REVIEW OF F35% AND F40% AS MSY PROXIES FOR WEST COAST GROUNDFISH

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Summary

During the course of this review the stock assessments of a number of Pacific west coast species were considered. For rockfish in particular, most stocks show continuous declines which is indicative of excessive fishing mortality. Examination of the stock-recruitment data for some of these rockfish species, notably widow, yellowtail and bocaccio indicates the additional mortality due fishing which these stocks can withstand is small because the zero fishing replacement line lies close the observed stock-recruit data. An equilibrium analysis was performed on three stocks for which sufficient data were available. These were widow rockfish, bocaccio and Dover sole. In the case of the two rockfish this analysis suggests that the maximum sustainable fishing rates are substantially below the F40% MSY proxy. For these two species at least, this proxy does not seem to be appropriate. Given similar stock trends and biology in other rockfish, it is very likely that the F40% proxy is also inappropriate for these species.

For Dover sole the analysis in inconclusive because the range of observed stock sizes is too limited. There are no compelling reasons to abandon the F35% proxy at present, particularly as recruitment does not yet show any sign of decline with lower spawning biomass. Existing harvesting rates would be expected to result in smaller stock sizes which will provide more insight into the stock recruitment relationship in the future. This may assist in the evaluation of harvesting strategies. However, because further stock decline is expected, the harvest rate policy should be kept under review.

In re-appraising the harvest policy for west coast groundfish there is a need to take into account, not only the stock-recruit information but also environmental effects and biological interactions between species. The final choice of harvest control rules should be evaluated in simulation studies.

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1. Introduction

In simple terms the present harvest policy is to fish the Pacific groundfish stocks close to Maximum Sustainable Yield (MSY). Not only is this encompassed in legislation but it is often believed to be a low risk harvesting strategy. It is not appropriate in this report to discuss the merits or otherwise of an MSY harvesting strategy except to note that adopting MSY target values or their proxies in management does not guarantee the "S" in MSY. In many ways this is at the heart of the problem with the Pacific groundfish stocks. Since the single criterion all stakeholders can agree on is that stocks should not collapse under fishing, it is important to establish that any harvesting strategy, at a minimum, satisfies such a constraint. The present approach of using spawner per recruit (SPR) proxies for MSY targets may well not satisfy this condition for some of the groundfish stocks, particularly the rockfish.

2. Harvesting policy

The present harvest control rule (HCR) used by the Pacific Management Council is described in a working document (MacCall, 1999a). It requires three inputs from stock assessments. These are virgin spawning biomass, B_0, current spawning biomass, B_t, and an exploitation rate function, $E(B_t)$, which maps B_t to catch at $F_{40\%}$ (or $F_{35\%}$ in some species). The quantity $F_{40\%}$ is the fishing mortality which gives an SPR of 40% of the unfished stock. The optimal yield, C_{oy}, can then be calculated from:

$$C_{oy}=E(B_t) \qquad \text{for } B_t>0.4B_0$$
$$C_{oy}=E(B_t)*1.33-0.133B_0/B_t \qquad \text{for } 0.1B_0<B_t<0.4B_0$$
$$C_{oy}=0 \qquad \text{for } B_t<0.1B_0$$

This rule basically gives a constant harvest rate above $0.4B_0$ but progressively reduces catch to zero as the biomass declines from $0.4B_0$ to $0.1\ B_0$.

The performance of such an HCR will of course depend, *inter alia*, on whether the critical values, F40% and $0.4B_0$ are appropriate. The reduction in harvest rate as the biomass reaches $0.1B_0$ will tend to protect at least some residual spawning potential. However, it remains to be determined whether a stock reduced to this level is actually capable of recovery even in the absence of fishing. Furthermore, since most stocks have not yet reached this level, it carries with it the implication that there is an acceptable risk associated with fishing the stock below historically observed values.

In addition to the purely biological risks of non-recovery at low biomass, the operation of the rule is vulnerable to estimation error. For example, if the stock is measured to be at $0.4B_0$, given the uncertainties in the assessment, what is the probability that the biomass is actually at $0.1B_0$? This problem is non-trivial if recruitment failure were to occur at such low biomasses and yet the fishery would remain at its maximum permitted rate.

The choice of biomass thresholds may be less critical if the adopted harvesting rate tends to drive the population toward a higher equilibrium value. If, however, the choice of harvesting rate is such that the stock is inevitably driven toward low biomass thresholds, then not only is the choice of threshold critical, but management will be characterized by the frequent need to implement stock rebuilding strategies or even fishery closures. This appears to be one of the problems with present harvest rate targets. Clearly this is undesirable. At present the choice of harvesting rate is based on simulation studies by Clark (1991) who concluded that a harvest rate corresponding to 35% of maximum SPR would tend to result in stock biomasses in the range 20-60% of B_0. Biomass values in this range often approximate to B_{MSY} and hence might be considered safe. It would be dangerous to conclude that Clark's findings hold universally. His study is useful in identifying a probable proxy for MSY in the absence of other data but it is important to seek case specific validation before having confidence in its suitability. The biological characteristics of many of the groundfish species, especially rockfish, which show low growth rates, a late age of maturity and prolonged periods of low recruitment makes them particularly vulnerable to an inappropriate choice of harvest rate.

The Clark study is based in a particular model which assumes all the population density dependent processes can be modelled in the stock-recruitment relationship. All other biological parameters, such as growth, age at maturity, natural mortality *etc* are assumed to be fixed. This means virgin biomass is calculated as the intersection of a linear replacement line with the stock recruitment curve. This is a common assumption but it is noteworthy that estimates of virgin biomass made in this way can be unrealistically high. It implies that replacement lines may not be linear but curve upward at high stock biomass, consistent with density dependent changes such as reduced growth rate, higher natural mortality and delayed maturity. Thus the generality of Clark's conclusions may be compromised depending on whether the biological information on growth, maturity *etc* was collected at or sometime after the unfished state. A particular problem would arise if the growth, maturity *etc* schedules are measured at low biomass but virgin biomass is obtained from direct observation. This would mean B_0 is inconsistent with the SPR data.

3. Stock Assessments

The most recent assessments of those stocks where sufficient data exist to estimate stock trends and fishing mortalities were briefly reviewed. These included, Dover sole (Brodziak *et al* 1997), Bocaccio rockfish (Ralston et al, 1996), Canary rockfish (Sampson,1996), lingcod (Jagielo *et al*, 1997), Yellowtail rockfish (Tagart *et al* 1997), chilipepper rockfish (Ralston *et al*, 1998), widow rockfish (Ralston and Pearson, 1997), Pacific ocean perch (Ianelli and Zimmerman, 1997) and sablefish (Methot *et al*, 1998). Many of these assessments make use of stock synthesis software (Methot, 1990) which is a well established maximum likelihood modelling approach used in the region. More recent assessments make use of Bayesian methodology, an increasingly popular approach to fish stock assessments, particularly where substantial uncertainties exist in the biological information available. There is no doubt that these assessments are among the best conducted anywhere in the world at present in terms of analytical methods, though the quantity and, perhaps quality, of data could usefully be improved. Particularly important is the need for fishery independent data collected in a consistent and enduring fashion. Without such information there is a danger that assessments may be misleading due to the inevitable and characteristic biases to which commercial catch and effort data are prone.

Notwithstanding the qualifications above there is no reason to believe that the assessments provide anything but the best available insight into the true status of the stocks. For the great majority of the species examined, the long term stock trends are downward (Ralston 1998) and even allowing for uncertainties, it is unlikely any other interpretation is possible given the data. This indicates that for many years, removals by the fishery have not been made good by incoming recruitment or somatic growth, showing that the fishery is living beyond its means. One may interpret such a decline either as fishery induced or environmentally driven, or a combination of both. It is sometimes argued that stock declines are environmentally driven and that therefore the fishery need not be scaled down. Unfortunately, if the environment really is the driving force then there is more reason to scale down the fishery because under adverse environmental conditions the sustainable rate of fishing will be lower, even if the fishery is not the cause of the decline.

The present approach to assessments is very technical and most assessment reports dwell on the quality of input data, the goodness of model fit and model performance. While these are essential elements of the assessment, too often glossed over by many practitioners, there is a danger of forgetting that there is a need for readily accessible summary information which not only succinctly characterizes stock status but which also illustrates the likely consequences certain management choices and harvest strategies. This information tends to be minimal in present documentation and there is little directed analysis to support, or otherwise evaluate, the present, harvest control rules. This should form a routine part of the assessments and is absolutely essential given the present poor status of the stocks. The scarcity of this information in reports and the problems of accessing the data quickly made it difficult to perform analysis on more that a few stocks in this review.

4. Stock and recruitment in relation to sustainability

Spawner per recruit analyses explicitly exclude the relationship between stock size and recruitment and therefore do not encompass the full dynamics of a population. It means that sustainability reference values derived from such analyses should be treated with caution.

Well established population dynamics theory dating back to Beverton and Holt (1957) suggests that the ability of a population to withstand exploitation depends on the shape of the stock-recruitment curve. In particular, the greater the curvature of the relationship as it approaches the origin, the more resilient the population is likely to be to exploitation. The converse of this, is that stock recruitment relationships which are close to linear, especially at lower stock sizes, pre-dispose stocks to precipitous decline when a critical value of fishing mortality is reached. Analyses by MacCall (1999a , 1999b and pers comm) for widow rockfish, yellowtail rockfish and sablefish based on the NMFS assessments all give evidence that the underlying stock-recruitment relationship is close to linear suggesting that these stocks will not be resilient to exploitation.

MacCall's analyses also show the replacement line for F=0 (ie no fishing). For stocks to be exploitable, this line needs to lie below most of the observed recruitment values. The zero F replacement line, in fact, lies very close to the median line drawn through the data (equivalent to F_{med}) which would indicate that the additional mortality due to fishing that these stocks can withstand is very small. The shape of the stock-recruitment curve and the proximity of the zero F replacement line to the data both suggest considerable care is necessary in the choice of harvest rate.

5. Natural mortality (M)

Calculating F_{msy} or its proxies is crucially dependent on the value of natural mortality. The Pacific groundfish assessments are all inclined to handle natural mortality in different ways. In some assessments it is estimated as part of the model fitting procedure, while in others it is a given constant. Moreover, in some cases successive assessments of the same species have changed the assumed value of M. While there may be sound biological reasons for modifying the value used on the basis of new information, regular changes in the assumption can play havoc with the implementation of a harvest control rule based on MSY principles because the reference values will change each time the assessment changes. This highlights the need to ensure that the assessment procedure is appropriate for a given HCR. It does not follow that the "best" assessment, however well performed, is the best assessment for the HCR in operation.

The estimation of M has always been problematic, whether it is done externally to the assessment or not. Some of the Pacific groundfish data appear to have enough information in them to be able to estimate M within the stock assessment. There are dangers doing this, however. Estimates of M will be correlated with estimates of F and survey catchability if these are also calculated as part of the model fitting exercise. It means that bias in the data can translate to biasses in the wrong parameters. For example, if total catch data are biassed due to systematic recording errors or poor discard estimates, the "unaccounted fishing" mortality may appear as an inflated estimate of M from the model. This will then influence the calculation of F40% *etc*. There is, of course, no simple solution to this problem, but once again, it highlights the importance of choosing an assessment procedure which is robust enough to cope with the demands of the HCR. Some thought should be given to the handling of M in assessments to ensure that it is appropriate for use in HCRs based on MSY principles

6. Case studies

The foregoing discussion outlines in general terms some of the issues relating to sustainability, the problems of estimation and reasons why the F40% proxy may not be suitable for some west coast species. This section looks at three specific examples to evaluate the appropriateness of the proxies presently in use. The starting point for the analysis below is the assumption that the most recent NMFS assessments are the best available interpretations of the data and stock status. This is because these have all passed through a review process and are the currently accepted assessments. Using estimates of stock size, fishing mortality rate and biological parameters derived from these assessments analyses were performed to investigate ranges of sustainable fishing mortality rates. The data were compiled from highly detailed model outputs from the assessments and had to be summarized in a suitable form at short notice for the review. As yet the robustness of the approximations made has not been tested, though it is believed the input values used for widow and Dover sole are satisfactory. The results of the analyses are described below.

Example 1: Widow Rockfish

Present NMFS assessments concentrate on estimating recent stock size from which a short term stock projection is made. While projections beyond a few years are inevitably speculative they do offer a means of exploring possible future outcomes based on our best understanding of the relevant stock dynamics. Two analyses are presented here. One medium term analysis examines likely stock trajectories over a ten year period while the other attempts to estimate expected equilibrium spawning stock values under different rates of fishing. Both these analyses require a model of stock and recruitment. Data for the analyses were taken from the most recent Widow assessment (Ralston and Pearson, 1997) and provided by Tiburon Laboratory staff.

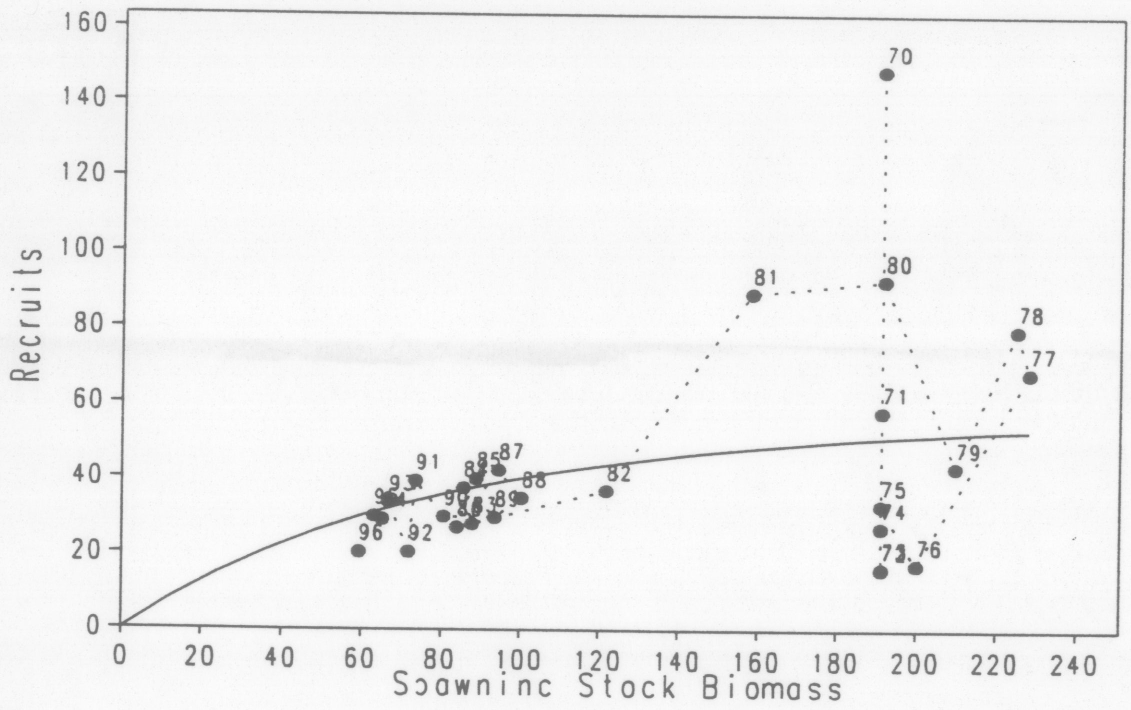

Figure 2. Widow Rockfish. Fitted stock recruit curve used in medium term projections.

Medium term analysis

Recruitment was modelled by fitting a Shepherd curve to the estimated stock and recruitment data from the stock assessment. Uncertainty in future recruitment was simulated by bootstrapping the residuals around the fitted stock-recruit curve. The stock size estimated for 1997 (Ralston and Pearson, 1997) was projected forward at a range of fishing mortalities. The initial stock size was assumed to have a CV of 20% and each realisation picked stock sizes from a lognormal distribution with this standard deviation. Figure 2 shows the results plotted as a contour diagram of the probability that spawning biomass is less than the 1997 value for different combinations of fishing mortality and year. The results illustrate that:

a) at present fishing mortality the stock is almost certain to decline further,
b) a reduction in fishing mortality of about 50% is required to stabilise the stock,
c) the rate of recovery is slow even with substantial reductions in fishing mortality and
d) the F40% target (F=0.153, relative F of 0.86 in Fig 2) will result in further stock decline.

These results hold even if the extrapolation of the stock recruitment curve beyond the range of observations is unrealistic.

Equilibrium analysis

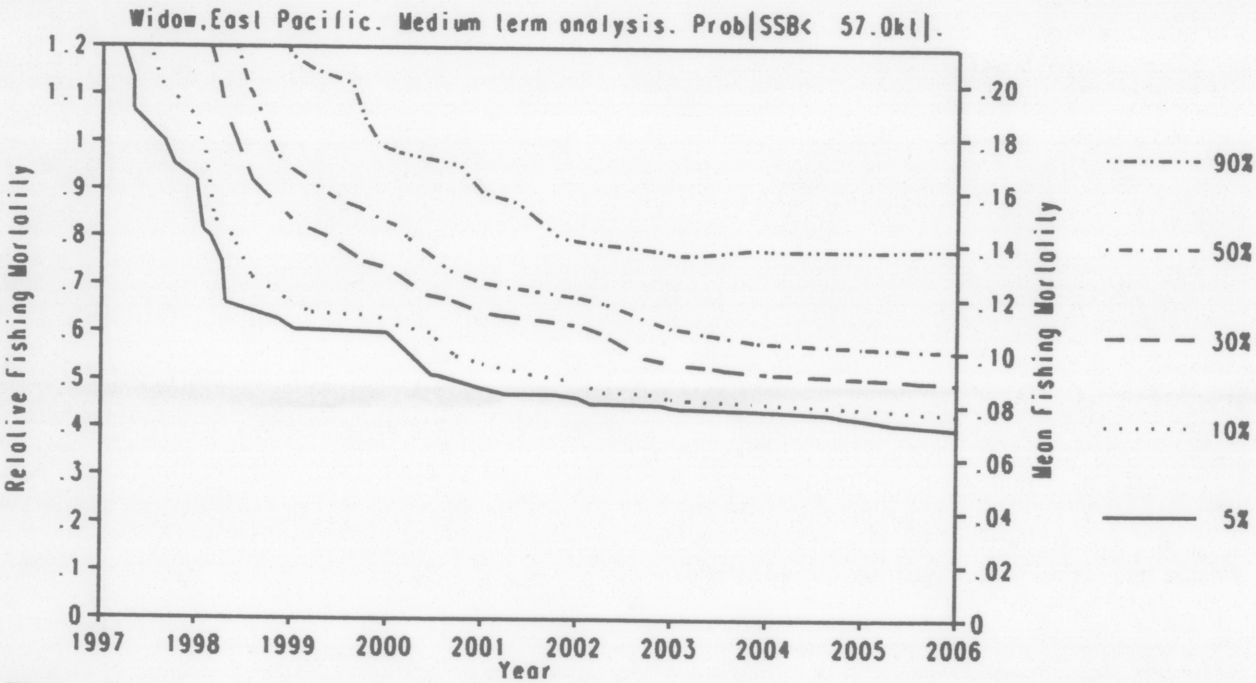

Figure 2. Widow rockfish. Results of medium term analysis. The contours show the probability that spawning biomass will be less than the 1997 value for combinations of year and fishing mortality rate.

Given the stock and recruitment data it is fairly straight-forward to calculate equilibrium yield and spawning biomass from the SPR curve. All that is necessary is to model the stock-recruit relationship. The methodology followed here is taken from Cook (1998) and involves drawing a non parametric curve through the stock-recruit data. The particular method used is a LOWESS smoothing procedure. This line, as with any function, can be used to read off expected recruitment for any spawning biomass. In order to calculate the fishing mortality associated with any equilibrium spawning biomass the following procedure is followed:

1) choose a spawning biomass, S
2) from the stock-recruit curve determine the expected recruitment, R, at S,
3) calculate the ratio S/R
4) from a conventional Pella-Tomlinson per recuit analysis determine the value of F which gives

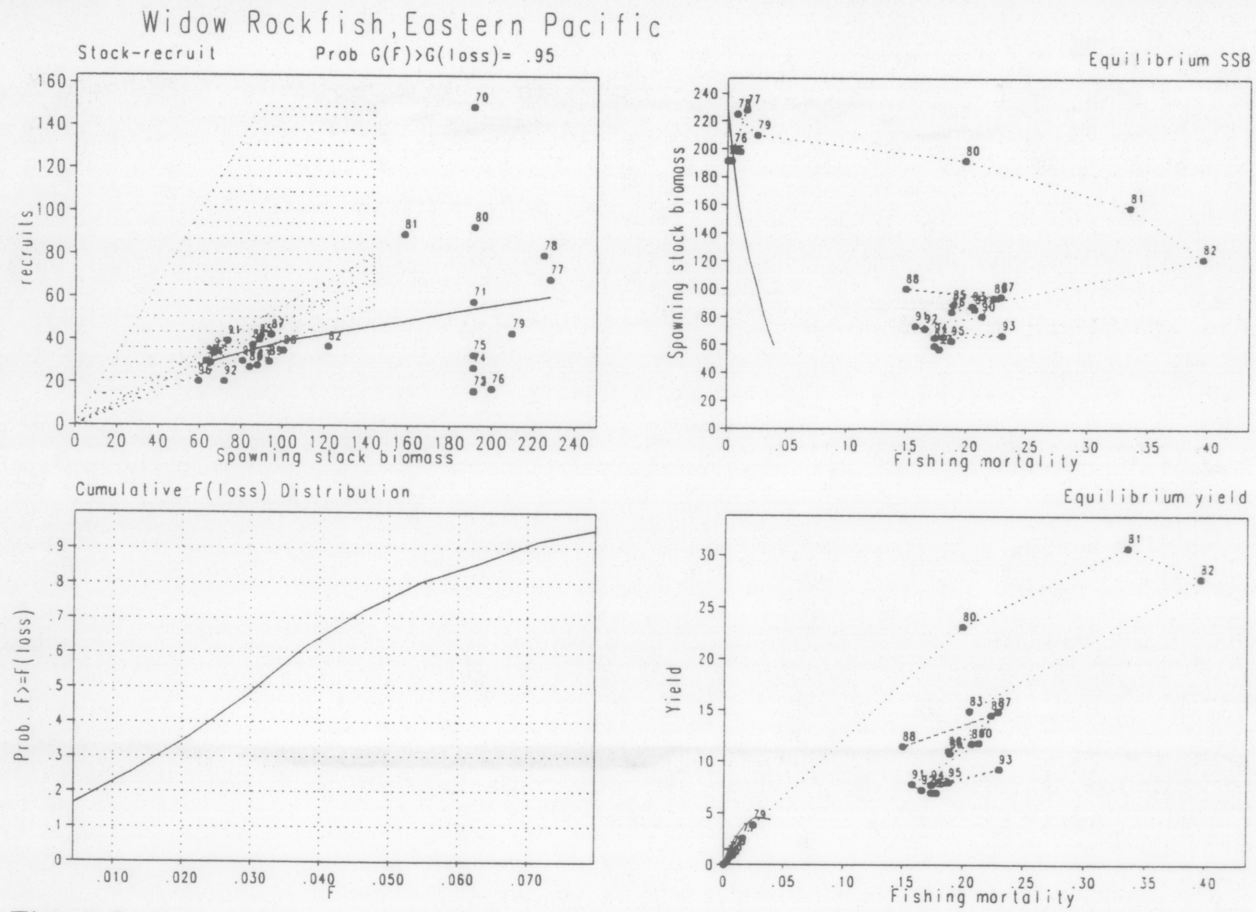

Figure 3. Widow rockfish.Top Left: Stock-recruit data with smoothed LOWESS curve. The vertically hatched area is the region in which the replacement line corresponding to the lowest observed spawning biomass lies. The horizontally hatched area is the region in which the replacement line corresponding to the most recently estimated fishing mortality lies (F=0.178). Top Right: Solid line shows the expected equilibrium for spawning biomass under different levels of fishing mortality. Observed annual data are indicated by years and joined as a times series by a dotted line. Lower Right: As top right by for yield. Lower Left: Cumulative probability distribution showing the probability that any given fishing mortality lies above the replacement line giving an equilibrium biomass at the lowest observed value.

the same S/R ratio, given schedules of natural mortality, weight at age, maturity and fishing selectivity.

The above recipe gives the fishing mortality rate which results in an equilibrium biomass S. A similar calculation can be done for yield.

In addition to the calculation of equilibrium yield, the analysis was extended to calculate replacement lines corresponding to the most recent fishing mortality rate and the fishing mortality rate which gives an expected equilibrium at the lowest observed spawning biomass (F_{loss}). This calculation can identify whether the present exploitation rate will lead to further stock decline.

Figure 3 shows the results of the analysis. The equilibrium spawning biomass (solid line, top right panel) is expected to decline rapidly as fishing mortality rate increases. The fishing mortality corresponding to the lowest observed biomass is approximately 0.04 (vertical hatched area in the stock-recruit plot in Fig. 3, upper left panel) whereas the present rate is about 0.18 (horizontal hatched area in Fig 3.). This indicates that present exploitation rates would be expected to result in significant further stock decline into unknown stock dynamics. The equilibrium plots also show the annual observed data. These lie to the extreme right of the equilibrium curve which indicate that the stock has been fished a long way from the expected equilibrium. It means that historical catches have been maintained by exploiting standing biomass which accumulated before the fishery began. Or to put it another way the resource is being mined and would be expected to collapse at present rates of exploitation.

The present estimate of the F40% criterion is approximately 0.15. Clearly, if the stock recruit data are close to reality then this exploitation rate is not sustainable. The equilibrium analysis would suggest a fishing mortality of 0.04 is an absolute maximum for the sustainable exploitation of the resource. The equilibrium yield curve (Fig. 3) also shows the expected yield and observed yield. This plot shows that the maximum sustainable yield is close to 5000t and that catches in excess of this value are not sustainable.

As robustness check, the analysis was repeated using the results of assessments run for different values of M and performing the analysis with alternative stock-recruit curves. These investigations did not alter the overall conclusions.

Example 2: Bocaccio

The equilibrium analysis performed on widow rockfish was applied also to bocaccio, a resource which appears to be all but collapsed. Figure 4 shows the results of the analysis. For this stock the fishing mortality rate associated with collapse is close to 0.1, substantially less than the fishing mortality rate operating over most of the period of the fishery. The observed sequence of stock sizes in Figure 4 lie well above and to the right of the equilibrium curve showing that the fishery has removed standing biomass rather than surplus production and is the cause of the stock collapse. At the most recently estimated fishing mortality rates the stock would not be expected to recover.

The estimate of F40% for this stock is approximately 0.18 which is nearly double the maximum fishing mortality rate which this stock can withstand. It indicates that F40% is not a good proxy for MSY.

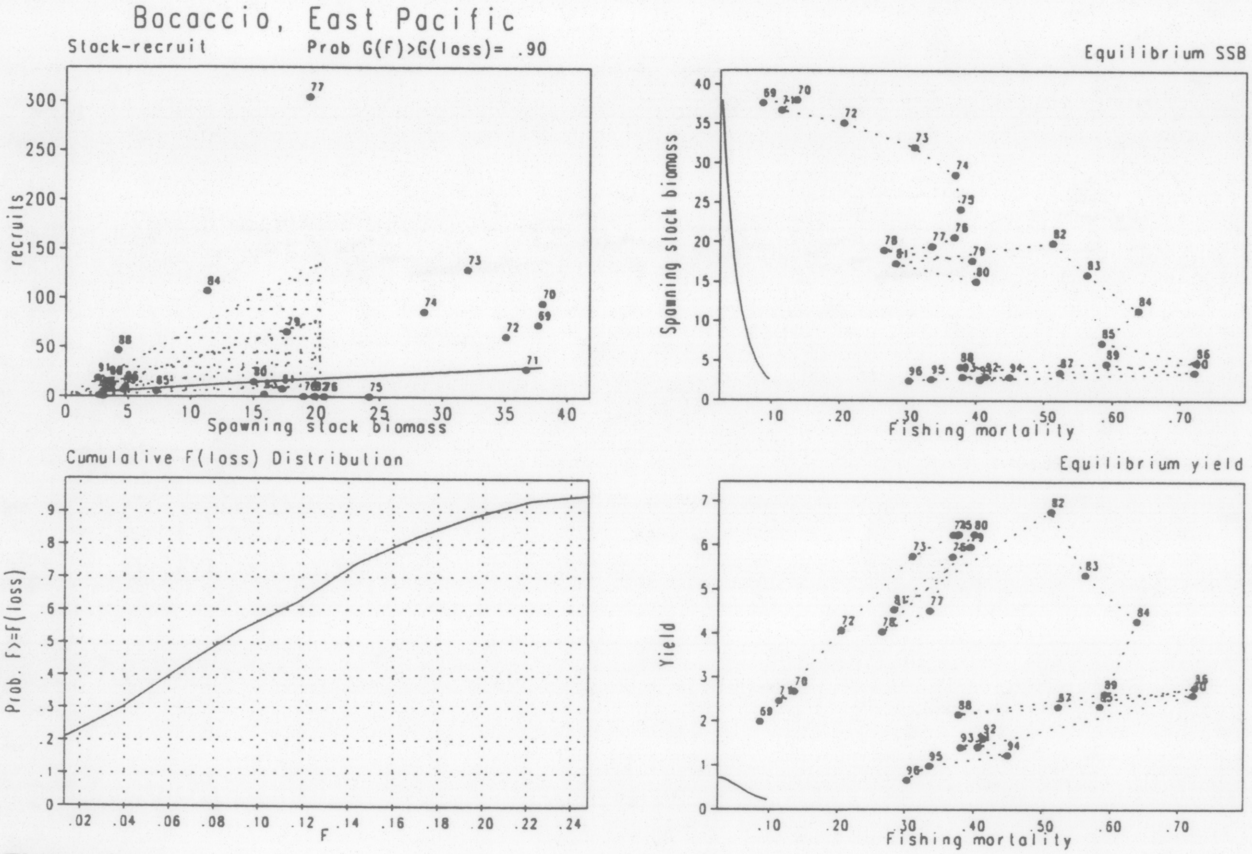

Figure 4 Bocaccio.Top Left: Stock-recruit data with smoothed LOWESS curve. The vertically hatched area is the region in which the replacement line corresponding to the lowest observed spawning biomass lies. The horizontally hatched area is the region in which the replacement line corresponding to the most recently estimated fishing mortality lies (F=0.30). Top Right: Solid line shows the expected equilibrium for spawning biomass under different levels of fishing mortality. Observed annual data are indicated by years and joined as a times series by a dotted line. Lower Right: As top right by for yield. Lower Left: Cumulative probability distribution showing the probability that any given fishing mortality lies above the replacement line giving an equilibrium biomass at the lowest observed value.

Example 3: Dover sole

The biology of Dover sole is very different to that of the two previous rockfish examples. For comparison the same equilibrium analysis was applied to this species. The result is shown in Figure 5. For this species only a limited range of stock size has been observed and over this range there is a tendency for recruitment to increase as stock biomass is reduced. Given the limited range of stock-recruitment data it is not possible to construct very meaningful equilibrium biomass and yield curves. The analysis does show, however, that at present rates of fishing the stock is expected to decline below is lowest observed value. This is because the present replacement line (horizontal hatching) lies above the replacement line for the lowest observed spawning biomass (vertical hatching).

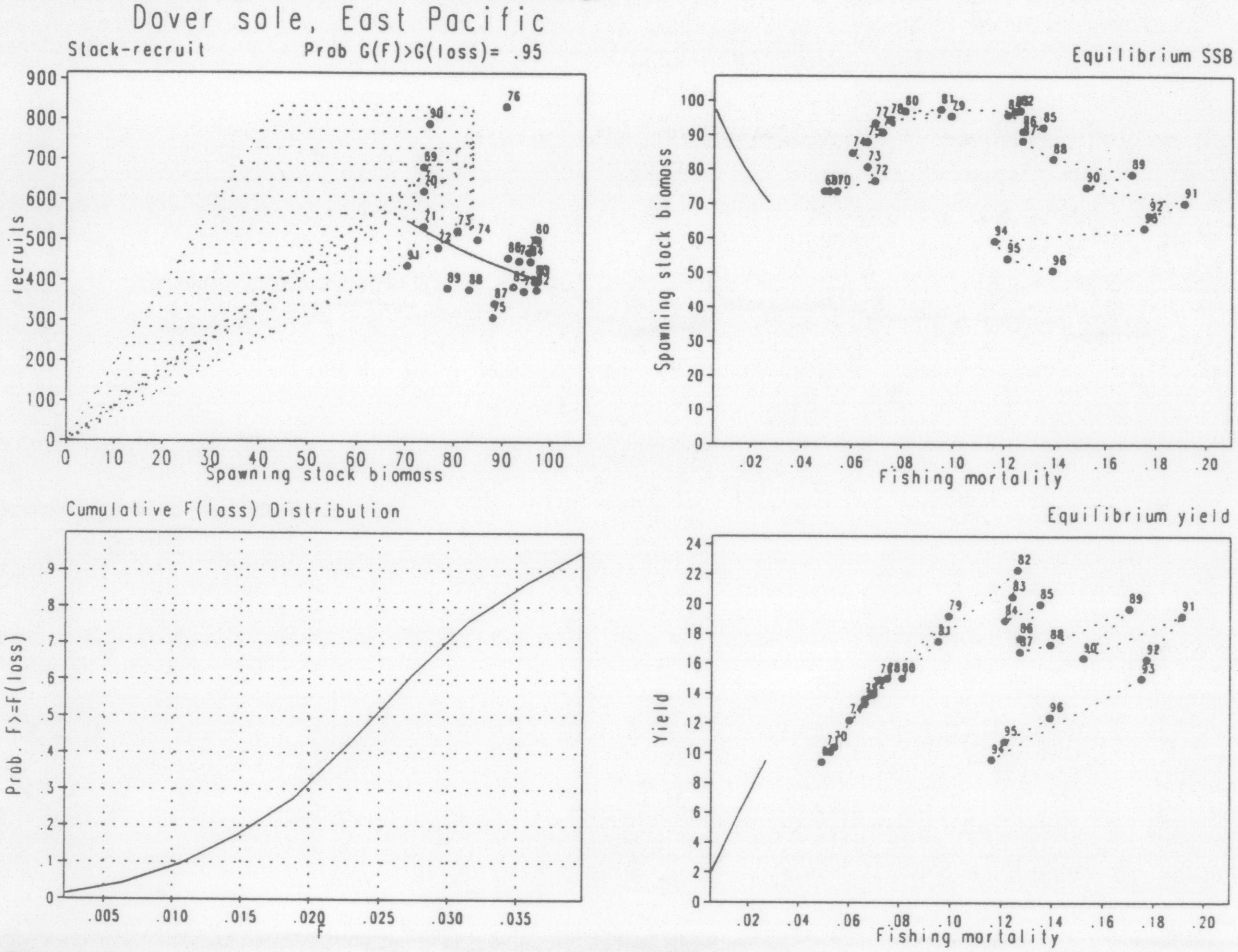

Figure 5. Dover sole. Top Left: Stock-recruit data with smoothed LOWESS curve. The vertically hatched area is the region in which the replacement line corresponding to the lowest observed spawning biomass lies. The horizontally hatched area is the region in which the replacement line corresponding to the most recently estimated fishing mortality lies (F=0.139). Top Right: Solid line shows the expected equilibrium for spawning biomass under different levels of fishing mortality. Observed annual data are indicated by years and joined as a times series by a dotted line. Lower Right: As top right by for yield. Lower Left: Cumulative probability distribution showing the probability that any given fishing mortality lies above the replacement line giving an equilibrium biomass at the lowest observed value.

The present F35% criterion is 0.09 and on the basis of this analysis would result in a smaller average spawning biomass than present values. However, the nature of the stock-recruit data, which do not show any sign of decline over the limited range of biomass, do not give any cause for immediate concern when fishing at this rate.

7. Discussion

The two rock fish examples examined appear to be able to withstand only very low rates of exploitation. This is not entirely surprising in view of their biology. The finding is consistent with related species in other parts of the world such a *Sebastes mentella* and *Sebastes marinus* in the North Atlantic. The F40% proxy does not appear appropriate for these species and it would appear that the general applicability of Clark's results fails in these examples. In order for Clark's results to be applicable, the SPR curve and equilibrium biomass curves need to be of similar shape when expressed on a relative scale. Figure 6 shows such curves for widow rockfish, and as can be seen they differ substantially. The Fs corresponding a 40% reduction of virgin biomass differ by a factor of 5. The fact that these two species appear exceptions to the rule raises the very likely possibility that other rockfish stocks on the Pacific west coast will fall into

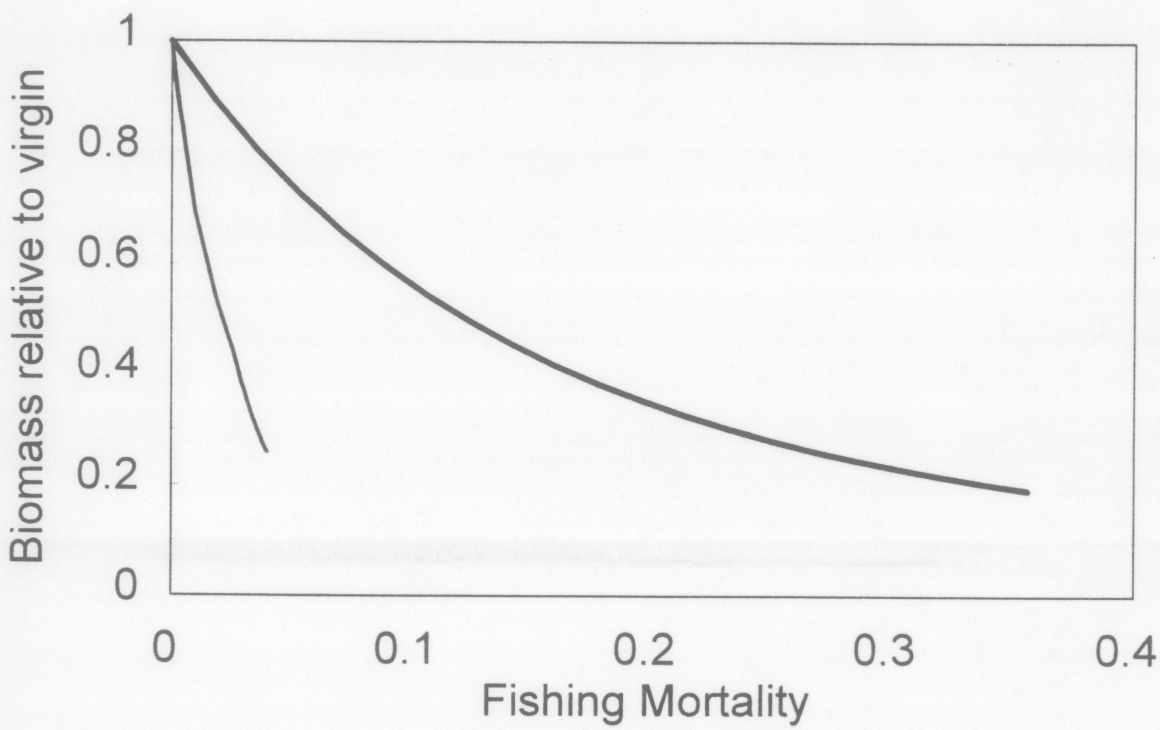

Figure 6. Widow rockfish. Equilibrium spawning biomass expressed as a proportion of virgin biomass plotted against fishing mortality. The thin line shows equilibrium biomass calculated using a stock recruit curve. The thick line shows equilibrium spawning biomass per recruit calculated using fixed schedules of weight, maturity, natural mortality and maturity at age expressed as a proportion of virgin spawning biomass per recruit.

the same category. It would be highly desirable to perform similar analyses on the other species so that appropriate sustainable exploitation rates can be identified. There does not appear to be any immediate problem with Dover sole, but given that the stock would be expected to decline under present exploitation rates, the harvest policy should be kept under review.

While the principal concern in this review has been the appropriateness of the F35% and F40% proxies, there is related issue, which may be relevant, in trying to implement a consistent harvest policy. Identifying a fishing mortality rate which is sustainable does not mean that the use of such a value in a harvest control rule will lead to sustainable exploitation. This is because the HCR will require quantities estimated from periodic stock assessments as inputs to calculate the appropriate catch. These quantities will be subject to errors of estimation. The HCR needs to take into account these errors and other uncertainties arising from implementation. It is important, therefore, that the performance of any HCR is evaluated through simulation studies (see for example de la Mare, 1986, Punt, 1995).

The equilibrium analyses conducted for this report make the strong assumption that the environment is constant. This, of course, is not the case in reality. Environmental regimes change and the Pacific west coast is not exception to this. MacCall (1996) , for example, describes possible long term regime shifts in this region. The implications of such changes affect the historical data used in the equilibrium analysis since they may be derived from more than one regime. Even if the data are consistent, in that they are characterize a single regime, the calculated equilibrium values may not be appropriate for future regimes. This requires that even more caution is applied in the interpretation of suitable harvesting policies.

The NMFS analyses and those conducted in this review are all based on single species population dynamics models. These may be adequate for the purpose but it should not be forgotten that many of the exploited groundfish stocks are likely to interact through predation. Given the large reductions in population size documented over past years, one might reasonably expect that the magnitude of these interactions will have changed. Such effects need to be considered in the choice of harvesting rate.

8. Acknowledgement

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