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REFERENCE POINTS FOR FISHERIES MANAGEMENT: THEIR POTENTIAL APPLICATION TO STRADDLING AND HIGHLY MIGRATORY RESOURCES

Explanatory note

The United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, at its second session, held in New York from 12 to 30 July 1993, requested the Food and Agriculture Organization of the United Nations (FAO) to prepare an information paper on the concept of maximum sustainable yield (A/48/479, para. 17 (c)). Pursuant to that request FAO has provided the present information paper.

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I. SUMMARY

1. A wide range of reference points has been proposed in the literature on fisheries management, primarily for management of national fisheries. No methodologies have been explicitly developed for straddling stocks and few specifically take into account the special characteristics of highly migratory species. As a result the present paper has had to rely largely on management experience with national fisheries.

2. Since it is axiomatic that a resource can only be assessed and managed based on a knowledge of removals throughout its range, the issue for straddling and highly migratory stocks is more a practical than a theoretical problem. Clearly the data collection and analysis required for the assessment of straddling and highly migratory stocks presents more problems when uniform standards for the collection of data are not established, than for the data-dependent management methods used exclusively in the national fisheries of developed countries.

3. A wide range of new biological reference points has been proposed in recent years and these tend to focus on defining acceptable levels of fishing mortality and minimum spawning stock criteria rather than on catch and fishing effort criteria. This attention to minimum spawning biomass is beginning to suggest limits which should not be exceeded, rather than targets for fishing, and this change in emphasis is well adapted to precautionary or risk-averse management strategies.

4. Where new targets for fisheries management have been proposed, whether based on desirable catch and effort, desirable stock size or economic considerations, they have all recognized that the optimum fishing effort for sustainable exploitation is below, even significantly below, the level of effort corresponding to the maximum sustainable yield (MSY). The biological and economic gains from significantly restricting fishing effort more than offset the losses in yield from choosing more modest targets, which in the long run are minor.

5. The choice of maximum sustainable yield as the accepted reference point for fisheries management purposes was applicable when fisheries were in an expanding phase and this reference point was used as a rough production target. As fisheries have become increasingly over-exploited, MSY may still be a valid reference point, but only as representing an upper limit beyond which stocks become progressively over-exploited and a minimum requirement for effort reduction policies.

6. Most of the difficulties experienced with using any target reference point result from the considerable uncertainties as to the current position of the fishery in relation to it, given poor data and environmental variability. Few fisheries are stable because environmental changes influence stock size. This means that stable production levels are only possible with widely varying fishing rates from year to year.

7. One of the difficulties with using MSY as the main reference point as a target for management is that of determining where the point is and where a fishery is in relation to that point. This can usually only be determined after MSY has been reached, and even substantially passed, and the level of production is clearly diminishing. It is suggested that MSY can still be a useful reference point if it is used as a limit reference point instead of a target. Once a limit reference point is reached it would automatically trigger certain measures to curtail fishing in order to commence stock rebuilding.

8. Standard fishing effort and current mortality rates caused by fishing on stocks can only be roughly estimated for open-access fisheries where effort is difficult to adjust and misreporting or poor estimates of catch affect the accuracy to which a given fishing rate can be measured.

9. The present paper recognizes the high level of uncertainty in management advice for straddling and highly migratory stocks owing to poor statistics, as the most serious impediment to implementing low-risk exploitation strategies. Improving data gathering and analysis should allow management to use less restrictive precautionary reference points without a corresponding increase in the risk of over-exploitation.

10. For comparative evaluation, a summary of the main reference points considered in the present paper is contained in annex I, together with their respective data needs and advantages and disadvantages.

II. INTRODUCTION

11. Fisheries management is not synonymous with the attainment of a single reference point. This has already been recognized with the acceptance of the concept of optimum sustainable yield, as contained in the 1958 Geneva Convention on Fishing and Conservation of the Living Resources of the High Seas. The concept of optimum sustainable yield recognizes economic, social and biological values for the basis of fisheries management objectives. However, because of economic and social differences amongst fishing countries, optimum sustainable yield does not have a standard technical application and therefore cannot be considered a technical reference point. It does, however, remain a valid concept for fisheries management based on a mix of references as long as the fishery remains within a "safe area" as defined by technical reference points.

12. Marine fish populations are not visible for direct census and therefore assessments are made on the basis of conceptual models whose validity is often open to question, and changes with time. These models rely on estimates of biomass, catch and fishing effort, and mortality rates that all contain significant uncertainties and these affect estimates of stock size. Errors can occur in resource surveys, in the use of inappropriate models, misreporting or non-reporting of catches, as well as in estimates of the effective fishing effort exerted on the stock under "open access" conditions.

13. The basic premise for fisheries management follows that of animal husbandry, in aiming to provide a sufficient number of spawners (i.e., escapement) for new recruitment to a fishery. Beyond this requirement the stock

is surplus to conservation needs and can be taken (i.e., catch). In this way the prime consideration for fisheries is that of catch versus escapement. Catch has therefore to be controlled to ensure that sufficient escapement occurs to satisfy spawning requirements. The effectiveness of protecting spawners is measured by monitoring new year classes entering a population as well as monitoring the age structure of the population. Not all fishery models have the same data requirements or impose the same costs in data collection and analysis. Analytical models incorporate growth, mortality rates and information on fecundity, but they are used mostly in developed-country fisheries in high latitudes. Such data are not commonly available for many tropical species, which means that management for such fisheries, by referring to a single reference point, will be problematic and require precautionary approaches to avoid stock collapse.

14. The necessity of using analytical models for the assessment of fish stocks imposes data requirements that are demanding. The provision of proper systems for collecting, storing and analysing fishery information and conducting fishery surveys and research, are mandatory for determining whether management targets are being met and for evaluating the effectiveness and impact of a management regime. Further, it can be demonstrated that for a comparable level of risk of stock collapse, a fishery with poor research and management must be fished less intensively than if research and management are well developed.

15. All technical reference points require estimation of the relationship between fishing mortality and stock size (see annex I). Estimates of stock size and fishing effort are not always easily defined and can be modified by environmental conditions which can change a stock’s availability to fishing, its vulnerability and hence the effective fishing power of a fleet.

16. In order to determine when an optimum has been reached there must be continuous statistical monitoring of the catch, the fishing effort and a range of biological and economic information. There must also be a realistic appreciation that the actual values used can only be known with questionable precision. It is also important not only to consider the effect of managing a fishery according to certain reference points but also to consider the potential consequences of applying wrong reference points under the conditions of uncertainty that always apply to the management of a fishery, or misinterpreting the position of the fishery in relation to a correct reference point.

17. The assessments of fish stocks presented to fishery management forums are characterized by the use of standard "accepted" procedures which, once adopted, are only changed when evidence of a clear improvement in methodology is generally accepted by all parties. In time, the methods used acquire a conventional character, which can disguise the level of uncertainty associated with population estimates for a fishery. Explicit estimates of accuracy or precision are rare in the stock assessment literature, and further attention to defining more precisely level of error and the associated risk of exceeding fishery management targets is required. Annex II illustrates three important points:

(a) It is clear that the current stock size and fishing mortality are known with relatively low accuracy in most fisheries. Although with a history of past assessments the above estimates may improve, it should be recognized that even under optimal conditions fisheries management does not operate in a risk-free environment. Total yield may appear to be known with a higher precision than other variables, but often suffers from high or unknown biases as a result of discarding and misreporting, particularly if management is by catch quotas. Survey estimates of biomass typically have a higher variance but may be less biased, and have the potential to be improved with research investment. In all cases, the relative change in population size from year to year will be known with more precision than absolute values;

(b) Management targets with equal levels of risk will require lower levels of removals and more conservative reference points if statistical data are poor and non-reporting or misreporting is the case, than if proper attention is paid to data gathering;

(c) In order to reduce the risk of error in determining the present position of the fishery relative to the reference point, two or more different stock assessments, using independent data sets, will be necessary, but the exact status quo for the fishery is unlikely to be known with an accuracy of more than ± 10-30 per cent, even with a high expenditure on research.

18. This means that maximum sustainable yield (or any other reference point used as a target) will be exceeded at least 50 per cent of the time, and often by a considerable margin. In the case of MSY, this target reference point (TRP) has lost its reputability, primarily as a result of errors in population estimates, and the corresponding consequences to fisheries. Unknowingly overfishing this target in error is more serious and less easily reversible than underfishing it. Had full account been taken of errors in the population estimates, fishing effort would have been aimed at lower levels of exploitation. Based on this perception, and taking risk and uncertainty into account, the present paper suggests that target fishing rates should be set at levels of effort below that yielding MSY, with an explicit attempt made to assess the probability that a dangerously high fishing rate, or limit reference point (LRP), be only rarely exceeded.

19. The conclusion is therefore that insufficient attention has been given to "errors in estimates" and in view of the inherent uncertainty that exists in managing fisheries, no single target reference point can be relied on for the basic conservation of fisheries. A set of reference points or management criteria is required, with renewed national commitment by all parties fishing a highly migratory or straddling stock towards statistical gathering. This should focus proper attention on determining confidence intervals on data sources through standardization of data gathering and analysis procedures, cross-referencing and subsequent adjustments to management targets. The present paper provides comments on the usefulness of specific reference points, in particular their application either as target reference points, or as so-called limit reference points which automatically trigger pre-negotiated management responses.

III. REFERENCE POINTS: AN EVALUATION

20. A reference point is considered to be a conventional value derived from technical analysis which represents a state of a fishery or population, and is intended as a guide for fisheries management.

21. Traditionally, reference points have been considered desirable targets for management. It had been assumed that it is possible to "tune" a fishery such that one or more control variables, as determined from statistics, are (believed to be) close to a pre-established reference point. Such a target for management can be referred to as a target reference point (TRP), and MSY had classically been used in this sense.

22. Reference points are usually derived from a particular biometric or econometric mathematical model. The models underlying the MSY point were originally equilibrium models implying that the points on the curve represented the yield that would result from a given standard effort applied for the years necessary for equilibrium to be reached.

23. It is important to recognize that no TRP known to date is stable, whereby a fishery will gravitate to an equilibrium point automatically, or return to that point immediately if disturbed. TRP management, particularly if based on catch limitations or total allowable catches (TACs), requires active monitoring and continual readjustment of management measures on an annual time scale, because of the substantial uncertainty in the status of a fishery in relation to its reference point.

24. Management by reference point should recognize this inherent uncertainty in our knowledge of the status of the stock, and the fact that, ironically, our knowledge of the current status of the resource is poorer than our ability to reconstruct stock status in previous years. Such uncertainties will inevitably be greater for straddling and highly migratory resources, where multiple fisheries render common data gathering for the stock problematical.

25. It is incorrect to assume that a given level of fishing effort allows a surplus yield to be maintained indefinitely without regard to environmental conditions. Dramatic improvements in fishing technology have allowed fleet fishing power to be exerted rapidly and moved from one fishery to another in short time periods. The reference point MSY, which in the 1950s could take half a decade or more to reach, can now be achieved in the first year of a new fishery. Under circumstances of high initial catch rates, a wide overshoot of MSY is inevitable, resulting in associated ecological changes and serious economic problems in reducing fishing effort so as to adjust to a lower equilibrium MSY level in later years.

26. As a result, the use of production models, in particular those that assume equilibrium in forecasting short-term yield, has been criticized. Problems with making decisions under conditions of uncertainty with data, environmental conditions and spawning success have resulted in management of many fisheries relying on analytical models, whereby the catch data are supplemented with biological sampling and regular surveys of fish populations. The problem of high precision has, however, not been solved, and the techniques for

establishing whether a reference point is being met in a given year remain based on the validity of the population models used, and on our best estimates of the dynamics of a fishery. There is presented below an examination of reference points which are formulated mostly in terms of the role of fishing mortality (F) which these points are intended to achieve.

A. The maximum sustainable yield criterion: F_{MSY}

27. The 1982 United Nations Convention on the Law of the Sea specifies only one technical reference point (the maximum sustainable yield) as a descriptive term for the highest point of the curve traced between the annual standard fishing effort applied by all fleets and the yield that should result if that effort level were maintained until equilibrium is reached. This is at first sight an obvious target for management of a single-species fishery, and it was widely used for this purpose by fishery commissions in the 1960s and 70s. Subsequent developments in the theory and practical experience in fisheries management have cast doubts on MSY as a safe TRP.

28. MSY, and its equivalent levels of standard fishing effort/fishing mortality rate (f_{MSY}/F_{MSY}), was formulated first for the symmetrical Graham-Schaefer or logistic model (see annex III). The concept was model-based and required statistical fitting of historical catch and standard effort data. The effort level at which the f_{MSY} catch occurs can be converted to a fishing mortality F_{MSY} if the constant of proportionality, q, is known. Choosing F_{MSY}, or any other reference point, implies that the underlying mathematical model of fish population dynamics is (at least implicitly) agreed on in choosing this TRP. The question may however be less one of selecting a reference point with the most robust theoretical underpinnings, but one that provides conservative advice under conditions of uncertainty, and from this perspective the MSY level has not performed well.

29. Few explicit estimates have been possible of the accuracy with which MSY conditions have been reached, but inspection of many production models suggests that knowledge of the current death rate attributable to fishing (and hence the accuracy with which a given target for the fishing rate is attained) is hardly likely to be better than ± 20 per cent. The MSY is obtained by statistical fitting of historical data to the model, and this implies that what happened in the past has a similar probability of occurring in the future. However, this does not take into account variations and trends in environmental conditions or in ecosystem species composition under fishing pressure. In a series of years with very poor recruitment, a fishing mortality rate will produce a yield well below that predicted for the same level of effort from fitting the model to past data series. Attempting to harvest the statistically obtained MSY in these years of low stock size would require fishing above, and possibly well above, F_{MSY}. For this reason, the use of the term "sustainable" when speaking of a "maximum sustainable yield" obtained in the conventional way has been criticized.

30. Given the uncertainty as to the actual status quo with respect to this (or any other) reference point, a fishery believed to be operating in the region of F_{MSY}, in probability terms, is 50 per cent of the time either overfishing or underfishing with respect to this benchmark. The biological responses of the resource to overfishing or underfishing are not necessarily symmetrical: overfishing leads to fewer age groups in the fishery, hence increasing the contribution of occasional good year classes to the overall yield, as well as leading to declining mean sizes and catch rates and progressively increasing the return time to acceptably high stock sizes. Relatively constant year-to-year recruitment is the exception rather than the rule, but reduced or less regular recruitment with declining spawning stock size is accompanied by increased dependence for stock replenishment on newly maturing age classes. Increased variations in abundance as a result of a greater influence of environmental changes on the stock size lead to increasingly heavy reliance on research data, especially if catch quotas are the preferred management measure. From theoretical considerations, a management system that treats a stock assessment simply as providing a TRP, without recognizing statistical uncertainties in the fishery management process, will not be effective.

31. Model uncertainty is often a serious problem. The uncertainty as to which type of yield model is appropriate for a particular fishery can, unfortunately, only be resolved when overfishing has occurred and the total effort that provides MSY has been exceeded. Catches may then drop (implying a dome-shaped model) or reach a plateau (as is often the case in tropical shrimp fisheries), giving, finally, the clue to the appropriate type of model.

32. As a result of the uncontrolled fleet dynamics of fishing investment, effort overshoots of the f_{MSY} target are an almost inevitable feature of open-access fisheries, so that the type of model to use, and the level of effort or fishing mortality which approximately corresponds to MSY, may be only relatively well known, even in the best of circumstances. Controlled overfishing strategies have even been proposed as one way of more precisely locating MSY conditions. Such strategies are however dangerous and difficult to reverse: surplus fishing vessels, once established in a fishery, may be difficult to displace, with limited alternative income-earning opportunities, and a loss in economic yield will certainly occur. It is for this reason also, that other, more desirable and safer target fishing rates (such as two thirds of the effort providing MSY) have been difficult to agree upon.

33. The effects of heavy fishing in reducing stock size can lead to a species losing its competitive advantage as its ecological niche is occupied by other competitor species with similar food requirements, but not necessarily of the same economic value (e.g., skates instead of haddock; dogfish instead of cod). The probability that the ecosystem will move to an alternative ecological configuration seems to increase as effort arrives at MSY levels or beyond.

34. It has been pointed out that there is often an erroneous identification of MSY conditions for little-studied stocks with the maximum average yield (MAY). This latter measure has occasionally been used as a reference point, but gives dangerous weight to the early, more productive years of the fishery when the virgin stock was being fished down. A literal interpretation of MSY for a stock subject to wide variations in recruitment, would be that level of catch which

could be removed in perpetuity from the resource with a low probability of endangering it under conditions of environmental and recruitment variability, i.e., where the same yield could be safely removed in good or bad years. This interpretation of "MSY" is radically different, and requires a different notation from MSY as normally derived, and this reference point is referred to here as the maximum constant yield (MCY). This TRP implies much lower levels of fishing mortality than at MSY as defined conventionally. Such a new definition could, however, provide a useful target for stock rebuilding, and could be estimated from simulation if some information were available on the likely variance of annual recruitment.

35. Following the postulation of the marginal yield concept, fishing at the effort level that corresponded to two thirds of the effort needed to produce MSY would yield a very large fraction (possibly as high as 80 to 90 per cent) of the overall yield at MSY, with a reduced risk of stock collapse. This empirical measure, although safer than f_{MSY}, like $F_{0.1}$, has been criticized as empirical and insensitive to changes in recruitment. Such reference points derived from production models, such as MSY, suffer from difficulties of population analysis if the competing fleets exploiting a resource do not exploit the same age groups in the stock. Under these conditions some form of analytical approach is necessary. The first of these analytical reference points defined was F_{MAX}.

B. The maximum yield per recruit criterion: F_{MAX}

36. The theory of population dynamics placed early emphasis on the calculation of that level of fishing mortality for a given size at first capture, which maximizes the yield from a fixed number of recruits with fixed growth and natural mortality schedules entering a fishery. This was one of the earliest benchmarks for fisheries management, and as with MSY, suffered from a number of failures as a target for fishing, since it does not take into account the effect of fishing at F_{MAX} on the reproductive potential of the population. Although generalizing can be hazardous, there seems little doubt that this reference point usually corresponds to a higher fishing rate than F_{MSY}, and that fishing at this rate over a period of time is liable to deplete the spawning stock and reduce future recruitment. Although there seem to be good reasons for retiring F_{MAX} as a management target, it could be a possible upper limit or limit reference point (LRP).

C. The marginal yield criterion: $F_{0.1}$

37. $F_{0.1}$ is the fishing mortality rate at which the slope of the yield per recruit curve as a function of fishing mortality is 10 per cent of its value at the origin (see annex IV). For a number of species there is no clear maximum to the yield curve per recruit, but unlike F_{MAX}, the $F_{0.1}$ point does not require this, since it is an arbitrary criterion based on the initial slope of the yield per recruit curve.

38. The $F_{0.1}$ measure, although arbitrary, is in a sense a bioeconomic criterion, in that a marginal yield of less than 10 per cent was felt to be the point at which most fisheries administrators would consider further increases in fishing

mortality or effort to be no longer economically worthwhile. This measure has been widely used in many fisheries of the North-west Atlantic. F-based strategies have been followed off the coast of eastern Canada for more than a decade, and $F_{0.1}$ is often used in establishing overall quotas. Declaration of the correct and unbiased catch data is essential to estimating current F-values under quota control, but there has been a gradual erosion of the accuracy of commercial catch reporting. This has affected scientific assessments, especially where fleet overcapacity is a problem. As a result there has been a high probability that target F-values are exceeded. This, and not just the changes in $F_{0.1}$ that occur with changing fishing patterns and input values for M (natural mortality rate: see below), may be the main explanation for declines in several stocks managed under $F_{0.1}$ criteria.

39. A more serious problem in using this TRP for straddling, and even more so for highly migratory stocks is how to calculate a value for $F_{0.1}$, if fleet-specific vectors of fishing mortality-at-age for an exploited resource are quite different within different jurisdictions, and the relative fishing effort levels in each jurisdiction change from year to year.

D. Reference points based on the natural mortality rate: M

40. New fisheries usually develop in the absence of adequate assessment information, and management has to proceed on the basis of information available at the time. It is important for the rate of increase in fishing during the early stages not to exceed the rate at which the capacity of the resource to support fishing is known. A more cautious approach may result in underexploitation, but this will not necessarily lead to a long-term loss of potential yield. In the 1960s and 1970s, many new fisheries developed for which the only data on stock status was one or several estimates of biomass from exploratory fishing or fishery surveys. In an attempt to provide some basis for fleet and fishery development, a simple empirical formula for MSY was proposed in terms of the virgin biomass B_0 and the natural mortality rate, M: notably, MSY is equal to half of the natural mortality rate times the virgin biomass ($MSY = 0.5MB_0$). This follows the symmetrical Schaefer yield model in assuming that MSY will occur at half the virgin stock size B_0, and that at MSY, the fishing mortality and natural mortality rates will be equal, so that if M is known, a target fishing rate at the same level could be defined such that deaths attributable to fishing equal those attributable to natural causes. Subsequently, a more cautious approach was recommended in which death rates attributable to fishing were maintained below those attributable to natural causes (predators, etc.).

E. The overall mortality rate at maximum biological production: Z_{MBP}

41. Production model theory begins with the idea that virgin populations are dominated by large, older individuals, whose contribution to biological production (growth, yield plus deaths attributable to predation) is lower than when younger individuals dominate the population. The existence of a mortality level Z_{MBP} can be postulated at which the biological production from the stock is

maximal, and this is shown for the Schaefer model in annex V. This raises the general observation that the causes of death of fish in the wild are rarely accurately known, so it might be better to use as an overall reference point the overall mortality rate Z experienced by the stock due to all causes of death.

F. Target reference points derived from stock-recruitment considerations

42. As a result of heavy fishing and depressed stocks, fishery scientists in the North or North-east Atlantic have moved in recent years towards emphasizing spawning stock considerations when offering advice to management bodies. This has been phrased in terms of spawning stock biomass or biomass per recruit ratios, and refers to the reproductive potential under virgin stock conditions. This has led to increased research in recent years on the density-dependent processes that underlie fishery dynamics. These density-dependent processes have revealed that the number of recruits increases as adult populations grow from very small sizes, but for many resources the number drops at a high adult population size, owing to individual competition for food, space and spawning sites.

43. Simulations have shown that for northern demersal stocks a yield of at least 75 per cent of MSY is possible as long as the spawning biomass is maintained anywhere in the range 20 to 60 per cent of the unfished level, irrespective of the spawner/recruit relationship. For north-temperate groundfish stocks, a relative spawning biomass in this range can be achieved by choosing an effort level that will reduce spawning biomass per recruit to about 35 per cent of the unfished level. The equivalent reference point is usually very close to $F_{0.1}$. The relationship between spawning stock size and number of recruits is of key importance to the decisions made with regard to reference points, but a long time span of annual data on adult population size and recruitment under a wide range of population sizes is needed to produce a reliable stock/recruit curve (see below). This is rarely available for setting reference points for less frequently studied stocks.

44. The use of reproduction-based TRPs has been pioneered in the International Council for the Exploration of the Sea (ICES) area, based on plots of recruitment on spawning stock biomass. Three arbitrary criteria have been proposed, one of which, FMED, has the characteristics of a TRP and corresponds to the fishing mortality when increases in stock size attributable to recruitment in half of the years have more than balanced losses attributable to mortality. Two other benchmarks (F_{LOW} and F_{HIGH}) surround F_{MED}, and are similarly defined to result in recruitment exceeding removals in 90 per cent and 10 per cent of years, as represented by the proportion of data points for recruitment above the line through the origin corresponding to that level of fishing mortality (see annex VI), and have the following properties:

F_{LOW} a low probability of stock decline, and some likelihood of stock increase;

F_{MED} likely that current stock levels will be sustained;

F_{HIGH} likely that fishing at this level will result in stock declines.

All of these measures appear less susceptible to assuming an incorrect value of the natural mortality rate than F_{MAX} and $F_{0.1}$ levels. Although F_{MED} is the fishing mortality rate at which, on average, each year class replaces the spawning biomass of its parents so that the population fluctuates without trend, it should be noted that this measure, which is independent of the form of the stock recruitment relationship, fell close to F_{MAX} and F_{MSY} for Georges Bank haddock.

45. Calculations of the spawning stock biomass per recruit (SSB/R) can be carried out in a manner similar to that for yield/recruit calculations if information on maturity/fecundity at size or age is available, even if the stock-recruit relationship is unknown. These calculations are usually expressed as a percentage of the SSB/R under unfished conditions (per cent SSS/R). In a recent comparative study, per cent SSB/R was found to be positively correlated with natural mortality and negatively correlated with various indexes of size: thus cod and most flatfish support low levels of per cent SSB/R, but some pelagics require values as high as 40 to 60 per cent for consistent stock replacement. Although these conclusions agree with those in the section on reference points above, it is probably dangerous to extrapolate them widely outside their region of origin, since the detailed data sets this generalization is based upon are mainly restricted to demersal fishery resources in higher latitudes. None the less, the use of per cent SSB/R criteria is not as information-demanding as other reproductive criteria, and has potential in the present context.

G. Target reference points derived from economic considerations - the optimal fishing effort: f_{MEY}

46. The normal workings of the market are believed to maximize economic benefits to participants, but in open-access ocean fisheries the institutional framework does not ensure that the individual efforts of fishermen, working to improve their individual economic situation, will guide the net sum of private activities towards the common good. In fact, recent FAO analyses of global fishery trends have revealed a general state of overexploitation of many world fishery resources, and that the high level of over-investment in fleets is the major causal factor for overfishing within and outside exclusive economic zones. Combined with restrictions on fisheries within exclusive economic zones, this has been a motive force for movement into largely unrestricted fisheries beyond 200 miles.

47. An extensive literature on fisheries economic theory has developed in which the Gordon-Schaefer equilibrium production model plays a central role. This theory is summarized briefly in annex III, which shows that theoretically there is at least one economic target for exploitation, the effort level yielding the greatest rent from the resource, and that for a linear cost curve, this is realized at a lower level of overall fishing effort than MSY. The optimal effort level, however, is responsive to changes in the economic environment, such as the market price of fish, interest rates and the costs of fishing, and is not independent of changes in fish abundance.

48. Although economic considerations obviously should play an overriding role in national decisions to participate in a fishery, perhaps one further reason why such economic reference points may not be practical for the management of straddling stocks (and even less so for highly migratory resources) is that each national fleet may have a different economic optimum, depending on its costs, earnings and national market prices. In practice, F_{MEY} is not easily defined in most fisheries involving fleet components with different gears and fishing practices. Most fishery administrations pay little attention to the size or composition of fleets and few actively monitor fishing equivalencies between different fishing vessels or gears. Not surprisingly, fleets experience economic difficulties either from declining catch rates per vessel even if overall declines in total catches are offset by price increases, or from increases in costs of a number of important inputs. Because of the socio-economic impact of a reduction in fleet operations, Governments often resort to subsidies to alleviate such impacts. This of course increases the structural difficulty associated with reducing fleet size/fishing effort and fish mortality, etc.

49. Although distance- and labour-related costs and market prices differ between countries fishing the same straddling stock, a criterion for an economic reference point should ideally eliminate fleet and industry subsidies, grants, loans, etc., since these payments distort operations. The extraction of resource yields, even if not at a maximum, would help to ensure against the negative effects of economic distortion. There can be little justification for continued unprofitable fleet operation if this destroys or prevents stock recovery.

50. MEY cannot be usefully considered as a TRP as long as the condition of free and open access prevails. Fishing effort will continue to expand past MEY to the point at which total revenues equal total costs and this point will also be to the right of MSY on the fishing effort axis, and likely to result in government interventions to alleviate economic hardships to fishermen and the industry when catches/profits decline.

IV. LIMIT REFERENCE POINTS FOR FISHERY MANAGEMENT

A. F_{MSY} as a limit reference point

51. Annex VII shows that using an LRP rather than a TRP could provide flexibility in choosing a more cautious F-based TRP that may be useful for management purposes. The approach is illustrated in the case of F_{MSY}, and considers three aspects that are each related to:

(a) The variability of the current fishing mortality (F_{NOW});

(b) The risk level that management may wish to take so that F_{MSY} may not be exceeded;

(c) A knowledge of the F_{MSY} which is accepted as the LRP.

52. The value for current fishing mortality rate F_{NOW} is usually the best estimate resulting from the analysis of statistical information and surveys, and its variability can be specified either in absolute terms (as a standard deviation) or as a fraction of the best available estimate of F_{NOW} itself. The approach suggested in annex VII is to establish a cautious F-based target for management such that despite uncertainty as to the exact current rate of fishing, this should not exceed some higher LRP (in this case F_{MSY}), more than an acceptable proportion of the time.

53. For example, the table in annex VII illustrates that with an acceptable 20 per cent risk of overshooting F_{MSY}, and a best estimate of current fishing mortality known to an accuracy of ± 50 per cent, the corresponding "safe" F-based TRP should be set at a fishing rate of F_{NOW}=0.42. That is to say, if F_{MSY}=0.6 is set as an upper limit to fishing mortality, then to be certain that this limit is not exceeded more than 20 per cent of the time, the fishing mortality rate to be aimed at should be F_{NOW}=0.42 instead of 0.6. These calculations illustrate the importance of sufficient and accurate information on the status of the fishery in developing risk-averse management strategies.

54. A more elaborate use of MSY as a limit for exploitation was incorporated in the new management procedure developed by the International Whaling Commission, where a maximum harvest of 90 per cent of MSY (set at 60 per cent of the unexploited stock level) is agreed upon. The overall catch is reduced progressively by 10 per cent for each 1 per cent shortfall of the stock below the MSY level, leading to a threshold for entry of the stock to a fully protected category, as soon as stock size drops to 90 per cent of the MSY level. This example also illustrates one other essential feature of an LRP-based management system: the pre-negotiation of future automatic management responses once the system enters a pre-agreed endangered state.

B. Limit reference points derived from stock recruitment considerations

55. Scientific attention has focused recently on the definition of LRPs which signal a dangerous situation of reduced probability of future recruitment to the fishery. Practical management advice has been recommended on the basis of a safe minimum spawning stock size, or on an F-level that provides what is believed to be a safe limit for spawning stock biomass/recruit (SSB/R), expressed as a percentage of the spawning stock biomass calculated for the virgin stock. Thus it has been suggested that to fish at some fixed rate is safe for demersal fish stocks so long as the spawning biomass remains above a pre-defined threshold size, but to suspend fishing when stocks drop below this level. Specific criteria that fall in this category, as mentioned, would be the F_{HIGH} used in the ICES area, since above this point there is little evidence that the stock can produce enough recruits to sustain itself. In the ICES area the stock biomass below which the probability of a poor recruitment increases as spawning stock decreases is referred to as the minimum biologically acceptable level (MBAL), and is intended for use as an LRP.

56. In the United States of America, fisheries are managed through management plans which require operational definitions of overfishing based on a maximum

fishing mortality rate, minimum stock biomass or other appropriate biological reference points. Sixty per cent of these definitions to date have been based on spawning stock biomass per recruit analysis, with typical values ranging from 20 to 35 per cent of virgin stock levels. A survey of 91 spawner recruit data sets for Europe and North America suggests that the replacement per cent SSB/R (i.e., the fishing strategy which, on average, replaces the spawning stock) varies considerably between taxonomic groups, but averages 20 per cent overall. Given the relative depletion of many of these stocks, it is possible that these levels should be regarded as limits to exploitation rather than targets.

C. Limit reference points as "sets of rules"

57. LRPs can be incorporated into a set of management criteria, which if one or more are infringed, triggers a pre-set management response. One such set of constraints has apparently been developed for the Eastern Bering Sea/Gulf of Alaska groundfish fishery and includes (a) a threshold biomass set at 20 per cent of the virgin stock biomass, (b) a maximum fishing mortality rate set at 30 per cent of the relative spawning stock biomass per recruit and (c) a maximum fishing mortality rate set at 80 per cent of the natural mortality rate (M) for the species concerned; other possible warning signals suggested elsewhere are: (d) when total mortality Z rises above that corresponding to the maximum biological production from the stock, (e) when the mean size caught falls below the mean size at first maturity, (f) when the proportion of mature individuals in the stock falls, below some agreed percentage of that for the virgin stock and (g) when annual recruitment remains poor for a predetermined number of years in a row. Other robust indices which are often associated with low stock size, and hence reduced intra-specific competition, are increases in weight-at-age and reduced size at maturity.

58. For short-lived species (e.g., some squid resources), sets of rules may be invoked in sequence in the same season. Thus, fleet size and overall effort can be controlled to aim for a target level of escapement to spawning as an agreed percentage of that calculated for the same number of recruits with no fishing. This level can be fine-tuned during the season if a real-time measure of accumulated catches is maintained, and when ongoing surveys of abundance/availability allow real-time changes in the abundance of pre-spawning individuals to be monitored.

D. Limit reference points derived from economic considerations

59. It is generally acknowledged that one limit reference point on the curve of total revenue plotted against fishing effort, although extremely undesirable, is the point of bionomic equilibrium at which total earnings from the fishery equals the total costs of fishing. Although beyond this point the fishery is operating at a loss, the effort level corresponding to this point (point E in annex III), can in fact be exceeded, especially when subsidies distort the real cost of fishing. Since the catch rate is often assumed proportional to biomass, the catch rate or catch per unit of effort per standard fishing day is one LRP criterion employed, particularly in some fisheries for highly migratory resources where survey methods are difficult to implement. A useful economic

LRP is the minimum catch rate which yields daily earnings per cost of fishing at which the fleet extracts zero resource rent. It is presumably axiomatic that a fishing operation that generates zero or negative resource rent, but contributes to dangerously depleting the stock is difficult to justify. A possible economic measure that might be applied by participating countries in a fishery on straddling or highly migratory stocks would be to require participants to demonstrate that resource rent is being extracted from their fishing vessels.

E. Reference points based on measures of the size at capture

60. In assessing the effects of size at first capture on the yield per recruit from a stock, an optimum size at first capture that provides the maximum yield per recruit can be calculated for a given set of population parameters and a particular level of fishing mortality. In the case of straddling stocks and highly migratory species, however, it is not always possible for this optimal size at first capture to be maintained throughout the range of the unit stock, since different age groups may have different distributions or availabilities within the jurisdictions in which the stock may range. Maintaining a single optimal size at first capture would only be possible if arrangements were made for all harvesting to be carried out in seasons and jurisdictions in which the optimal sizes were available.

61. The problem of controlling overexploitation is, of course, most pronounced when the age at first capture falls below the average age at first maturity and there is a high risk of recruitment overfishing. If control of fishing effort is unreliable, one reference point would be to require fishing only to take individuals at a size at and above that at first maturity without discarding and inflicting damage to undersized individuals. There may be an advantage in cases where the natural mortality rate is not precisely known for basing biological reference points on the overall mortality Z experienced by the stock. A more practical biological criterion has been proposed, i.e., to limit the overall mortality rate to Z^*, the level at which the mean size in the catch equals the mean size at first maturity. Evidently the use of this type of reference points requires attention to the selectivity of the gears in operation.

V. SPECIAL CONSIDERATIONS

A. Reference points for highly migratory resources

62. The reference points mentioned above for the management of single stocks have different degrees of applicability for highly migratory resources, although the specific life-history characteristics of these resources argue more strongly against exclusive reliance on dynamic pool models as a sufficient response to the needs of management and conservation. Sophisticated management arrangements may be needed to deal with sequential fisheries. Although occurring to a lesser extent for some straddling stocks, it is typical of highly migratory resources that multiple fisheries occur at different loci on the overall migratory route. Such local fisheries are often seasonal, and often too short to allow declines in catch rate with time and size to be unambiguously attributed to fishing as opposed to migration. Each fishery may exhibit different availabilities to

fishing and different age compositions of the catch. Under these circumstances, no ready alternatives seem available other than pooling catch data and performing a global assessment, and then, where possible, moving to define a more detailed escapement or gauntlet model.

63. One practical consideration that applies to multi-jurisdictional fisheries for a common stock is that each fishing location may be assessed as favourable or unfavourable in relation to a size-based reference point, the optimal size at first capture, as judged from yield per recruit or spawner per recruit analyses for the whole life history. The sacrifices needed either to achieve an optimal yield per recruit or to protect the spawning stock or juveniles from overfishing are not equal for all participants and often depend on the actions of one or a few coastal States where these critical life history stages are undergone. Under these circumstances, it has been noted that the overall yield from the population if all parties are obliged to harvest the stock exclusively within their areas of jurisdiction will be sub-optimal if only a few (e.g., juvenile) age classes are available in a given exclusive economic zone. The optimal solution from a yield-per-recruit perspective would then be to seek agreement to ban all harvesting except in seasons/areas where the size frequency, catch rates and international market prices are optimal but, of course, to provide a catch quota or other compensation to those parties prepared to renounce the fishing of sub-optimal sizes within their own jurisdiction.

64. The best overall reference point is one ensuring that a certain spawning biomass survives all fisheries to reproduce the stock. It is clear that this can be achieved in a variety of ways, all of which all result in the same agreed cumulative risk of death prior to spawning. If for highly migratory stocks the mechanism proposed in the preceding paragraph is rejected in favour of sub-optimal harvesting within each jurisdiction, the vector of mortalities-at-age, and the allocations to which they correspond, can be decided by negotiation between participants.

B. Ecosystem considerations and reference points for multi-species fisheries

65. The 1982 Law of the Sea Convention pays attention to the potential impact that fishing one resource may have on others and on the food web as a whole. These kinds of impacts are likely to be most pronounced for species that are competitors, predators or prey of the target species, or are taken as by-catch. A set of species-specific reference points that explicitly recognizes all of these specific types of interactions and quantifies them has not been applied and goes beyond the level of knowledge presently available for almost all marine ecosystems. A notable attempt to do this is found in the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) but many Antarctic fin-fish resources, despite the clauses in the Convention, are severely depleted. To a significant extent this is not the result of a lack of reference points, but rather to a lack of control of access and means to enforce it. A further comment is that the Convention seems to assume that fishing rather than natural variation is the key causal factor in declines in stock size (if not, it will be impossible to prevent a decrease in the size of a stock to below that

which ensures stable recruitment). In reality, stable recruitment cannot be ensured by management action, even if stock sizes above MBAL are maintained.

66. Article II (3) (c) of CCAMLR explicitly requires a management response to potentially irreversible changes to the marine ecosystem as a whole owing to a wide range of possible causal factors. This risks leading discussion on appropriate action into a debate on what actions are irreversible, when an irreversible change has occurred, what elements of the ecosystem are controllable and to what extent. The above doubts also apply to the suggestion that resources of a marine area should be managed under large marine ecosystem principles, by species assemblages, or even more ambitiously, by multi-species virtual population analysis. The latter theoretically allows the trade-offs between human and fish predators of different ecosystem components to become more explicit but is extremely data-intensive, and at this point is merely of theoretical interest in relation to most resources of the type considered in the present paper.

67. From a practical management perspective, there is relatively limited experience with management systems deliberately manipulating the relative biomass of ecosystem components, and this approach requires a prior decision about what the relative abundance of the different species in a given ecosystem should be: noting that this may differ considerably from virgin stock conditions without necessarily compromising the survival of any of the species involved. Such changes affect the equity of fleets fishing different resources and requires negotiation between users of different components of the food web prior to selecting species-specific reference points for the ecosystem component in question. An example of an unresolved contention of this type is the tuna purse seine/dolphin interaction in the East-Central Pacific where there is disagreement between the users of these interacting resources on the effects of the overall tuna harvest rate and exploitation strategy on both resources. As an example of the complexities of species interactions which may nullify comprehensive multi-species approaches, it should be noted that at a high prey biomass (e.g., of a small pelagic fish, the sprat), cod food requirements may be provided for, but large sprat stocks prey on cod eggs potentially affecting cod recruitment.

68. In mixed-species fisheries such as most trawl fisheries, attempts have been made to manage a complex of stocks exploited by trawlers using separate trip limits or reference points by species, or two-tiered quota systems as used by the former International Commission for North-west Atlantic Fisheries, where the total allowable catch (TAC) for all species is less than the sum of TACs for individual species. Both of these approaches have usually led to high discards of unwanted species.

69. Adjusting the exploitation rate in terms of the natural mortality rate may be an empirical approach that could lead to a set of values for species F that are relatively invariant. This is more desirable than making F a function of current species abundance, which with variable environmental conditions would make the fishing mortality TRP a rapidly varying function of environmental conditions. Scaling the species-specific values of F-based LRPs for different food web components according to their relative rates of natural mortality remains a theoretical possibility, but one that seems difficult to implement for

fishing gear such as bottom trawls that are relatively unselective by species. For such unselective types of gears, a precautionary approach, aiming at very little or no risk at all for all species being exploited, would imply that the ecosystem exploitation regime is defined in terms of the species with the least resistance to harvesting, leading to gross underexploitation of the system and possibly foregoing important development opportunities; this suggests that developing more selective modes of harvesting is a high priority.

VI. SETTING MANAGEMENT OBJECTIVES

A. Multiple options for fisheries management

70. Prior to deciding upon one or several of the reference points summarized in annex I, the management objectives for a fishery must be agreed upon. For the stock component within exclusive economic zones, objectives may be decided upon from a mixture of social, economic or biological criteria. For distant-water fisheries, although economic criteria are important, they are not necessarily the same as for the coastal State, and there may be other criteria based on food security or access that are not exclusively economic. This contrast of objectives has already been evident within the Northwest Atlantic Fisheries Organization. Nevertheless, agreement on the appropriate technically defined reference point is the basis for a common approach to the management of straddling or highly migratory resources. By introducing limit reference points for triggering automatic management responses, agreement may be facilitated. In general, the optima for each objective will differ (see annex VIII), and parties will have to arrive at a compromise which takes into account, to the extent possible, the requirements of all sectors having an interest in the marine environment and its resources.

71. Most of the economic activities mentioned in annex VIII can coexist at medium to high biomass levels, but not at low biomasses. The problem in carrying out all of these strategies, is that many resources require a period of rebuilding in order for lost options requiring medium-to-high biomass levels to be recovered. For those few resources which still fall in the category of underexploited stocks, precautionary or probing strategies are suggested, which restrict fisheries to fishing intensities well below the likely MSY levels revealed by exploratory fishing.

B. Components of a reference point-based management system

72. The setting of management objectives for a new fishery and the actions they lead to should perhaps follow, with some variations, the following sequence:

(1) Exploratory fishing and research;

(2) Assessment of the state-of-living marine resources;

(3) Formulation of long-term management objectives and related reference points;

(4) Negotiation of effort or catch allocations by countries and fleets;

(5) Framing of an international management agreement and its approval by Governments;

(6) Translation of international agreements into fisheries laws and regulations;

(7) International or coordinated national provisions for control and surveillance of all participants;

(8) Provision for the routine collection of statistics and samples;

(9) Setting of annual targets for the fishery, where applicable;

(10) Monitoring of the stock, the fishery and the enforcement of fisheries law regulations;

(11) Review of objectives, research results, assessments and control measures.

73. Some items in this sequence (e.g., 3, 4 and 5), although they should be kept under regular review, will be difficult to achieve, and renegotiations to revise them may be difficult. Other items (e.g., 6, 7 and 8) will need to be reviewed at intervals of several years as conditions in the fishery change, and items 1, 2, 9, 10 and 11 will need to be reviewed annually if the optimal benefit from a resource is to be realized and the probabilities of overshooting the chosen TRP, or entering a dangerous zone, as indicated by an LRP, are to be minimized.

74. It will rarely be the case in the late twentieth century that a new fishery will arise that does not affect existing marine harvests, and where sequence 1 to 11 above can be redefined uninfluenced by an existing harvest regime for this or an associated resource. New fishery objectives in a region are almost always superimposed on or replace old ones, and often follow from the use of a new technology or the need to satisfy a new market demand, so that there will be a need to regularly revise the objectives of the fishery. Among the reasons for modifying the regulatory framework, which is growing in importance, are non-harvest uses of the resource, as a result of the interests of constituencies outside the fishery sector. There is thus a considerable danger that for multi-user resources there will be frequent changes in objectives. This can lead to time-consuming negotiations with a consequent danger of overexploitation as a result of disagreement between the parties concerned.

75. In the absence of a speedy negotiated settlement for a new reference point and associated management regime, a safe pre-emptive settlement should be arrived at following a precautionary approach. Given the problems involved in a group of States arriving at a system such as (1) to (11) above, there should be a strong bias in favour of continuity and conservation, and the avoidance, where possible, of new objectives and untested new technologies.

C. The role of scientific advice in defining reference points for management

76. Traditionally, the assessment and management of fish stocks has been a two-tier process: scientists present assessments in the form of one or more catch or fishing mortality levels aimed at maintaining or rebuilding stocks, and the managers make decisions on the level of harvesting to be followed. While fishery scientists may be the most highly qualified to assess the risk involved in any recommendation they present to management, they are aware that considerations of an economic and political nature influence the level of exploitation chosen by the fishery managers. In some fishery management forums fishery scientists have seen that the presentation of a range of possible quota levels results in the selection of one towards the upper level of the range of values decided upon. This type of consideration, and the high degree of uncertainty inherent in the assessment process, has often led to scientific advice being presented to decision makers not in terms of the uncertainty of the estimates concerned, but as one, or several, explicit levels of fishing mortality or annual catch, each referring to one of a number of alternative management strategies.

D. Stock-rebuilding strategies

77. Stock rebuilding is not achieved in a single year and F-based reference points corresponding to lower fishing rates need to be assigned some years in advance; one weakness of most current management systems is their heavy dependence on short-term decision-making. Nevertheless, the benefits of losing immediate gains while returning to safer biomass levels do merit examination. For example, for relatively long-lived species such as cod and haddock, it has been shown that rebuilding over moderate time spans (for example five years) is less economically destructive than short, sharp reductions in fishing mortality (two-year rebuilding plans), while longer rebuilding periods are likely to be too long to afford visible signs of effective recovery. In the case of short-lived stocks, the rebuilding time is likely to be correspondingly shorter. For many stocks which are currently heavily exploited, larger-than-normal cohorts make up a progressively larger part of the annual yield, but may not occur very frequently. Focusing on the protection of these larger-than-normal cohorts may offer the most rapid approach to rebuilding a stock.

E. Risk analysis and the use of reference points for managing resources in a fluctuating environment

1. Risks of over-harvesting and under-harvesting

78. Over-harvesting may lead to stock decline or collapse. If the conditions for safe harvesting can only be met by research, management and enforcement that exceed the resource rents likely to be generated by the resource, serious consideration should be given to reconsidering the desirability of sustained harvesting. Under these circumstances, when biomass is well above safe limits, intermittent harvesting or culling under close supervision may be a less costly alternative than trying to maintain a low but constant rate of harvesting.

79. The risks of under-harvesting are usually defined in terms of the short-term reduction or interruption of a steady flow of benefits to participants in the fishery and consumers, even though this may result in a net gain in the long term. One factor opposing such a risk, for participants, may be the rise in market prices resulting from a reduction in supply. Biologically, for species with low natural mortality, yield foregone should be largely available the following year, when the survivors in the unharvested biomass will have increased in individual size, and may have contributed to the recruitment of the stock. Even for species with high natural mortality, the unharvested biomass will make a contribution through predation to other, possibly commercially valuable, components of the food web.

2. Risks attributable to environmental fluctuations

80. The routine application of reference points in fisheries management would be greatly simplified if environmental conditions remained constant, but most fish populations show wide variations in annual recruitment, which follow a negative binomial or similar clumped distribution, with a large proportion of the exploited yield coming from a relatively small proportion of year classes. There is evidence that the chance of one or two very good year classes being succeeded by a string of poor ones becomes more pronounced as the exploitation rate increases, and this is the environment under which it will be necessary to test the performance of the different reference points.

3. Risks attributable to using the incorrect model

81. Four main uncertainties in simulating a fishery have been identified. These are: (a) measured uncertainty in inputs to the model (e.g., catches); (b) perceived uncertainty in inputs and uncertainty owing to data-dependent decisions during the analysis; and (c) model uncertainty. Testing a reference point using Monte Carlo simulations of a fishery is becoming more common. Such simulations can also be used to estimate the risks and costs of the management measures proposed, as long as all relevant factors are included in the simulation. In these modelling exercises there is always, of course, a danger that the wrong model will be imposed on the raw data.

F. Risk and precautionary approaches

82. A management framework that invokes pre-set actions once one or more reference points indicate that overexploitation is occurring is in effect a precautionary approach. One context for using this approach has been suggested by analogy to a thermostat: the fishery operating under strict access control, even if not subject to a catch target or limitation, once one or more LRPs or rules show evidence of overexploitation or illegal fishing, triggers a pre-established management action which reduces the fleet effort. This is maintained or reinforced until the resource shows signs of recovery, as judged by the same criteria. The effort control may be relaxed somewhat once the fishery is distant from all LRPs.

G. The uses of reference points with different management strategies

83. A frequent observation of fishery scientists is that although there are a number of useful and safe reference points for management, the design of the management regimes which use them is rarely optimal. Such regimes must include a decision-making forum to set guidelines, but the routine management and control and surveillance capability as well as the statistical sampling needed to generate objective ongoing information on stock status must operate largely autonomously once reference points, sets of rules and consultative and management procedures have been established. In this connection, the lack of definition of interactions between the successive stages in the management process is a serious source of uncertainty which can adversely affect the success of management, as can the use of exclusively short time horizons for determining harvesting strategy.

84. Shall there be open-access regimes or control of fishing? Many recent studies have emphasised that the open-access nature of most marine fisheries has been the principal cause of stock depletion, loss of biodiversity and of potential economic earnings, and of adverse impacts on fishermen’s communities. Three types of management measure may be envisaged which control the effort exerted on the stock: (a) input controls, such as vessel and gear limitations in size and fishing power, restrictions on credit, limited licence or limited-access schemes; (b) output controls, such as restrictions on the total amount of fish harvested annually by the whole fleet (TACs), by individual vessels (individual quota schemes), or by taxes on landings. Such individual quota schemes are often made transferable through the creation of a market for access rights which, as in the case of landing taxes, may be employed by the management authority to extract revenue from the fishery.

1. Management using catch quotas as target reference points

85. It has been shown that for stocks with wide fluctuations in abundance (as for many pelagic resources), a constant catch quota corresponds to constantly varying rates of exploitation, and unless it is set at a low level, a significant probability of overexploitation always exists. Quotas tend to lag behind by one or several years the actual variations in recruitment, and particularly as good year classes are approaching full exploitation. A quota that would have corresponded to $F_{0.1}$ or even lower levels when the peak year class was entering the fishery now corresponds to f_{MSY} or even higher levels, and there is marked reluctance by industry to accept a sudden drop in supply under these circumstances. In the North Atlantic, management to date has been largely based on TACs, but there is growing evidence that advice on desirable catch levels has become less reliable as a result of unrecorded catches and high discards. The TAC recommended by scientists, that finally agreed to after political decision-making and the actual catches taken, have tended to increase in sequence.

86. If information is scarce or uncertain, then one of the few feasible quota options may be a very low, fixed quota, using TRP criteria developed to ensure a

pre-set probability of F_{MSY} being exceeded, or with TRP criteria such as F_{MSY}. This approach could be adapted to straddling-stock management, with a cutoff point dictated by one or a series of LRPs which measure when stock size is critical, and the fishery should then be temporarily interrupted until unambiguous signs of recovery are seen.

87. One of the mandatory requirements for quota management under open access, even at apparently reasonable F levels such as $F_{0.1}$, is the need to ensure accurate, real-time estimates of catch, age composition and standardized fishing effort. The fact that many conservatively targeted quota management systems have failed, even for proprietary resources of exclusive economic zones, should prompt a re-examination of all facets of the management procedure. The degree to which quotas chosen correspond to the projected fishing mortality rate has been questioned even for some developed country fisheries. Still more serious in their effect is the degree to which subsequent exploitation rates can be maintained with the quotas allocated, without politico-economic considerations being allowed to stretch the quotas proposed by fishery scientists.

88. A number of authors have shown the advantages of fixing the level of fishing effort as opposed to fixing catch quotas. It has been noted that if harvesting for sustained yield is the management strategy, environmental perturbations will cause more serious departures from equilibrium conditions than when a constant effort strategy is followed.

2. Management by direct fishing-effort control

89. This strategy corresponds to one of fishing-effort control aimed at a target F- value, usually under some system of limited entry. Early criticisms of this approach were that problems of restraining increases in catchability attributable to learning by skippers and as well as those attributable to technological improvements to boats and gear both lead to creeping increases in fleet fishing power. One disadvantage seen in the early optimistic days of quota control was that, under effort control, catches would vary more widely from year to year than with TAC management, but this is still more desirable than stock collapse. Other more valid objections relate to pelagic stocks such as herring where vulnerability to fishing increases at low stock sizes, so that the fishery can enter an unstable area unless some limiting LRP is applied, as in the case of the constant escapement strategy. The objections to direct effort control need to be reassessed in the light of recent failures of quota control. Effort control measures have the virtue, especially for poorly documented straddling stocks, of providing more stable rate of exploitation and less need for drastic year-to-year renegotiation of management targets than quota control.

3. Management with a constant escapement policy

90. Salmon management has classically been based on attempting to achieve a minimum escapement to spawning, and many such fisheries in western North America aim for fixed escapement objectives. A similar approach has been adopted for some straddling squid fisheries. Such a management approach is compatible with spawning biomass reference points.

VII. CONCLUSIONS

91. Fishery managers, whether they operate in relation to fixed reference points or in relation to less clearly defined criteria, should be recognized as acting in an uncertain environment with incomplete information on which decisions can be taken. As such, the present paper strongly recommends that clear objectives be formulated by all participants and that all uncertainties, whether attributable to the institutional structure or environmental or statistical variability, be recognized and explicitly incorporated into the decision-making process, leading to risk-averse management policies.

92. The paper distinguishes between two different uses of reference points: as targets for management, and as limits beyond which fishing intensity (measured as fishing mortality) should not go. This second framework is believed to be closely compatible with precautionary approaches and by explicitly recognizing the informational inadequacies, allows a new target for management to be defined in relation to this limit.

93. Essential to the effectiveness of this approach, however, is that once the best estimate of the current rate of fishing equals or approaches the limit reference point a pre-negotiated management response should be triggered which significantly reduces the current level of fishing mortality to which the stock is subject.

94. The level of fishing mortality that corresponds to MSY conditions, as usually formulated, is not a generally acceptable target for fisheries management. It may, however, with other reference points such as F_{MAX}, still be useful as a limit reference point for fishing, allowing a lower rate of fishing to be defined from statistical considerations that ensures that this upper limit is rarely exceeded. The paper suggests a framework for such procedure.

95. Judging from FAO and other sources, the current situation of global fish stocks is of full exploitation or overexploitation of many of these under the impact of overcapitalized fleets. Straddling and highly migratory resources have received the impact of effort displaced from more carefully regulated national fisheries, and in many cases are in need of stock rebuilding. Under these conditions reference points that lead to stock rebuilding are believed to be appropriate, and a number of these based on economic, reproductive, stock production and ecological interactions are available, which should lead to stock rebuilding if all participants in the fishery cooperate to ensure that information is adequate to define stock status.

96. It is stressed in the paper that a risk-averse approach would be one seeking to define overfishing in relation to not one, but multiple reference points, for a fishery operating under common technical criteria. Such a suite of reference points could allow for errors in misinterpretation resulting from criteria based on one source of data only.

97. Although the issue of the appropriate management approach to take in straddling and highly migratory stock management goes beyond the scope of the present paper, it is questionable whether any fisheries management framework that attempts to operate by reference to any of the reference points mentioned in this paper will have a significant chance of success under free and open access to all interested participants.

Annex I

RP	Theoretical basis	Data needs	Advantages	Disadvantages	As TRP	As LRP	SR
F_{MSY}	Production model (refer paras. 27 to 33)	Annual data series for yield + calibrated effort for all stock removals	Well-studied: estimates and Y,f series available for many fisheries	High danger of overfishing as TRP	N	YY	N
F_{MCY}	Simulation from Annual recruitment series (refer para. 34)	Probability distribution of annual recruitment and population parameters	In theory, allows quota management with threshold	Data-intensive (needs data on recruitment viability)	Y	N	Y
$2/3F_{MSY}$	Production model (refer paras. 32 and 35)	A production model is assumed fitted	Simply calculated if production model exists	Empirical: requires historical data on Y and standard f/F	Y	N	Y?
$F_{0.1}$	Y/R calculation and current state of population? (refer paras. 37 to 39)	Population parameters	Well-studied: simple to calculate from population parameters	Empirical: varies with fishing strategy; no allowance for recruitment variation	Y	N	Y?
Z_{MBP}	Production model (refer para. 41)	Annual data series of standard catch rate and Z	Incorporates predation; requires simple historical data on CPUE; Z	In present form assumes Schaefer model	Y	N	Y?
Z*	Simulate overall mortality at age and mean size caught (refer para. 61)	Population parameters; mean mortality rate in population and mean size caught	Simply calculated from basic population parameters	Needs unbiased data on size, frequency of catch	N	Y	N
F_{LOW}	Estimate F giving 90 per cent of years with stock replacement (refer para. 44)	Assumes data for fitting stock recruitment (usually from cohort analysis)	Reflects past probability of recruitment	Needs historical data on stock recruitment	Y?	N	Y
F_{MED}	Estimate F giving 50 per cent of years with stock replacement (refer para. 44)	-	-	-	Y	N	N
F_{HIGH}	Estimate F giving 10 per cent of years with stock replacement (refer para. 44)	-	-	-	N	Y	N
$F_{SSB/R}$	Biomass/recruit analytic model (refer para. 45)	Population parameters and maturity-at-age data	Simple to calculate; flexible (depends on percentage)	No major problems	Y	Y	Y
F>=M	Empirical experience with fisheries for similar resources (refer para. 40)	Data on exploitation/natural mortality rates which have proved sustainable	For top predators. Low data needs (just estimate of M)	M values inaccurate. An empirical approach	N	Y	N
F<M	As above (for small pelagics) (refer para. 40)	-	For small pelagics. Low data needs (just estimate of M)	-	Y	N	N
F_{MEY}	Econometric modelling (refer paras. 46 to 50)	Historical data on yield/effort/costs and earnings	Can use production model fit plus cost/revenue data	Hard to define for multiple fleets/economic systems: varies with economic indicators	Y	N	N

* RP = reference point; Y = yes; YY = favoured; N = no; LRP = limit reference point; TRP = target reference point; SR = for stock rebuilding; CPUE = catches per unit effort (see text).

Annex VII

USING A LIMIT REFERENCE POINT TO SET A RISK-AVERSE RATE OF EXPLOITATION - THE F_{MSY} EXAMPLE

There may be circumstances when fisheries managers are able to specify an upper limit to fishing intensity, beyond which an undesirable state of the fishery is agreed to exist. As noted in the main document, this may be referred to as an LRP. In the following example it is assumed that the LRP is a pre-established "conventional" value for the fishing mortality corresponding to MSY conditions, agreed by all parties.

The managers acknowledge that they are operating in an uncertain environment and that the current "status quo" for the fishery, together with the F-value during the last season (=F_{NOW}), was not precisely known, but that some rough estimates of its standard deviation can be made. In the hypothetical case in question, there is strong evidence that the fishing intensity last year was below F_{MSY}, and it is assumed that if the same effort were to be exerted in the next season, it could be expected that the probability distribution of fishing mortality rates would remain the same. The managers feel however that it would be useful to define a target reference point in such a way that this results in a small, pre-specified risk that F_{MSY} is not exceeded.

Given this situation, the following illustrates one procedure for calculating appropriate target values for F_{NOW} which result in a pre-specified probability of an agreed LRP being respected. In this example, the LRP is assumed to be a pre-established value for F_{MSY}=0.6. There is no unambiguous evidence in the literature as to the most appropriate distribution function describing the uncertainty in the current value of F, but as a first reasonable choice the normal distribution is used (see the figure below), although similar calculations could readily be performed for other distribution functions.

Mathematically, the procedure adopted is the following: the level of the fishery can safely tolerate (quantified in the figure below as the shaded area on the right-hand tail of the normal distribution) is equivalent to the probability that the current F exceeds the target reference point, F_{NOW}. Referring to this chosen level of acceptable risk as P ($F>F_{MSY}$), the mean of the distribution must be resolved; i.e., the value of F_{NOW} that corresponds to the target reference point providing this margin of safety.

A mathematical package (MAPLE) was then used to solve for F_{NOW} for the nine cases presented in the table.