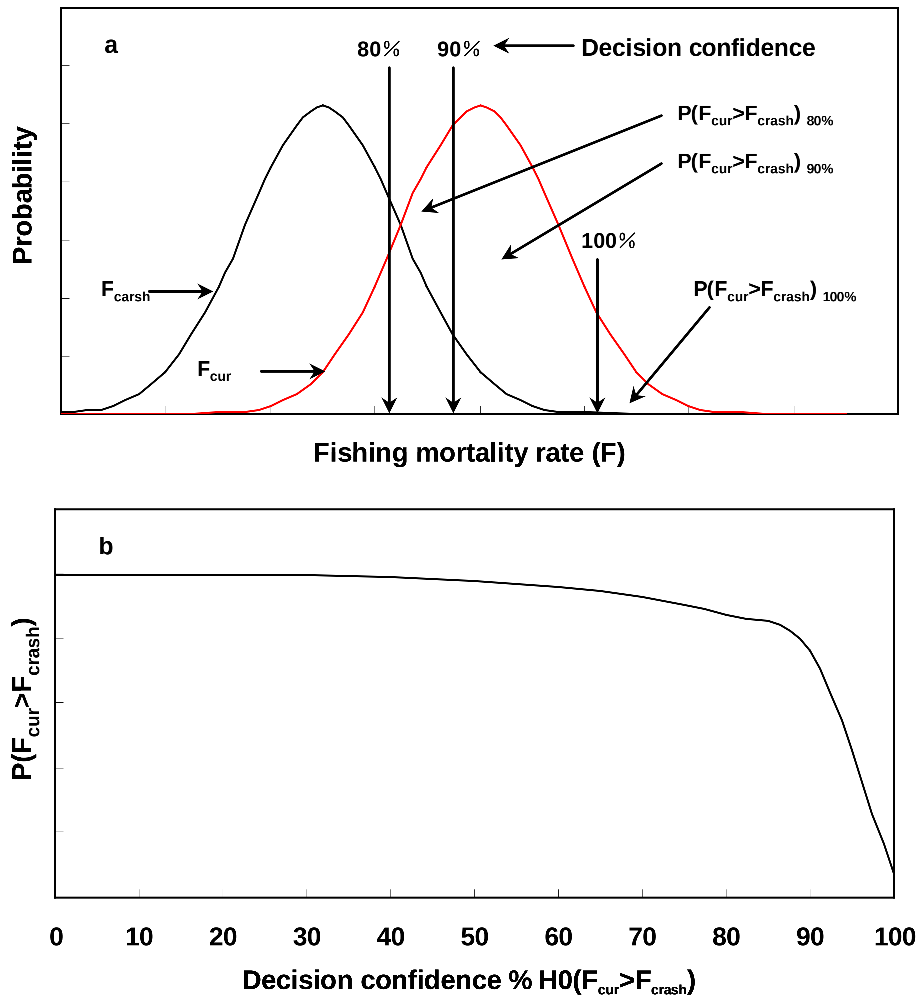


Fig. 2. The stochastic decision-making framework for assessing status of fish stocks.

a. Probability distribution function (PDF) for the current fishing mortality rate ($F_{cur}$) and biological reference point defining overfishing (e.g. $F_{crash}$). X% indicates decision confidence and equals the area under the $F_{crash}$ PDF on the left side of the X% vertical line. P($F_{cur}$ > $F_{crash}$)x% equals the area under the $F_{cur}$ PDF on the right side of the X% vertical line.

b. Probability profile specifying the P($F_{cur}$ > $F_{crash}$) for different levels of decision confidence.

Helser et al. (2001) developed an approach, stochastic decision-making framework, to make a probabilistic statement as to whether $F_{cur}$ > $F_{crash}$. The probabilistic statement specifies the conditional P($F_{cur}$ > $F_{crash}$) for a given decision confidence (%) calculated from the empirical distribution of $F_{crash}$ (Fig. 2). The decision confidence level can be thought of as a one-tailed α probability from standard statistical hypothesis testing (Helser et al. 2001). Thus, at the value of F along the domain of the x axis where the α = 90% (10% of the area under the $F_{crash}$ probability distribution function (PDF) on the right side of the F), the corresponding area under the $F_{cur}$ PDF gives the P($F_{cur}$ > $F_{crash}$). For each decision confidence level there is a corresponding P($F_{cur}$ > $F_{crash}$) that forms a probability profile (Helser et al. 2001). A low level of confidence might make the conclusion less trusted, whereas a high level of confidence might lead to an over-optimistic estimate of the current status of a fish stock (i.e., $F_{cur}$ compared with a higher value in the $F_{crash}$ probability distribution, making the fishery less likely to be defined as overfished). Choices of confidence level were, consequently, related to attitude towards risk (Chen and Wilson, 2002).

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