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Deciding on Precautionary Management Measures for a Stock Based on a Suite of Limit Reference Points (LRPs) as a Basis for a Multi-LRP Harvest Law

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Abstract

This concept paper discusses a semi-quantitative approach to precautionary fishery management easily understood by stakeholders and other non-technical personnel. A checklist is provided incorporating some 30 qualitative or semi-quantitative criteria to be completed by resource experts as a preliminary basis for deciding on priorities for precautionary management of marine resources or fisheries. Four tables are provided (incorporating characteristics respectively, of landing trends, environment and ecosystem, the stocks, and the fishery). The scoring of this checklist permits a semi-quantitative comparison between fisheries in terms of their relative vulnerabilities to non-precautionary harvesting, and allows qualitative but informed opinions to play a part. This approach may also be used in determining which aspects of the fishery require particular attention from research and management, including, if necessary, the formulation of appropriate Limit Reference Points.

It is proposed that multiple precautionary reference points be used which are relatively simply formulated and understood by stakeholders. These would need to be built into a management system incorporating pre-negotiated responses. Analogous to fuzzy logic principles, a methodology is proposed whereby a suite of simple limit reference points can be tuned to provide a gradated management response to the status of multiple precautionary criteria or indices, possibly including the results of questionnaires described in this paper. In this approach the fisheries management cycle incorporates a resource 'traffic light' in the public domain which indicates the state of the fishery, and incorporates a prenegotiated set of management actions in response to the number of red lights on a multiple Limit Reference Point board. The management action should increase in severity depending on the number of indicators that turn from green to red.

Key words: harvest laws, precautionary management, reference points

Introduction

The need to distinguish between Limit and Target Reference Points in fisheries management (Caddy and Mahon, 1995) is now well established as one operational component of a precautionary management system as specified by the FAO Code of Conduct and the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks. The precautionary approach to the use of reference points as noted in FAO (1995) suggests that they should form part of a harvest control law for the fishery in question.

Most harvest control laws formulated to date are specified as an allowable trajectory of points between reference points specified in terms of biomass and fishing mortality. Here it is assumed that the position of the fishery is known with a degree of precision and the management response and the adherence by the industry required to the harvest law is also expected to be achieved with comparable precision.

For many fisheries a history of quantitative estimates of past states of the fishery may not be available, or regime shifts, or changes in the fishery itself, may mean that historical data are unreliable as a guide for action or may be restricted to information on landing trends. Given that precautionary action cannot be delayed until adequate data have accumulated, it may be necessary then to seek a guide for management action in the interim. A broad review of all qualitative and semi-quantitative information on the fishery is important before deciding on priorities for setting limits to management action. It is proposed that qualitative or semi-quantitative information can be incorporated into reference points and into a control law incorporating them. Such a situation where informal knowledge from resource users is incorporated into a decision-making system leads to the use of questionnaires as routinely applied in environmental assessments, as followed under the ISO-2000 standard approach used in a range of industrial management systems that incorporate uncertainty. Such a questionnaire (Caddy, 1996) has already been proposed strictly based on the management-related Articles of the Code of Conduct. Scorings of multiple questions provide a semi-quantitative index of the degree of precaution currently applied in the management system. A similar approach using more technical information seems feasible, and is proposed here as a preliminary to introducing technical management measures, which can in part at least, be built round an information system incorporating multiple non-quantitative criteria. This approach can facilitate discussions between fishery scientists, fisheries managers and the industry/stakeholders. It can also be incorporated as an integral part of an information-poor fisheries management feedback system, driven by semi-quantitative or qualitative information and appropriate prenegotiated responses.

Rivard (1998) shows that even in well-researched fisheries, non-parametric approaches to management can be important where data are limited. However, there have been few approaches that tackle the problem of specifying reference points and harvest control laws in information-poor situations such as are typical of developing-country fisheries, and in many invertebrate fisheries even in developed countries (Caddy, 1999). It is stressed that the success of simple 'rules of thumb' in setting limit reference points depends on them being incorporated into a harvest law. This harvest law would not specify targets for optimal fishing, but should specify prompt and pre-negotiated responses to negative signals from a suite of LRPs, thus acting in the manner of 'fishery thermostat'. Such a hypothetical feedback mechanism is postulated to take the form of an 'LRP traffic light'.

Proposed Methodology

The criteria in tables 1–4 were developed largely from the FAO Code of Conduct for Responsible Fisheries, and provide categories of estimates and/or qualitative judgements believed to be relevant to evaluating the relative level of risk of a series of fisheries, which can be easily understood by non-technical personnel and stakeholders. It is suggested that for each unit resource a scoring be completed for each relevant category or row in Tables 1 to 4, and it may be desirable that a small committee of experts and stakeholders meet to discuss these scorings. Such meetings can be important for explaining precautionary approaches to management, but often prove difficult where management decisions are based on a single mathematically-difficult LRP. In the case of Table 1, based on information on past landings, score red, green or orange once for the resource in question. For Tables 2–4 inclusive, score one point for each row in green, orange or red columns; whichever colour is judged to be most relevant to the resource and category in question. Higher importance should be placed on the red (and possibly orange) scorings, which could then be incorporated into a summary table. At the very least, such a table will form a useful basis for discussion, and constitute a 'precautionary statement' for the fishery in question. A summary table could be derived by managers from the responses to tables 1–4 and used as background material in deciding on the relative importance of management measures, reference points, or the necessary research or data-gathering activities, needed to support the management system.

It would also be useful to group summary tables for those resources which are harvested together or which constitute predators and preys so as to provide, at least qualitatively, an information basis for a multi-species approach to setting reference points.

A Simple Multi-LRP Harvest Law

Simple LRPs as 'rules of thumb' for precautionary management

Caddy and Mahon (1995) noted that in circumstances where uninterrupted series of data on age composition and biomass are not available, and where it is not possible to fit a stock-recruit relationship, there may still be some information available from past harvesting which allows an approximation to MSY conditions to be arrived at, where estimates of growth, natural mortality and virgin stock size have been made. Under these conditions, while it may be difficult to formulate a formal harvest law involving trajectories of fishing mortality and biomass, it may still be possible to formulate

A Precautionary 'Traffic-light' Approach for Deciding on the Importance of Management Measures and Limit Reference Points and as a Basis for a Multi-LRP Harvest Law

TABLE 1. Characteristics of historical landing trends (After Caddy and Gulland, 1983, and Spencer and Collie, 1997.

Complete for each stock with single colour characterization

Environment	Past landing trend	Research priorities	Management actions
Stable ?	**No trend (GREEN)**	Check historical series. Investigate possible feedback mechanisms leading to 'stability'	Avoid exceeding recent/historical levels of exploitation/set cautious LRPs.
	Long-term trends?	*Possible concerns:* Climate change? Environmental forcing? Eutrophication? Simplified/changed food web? Behavioural change? Check biodiversity/ species interactions?	Thresholds should be based, inter alia, on biomass or R-based LRPs.
	Declining trend? (RED)	Check R! Check life history vulnerability/check variance in data sources/intensify surveys + environmental monitoring.	High level of precaution! Assume downward trend is continuing: adopt extreme precaution! Pre-negotiate responses/sharp effort cutback/negotiate stock rebuilding plan!
	Upward trend? (GREEN)	Has R increased? Change in effective effort/ availability? Predator temporarily scarce? New entrants? Is there misreporting?	Stock maintenance strategy/or constant harvest for stock rebuilding? Impact of increases on predators/prey?
	Regular fluctuations? (ORANGE)	Monitor R; Time-series analysis. Environmental linkages or predator prey fluctuations?	Forecasting possible? (Constant) escapement strategy with threshold? Biomass-or R-based LRPs?
	Aperiodic fluctuations? (RED)	Monitor environment/predators+prey. Time series analysis/VPA/Dynamic production models?	Constant exploitation strategy with threshold? Biomass-or R-based LRP's.
Unstable?	**Degraded?**	Habitat destruction? Stock depleted? Environment unfavourable or low spawning stock? Prey depleted?	Formal recovery plan with time schedule/clear objectives. Protect spawning/nursery areas/migration routes

TABLE 2. Characteristics of the environment and ecosystem.

CRITERION	COMMENTS	GREEN	ORANGE	RED	MANAGEMENT IMPLICATIONS OF RED STATUS?	LIMIT REFERENCE POINT FOR RED?
Environment						
1. Latitudinal range	If a stock is close to latitudinal limits of species, stock size fluctuates more with environmental change.	The local fishery operates in the centre of the species range of distribution/few 'bad' recruitment years.	The annual recruitment declines when environmental conditions are extreme.	Recruitment is irregular, only being good in extreme (e.g. warm/cold) years.	Effort control leading to variable yields. Recruitment survey and periodic closures following 'bad' R years?	If R index falls significantly below mean value for n consecutive years, prepare to reduce catches/effort drastically.
2. Life-history vulnerability	Stocks with restricted range at one or more life history stage are vulnerable.	Stock occupies a large uniform environment throughout its life history.	Stock occupies a more restricted and variable environment during some critical life history stage.	Stock occupies a small, vulnerable, very variable environment during critical life history stage(s).	Pay attention to linkages with other societal sectors affecting nursery areas (pollution?): take (legal?) remedial action.	Recruitment and environmental monitoring of nursery areas or critical habitats. (Recruitment-based LRP as above).
3. Presence of unfishable areas in stock range	Refugia may be created by unfishable conditions.	Large part of stock area unfishable/no access.	Significant percentage of stock areas inaccessible.	All stock areas fishable.	Could consider closure of areas/ marine parks.	N/A
Predators and Prey						
4. Relative number/ value of predators	The status of predator populations and their food needs is a key issue.	The predators on the stock are depleted/ few/subject to heavy fishing/higher in commercial value than the target species.	The predators are moderately abundant/several/ subject to sustainable fishing/ similar in commercial value to prey.	The predators are very abundant/ many/of low commercial interest/ low rates of exploitation.	Promote balanced exploitation of food web components. Fit predator-prey model as basis for prediction?	Monitor predator/prey relative abundance as means of forecasting, e.g., increased M on juveniles. Use to develop predator- based LRP?

TABLE 2. (Continued). Characteristics of the environment and ecosystem.

CRITERION	COMMENTS	GREEN	ORANGE	RED	MANAGEMENT IMPLICATIONS OF RED STATUS?	LIMIT REFERENCE POINT FOR RED?
5. Relative number/ value of prey	Predators dependent on a few, dominant food items depend on adequate biomass of these.	The prey species are diverse and not subject to significant fishing pressure/are not subject to serious abundance fluctuations.	The prey consists of only a few species, most of which are commercially fished/ are subject to moderate abundance fluctuations.	The prey consists of one or two species, which are heavily fished/are subject to serious abundance fluctuations.	Ditto. Allocate a biomass share of prey to predators.	An index of relative predator/prey abundance could warn of stock downturns or, vice versa, favourable conditions for harvesting.
6. Vulnerability to fishing gear	If gear is efficient for all ages, escapement depends solely on effort.	Only some age groups vulnerable to fishing in only part of range with current gear, i.e. refugium exists.	Fishable age groups available throughout range with current gear.	All age groups fishable throughout all range with current gear; high discarding or incidental mortality.	Monitor and regulate via discarding penalties/develop selective gear/take measures (seasonal/ area closures?) to ensure adequate escapement to spawning.	Use discard data (from observers or surveys) as basis for closure of areas of juvenile concentration. (Black-box systems useful to reduce costs of MCS.)

TABLE 3. Characteristics of the stock.

Criterion	Comments	Green (TRP?)	Orange (LRP?)	Red (LTP)	Management Implications of Red Status?	Limit Reference Point for Red?
1. Recruitment regularity		Annual recruitment is regular, and variation occurs within a limited range.	Annual recruitment occurs but is very variable.	Annual recruitment occurs intermittently.	(See Table 1.1)	(See Table 1.1)
2. Stock definition?	Absence of data on stock admixture seriously compromises stock assessment results.	Stock status clear with relatively minor admixture with adjacent stocks.	Stock status debatable/could be some admixture with adjacent stocks which are nominally managed separately.	Stock status unknown/likely to be mixed stocks/species managed together.	Genetic/tagging investigations a priority to define/separate stock/species components and extent of intermixing.	Precautionary reference points should be based on conservation of the most vulnerable of the suspected stock/species.
3. Surveys?	Current thinking gives more credibility to direct biomass estimates than from commercial statistics.	Properly designed surveys of stock area at least annually.	Occasional surveys of part or whole of stock area/fishery prospections.	No surveys or direct biomass estimates.	Priority to be given to a direct estimate of stock.	Once there is a survey in place, S-R and other sophisticated LRPs can be developed.
4. Biomass (of spawners?)	Levels of cut-off to be set based on species biology.	>30%? B(0)[1]	20-30%? B(0)	< 20%? B(0)	Need for immediate stock recovery plans/implement pre-negotiated drastic effort reduction.	20% B(0)?

[1] Virgin stock biomass

TABLE 3. (Continued). Characteristics of the stock.

Criterion	Comments	Green (TRP?)	Orange (LRP?)	Red (LTP)	Management implications of Red status?	Limit Reference Point for Red?
Vulnerable to recruitment/overfishing?						
5. Fecundity (MLF = Mean Lifetime Fecundity)	(Range from high-fecundity species to vivipary or brooding of young).	High (MLF = 200 000 - 1+ million?).	Fecundity medium (MLF = 10 000 - 200 000).	Fecundity low (< 10 000, or even (ov-/vivipary)	Monitor population fecundity/egg+ larval surveys?	Especially for lower fecundity species, use life history table to determine F-based LRP's?
6. Age/size at maturity l_m [2] (Relative to size at = 0% gear retention l_c).	Species that are exploited before maturity are more vulnerable.	Small ($l_c \ll l_m$)	Roughly equal ($l_c = l_m$)	Large ($l_c < l_m$)	Be especially careful to keep exploitation low enough to avoid spawning stock depletion! Perhaps close areas of concentration of spawners/adults?	Use Z^2 as LRP. Use F-based LRP (within an escapement strategy?).
7. Marked spawning aggregations occur	Vulnerability of spawners and spawner areas well known.	Spawning diffuse, year round/closure during spawning season/lower value for ripe fish.	Spawning aggregations diffused, or not easily fishable or seasonal fishery/high value for spawners.	Spawning grounds well known, easily fishable/open year round and restricted in extent/'Ripe' fish command high prices.	Close/restrict access to spawning areas seasonally? Reinforce MCS[3] measures at this time. Monitor escapement.	Set escapement-based control measures such that 20?30? etc., escapement reference points are established.
8. Nursery areas	A localized nursery area close to coast is vulnerable to various impacts.	No nursery area: Juveniles everywhere in range.	Juveniles restricted in extent and season.	Associated with vulnerable/restricted habitat/in estuaries, lagoons, mangroves, etc.	(Seasonal) Closure of nursery areas, especially towed gear in contact with bottom. Annual survey of nurseries	Mesh/gear limitations? Develop recruitment index?

[2] Monitoring control and surveillance
[3] See Die and Caddy, 1997

TABLE 3. (Continued). Characteristics of the stock.

Criterion	Comments	Green (TRP?)	Orange (LRP?)	Red (LTP)	Management implications of Red status?	Limit Reference Point for Red?
9. Species changes sex with age, or large dichotomy in growth by sex	Some fish, e.g. groupers, change sex with age; others grow at different rates, e.g. hakes.	No sex change/ growth difference with sex.	Minor changes but requires separate assessment by sex?	Wide difference between sexes in growth/range etc., or protandric/ protogynous hermaphrodites.	Avoid heavy fishing that unbalances sex ratio by fishing out individuals of larger sex.	Monitor sex ratio, and use as basis for a LRP?
Total mortality rate (Z) Useful if M uncertain, or death due to causes other than fishing can be important						
10. Z < Z(MBP)?[4]	Maximum Biological Production, e.g. Logistic Model, is Reference Point when total production (to fishery and predators) is maximized.	Z < Z(MBP)	Z = Z(MBP)	Z>= Z(MSY)	Monitor size/age composition to estimate Z.	Define Z-based LRP
Fishing mortality rate (F) (Z > Z?)[5] Assumes knowledge of M for VPA, or from catch curve analysis						
11. F(MSY) = M?[2]	Use of empirical LRP (based on similar stocks?)	(Demersals or low M species?)	(Small pelagics or high M species?)		Base cut-off points on experience with similar species?	Define and apply M-based LRPs.
F(MSY) > M?	ditto		(Demersals or low M species?)	(Small pelagics or high M species?)[6]	ditto	ditto
F(MSY)>>M?	ditto			(All)	ditto	ditto

[4] See Caddy and Csirke, 1983

[5] See Garcia, Sparre and Csirke, 1989

[6] See Patterson, 1992

TABLE 4. Characteristics of the fishery.

CRITERION	COMMENTS	GREEN (TRP?)	ORANGE (LRP?)	RED (LTP)	MANAGEMENT IMPLICATIONS OF RED STATUS?	LIMIT REFERENCE POINT FOR RED?
1. Allocation of rights?	Fisheries where no rights allocation = open access are doomed to overcapacity/ decline!	Rights allocated completely/good industry/gvt cooperation/ITQs or community-based.	Some sectors are not included in rights allocation/ controversy over rights between participants.	No allocation of rights.	Move as soon as possible to specific allocations/user rights.	Use MCS-based index of infringements as measure of uncertainty of situation?
2. Management structure?	Is there a clear line of authority and action in management? If not, crucial decisions will not be made in timely fashion.	Management operates through clear structure of decision-making based on objective data accepted by participants.	Management decisions may be overridden by political considerations: decision tree is ambiguous.	No single body with clear management authority over whole stock area exists	Develop as soon as possible a clear decision making structure for management	N/A
3. Is there a management plan/decision rule/harvest law?	Agreement on long-term objectives is essential to proper management.	A harvest law exists, dictating when LRPs are triggered, and long-term objectives are met.	A number of (conflicting) objectives between stakeholders not yet resolved.	All decisions are made ad hoc and subject to detailed negotiation on annual basis	Move to structured plan based on proper simulation of likely futures, and contingency plans in case of failure	Adopt management plan/harvest law based on estimates of probability/risk.
4. Fishing strategy?	Problems of conflict between stake-holders weaken possibility of proper management.	Typically only one stock fished per trip/no tranship-ment at sea/data verified by observers and/or satellite- transponder system.	Some boats may fish two and more stocks in a single trip/transhipment at sea occurs/data from log books/port interview.	Fleets fish two and more adjacent stocks in a single trip/transhipment at sea frequent/no observer systems or log books.	Seek to negotiate allocations/fishing zones by fleet and consultative process. Do comparative fishing power analysis.	Use one or more fleet statistics as index of stock changes.

TABLE 4. (Continued). Characteristics of the fishery.

Criterion	Comments	Green (TRP?)	Orange (LRP?)	Red (LTP)	Management implications of Red status?	Limit Reference Point for Red?
5. Is there a formal assessment?	In absence of regular (not necessarily annual) assessments, management is 'scat of the pants'.	A formal assessment has been prepared annually for a series of years and showed stock to be less than fully exploited.	The last assessment of the stock was some years ago, and showed stock to be fully exploited, but catch rates are holding up.	No formal assessment has been made, but there is symptomatic evidence of declining catch rates.	Priority to preparation of formal assessment/set precautionary reference points based on available data.	Probably assess-ment will allow precautionary reference points based on S-R/ biomass/total mortality.
6. Damage from fishing/discards	High discarding, if not properly recorded, leads to misleading information on stock status.	Low-level incidental damage/discarding in this or associated fisheries/high survival discards.	Moderate level incidental damage/ discarding/most survive.	High incidental damage by fishing/ high discards/few survive.	Close vulnerable areas to dragging gear/measures aimed at reducing discarding.	Monitor discards and use as ecological impact/ or monitor juveniles discarded.
7. Target species caught incidentally in fisheries aimed at other species	The by-catch of a depleted stock in another fishery can lead to commercial extinction if not controlled.	The 'other fishery' is small/localized in extent with respect to range of target species/is seasonal/is strictly regulated.	'Other fishery' coincides in extent with target species fishery/is of same size and importance/is almost year round/is loosely regulated.	'Other fishery' is larger than that for target species/is of greater importance/ is year round/is unregulated.	Ensure regulation of 'other species' has provisions to control by-catch/discards/up-grading. Monitor and close areas temporarily with high level of discards.	The proportion of catch of target species in catch can be used as LRP for management of 'other species?
8. Unit value of species	High value species are subject to infringements, even when depleted, which are difficult to detect.	The target species is of low value/price is independent of local abundance/the targeted fishery ceases at low catch rates/is not an important by- catch of other fisheries in region.	The target species is moderately valuable/ price goes up with decreased local abundance/and the targeted fishery ceases when catch rates drop to low levels.	The target species is highly valuable/price rises rapidly as local abundance declines/ occasional fishing will persist even on highly depleted stocks.	Access rights to be tightly enforced with monitoring through to consumer. MCS measures will need reinforcing, even on other fisheries taking species incidentally. Recovery plans for the stock must be agreed to.	Minimum biomass- or spawning stock- based measures will need developing, and possibly stock-recovery strategies.
9. Catch trends	Sharp increases in catch or sharp declines may presage problems.	Catch has been stable for a number of years.	Catch has been declining slowly.	Catch has declined sharply in last few years.	Monitor catch trends and correlate with size distribution changes.	Define a LRP based on, e.g., lower quartile of long-term catches?
10. Fleet trends	Evidence of new fleets/new gear/larger gear is index of future problems.	Fleet stable in size with same gear over last decade.	Fleet slowly growing/more powerful boats/ becoming more efficient/new gear being adopted.	Sharp changes in fleet size/power/ strategy/gear applied.	Monitor fishing power and licenses in fishery	Use total HP as index of changes in fleet or better, use survey index.

several limit reference points. From past experience with the same or similar resources elsewhere, these have a reasonable likelihood of being precautionary, and can even be tuned in light of experience. See also Caddy (1999) and Seijo and Caddy (in press).

Where some quantitative information on dynamics is available, one of the simple reference points given in Caddy (1999) seems feasible. For example, following Gulland (1971), such reference points might be formulated in terms of biomass and virgin stock size as:

LRP (precautionary TAC) < xMB_0, where x is significantly lower than the 0.5 used by Gulland.

Patterson (1992) noted that low values of x in Gulland's formulation MSY = xMB_0 are more precautionary for small pelagics (and presumably other stocks with high natural mortality rates). Caddy and Csirke (1983) proposed a reference point, the point of Maximum Biological Production (MBL), that is aimed at conditions when stock production to fishing and natural deaths is maximized.

Other examples were provided by Die and Caddy (1997) who also suggested that MBL is precautionary and relatively easy to calculate (Fig. 1). Based on a knowledge of von Bertalanffy's growth parameters and with some ideas on selectivity, Die and Caddy also suggested several simple reference points (Z*, F* and l_c*) that can be formulated as

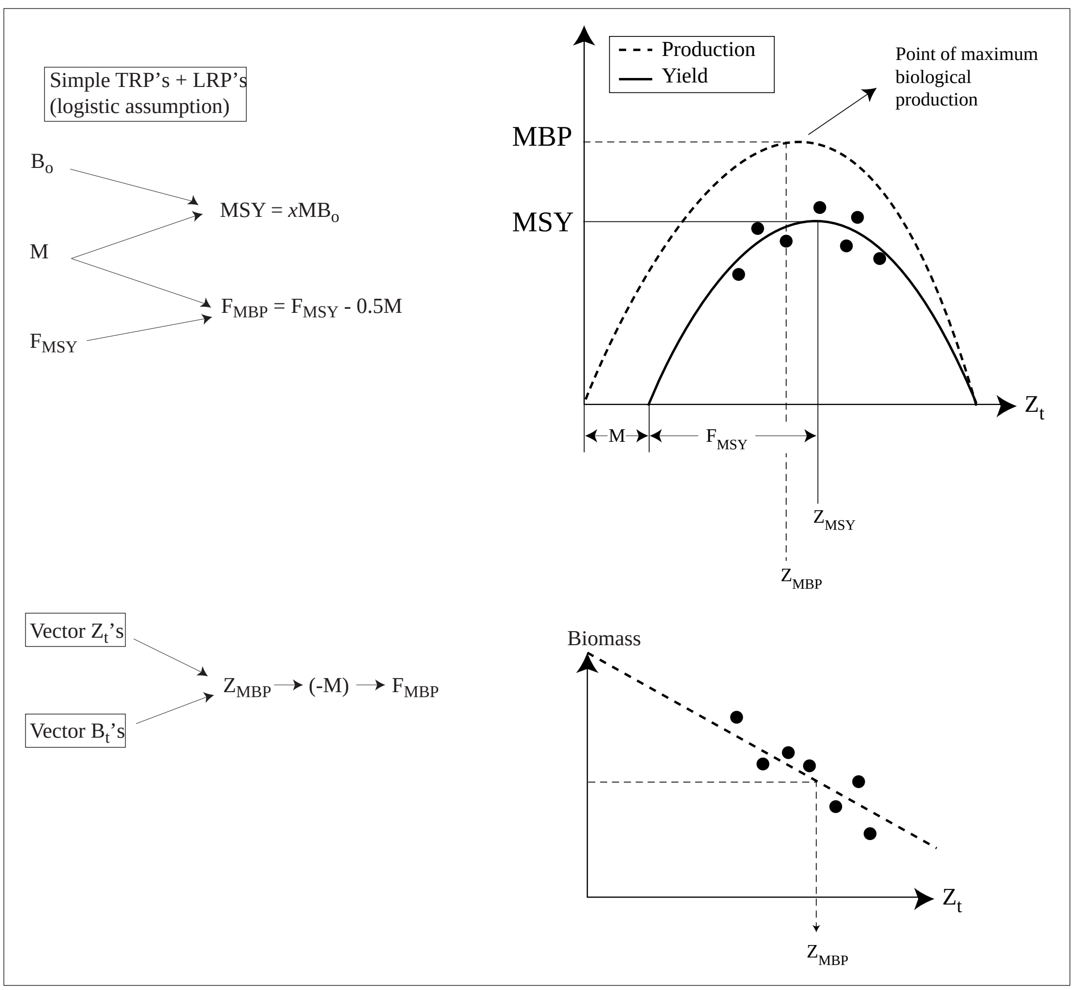

Fig. 1. Several target (TRP) and Limit (LRP) reference points based on production and biomass (after Die and Caddy, 1997) showing derivation of parameter values associated with the point of Maximum Biological Production (MBP).

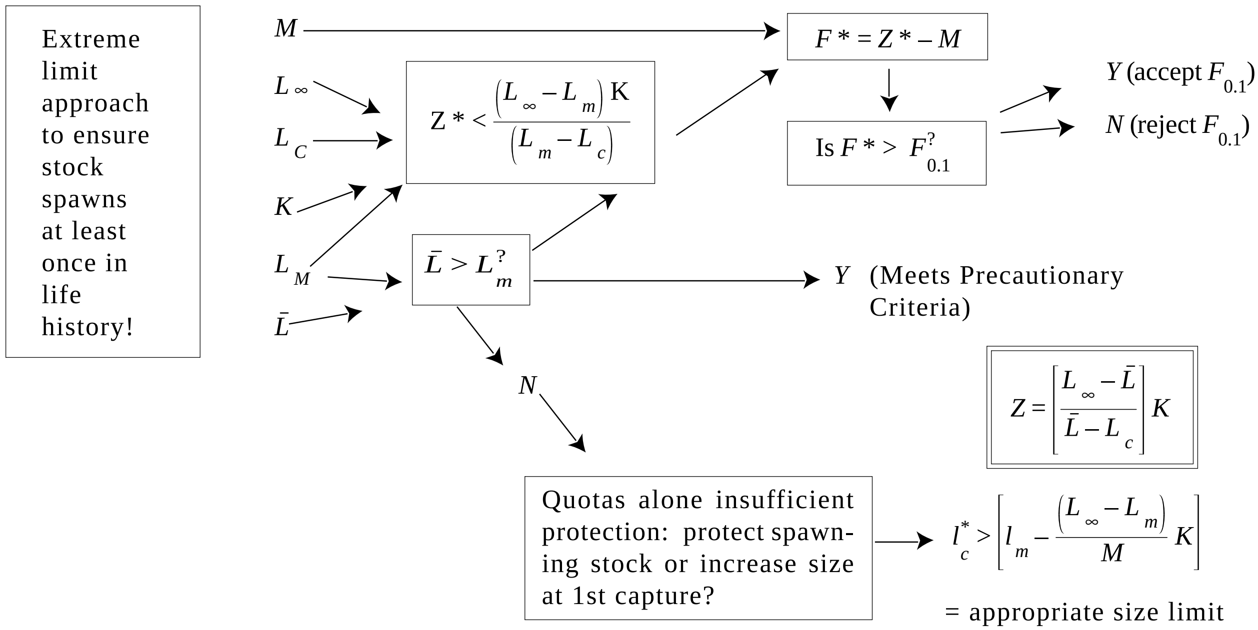

Fig. 2. Several simple size-based reference points formulated assuming that a precautionary approach should be allowed to spawn at least once in the life history (after Die and Caddy, 1997).

inequalities (Fig. 2). These follow from the assumption that a precautionary reference point is one allowing the cohort a reasonable probability of spawning at least once before capture, and this criterion can be used to test other F-based reference points for their conformity with this principle.

Finally, and this is the main emphasis of the paper, qualitative or semi-quantitative information incorporated into a questionnaire can be summed to provide scorings, and can be used to generate LRPs. This is similar in principle to the ISO-2000 standard approach used in environmental assessment. Obviously, tuning the scorings or cut-off points for semi-quantitative criteria to indicate when dangerous or hazardous conditions are approaching, will probably be necessary in light of local experience. One approach may be to agree on earlier years when the fishery moved from a safe to an unsafe condition, as a guide to choosing cut-off points for semi-quantitative data.

The use of suites of LRPs

Recognizing that such simple reference points or indices are not easily intercalibrated, nonetheless there may be advantages in not setting up a management system that relies on measuring a single LRP with high precision. A suite of reference points such as proposed here could form one component of a feedback system, as long as management and industry work together to ensure implementation. This approach would require pre-negotiating with stakeholders to ensure prompt action when most of the LRPs indicate that the fishery is no longer meeting a broad set of precautionary standards. It is believed that a suite of simple 'rules of thumb' based on past experience and experience elsewhere can be incorporated in such a suite of multiple reference points. These might even be simply measured criteria derived from a past year or years in the fishery when there was a transition from favourable to unfavourable conditions. It might be easier to achieve a general consensus from stakeholders that such events in the institutional memory should not be repeated. If values for criteria based on past 'bad' years have been chosen in consultation with experts and resource users, values for cutoff points should be chosen such that unsustainable fishing conditions can occur without some of these indices registering this situation.

Like any other control system, a harvest law specifying limit reference points only forms part of the total management system. The rapidity and effectiveness of the management response to a LRP changing from green to red will determine whether a harvest law attains the required precautionary objective. Achieving consensus from stakeholders on severe management restrictions when these are needed may be difficult if the technical basis for action is not readily understandable. Given this, any justification for choosing very sophisticated or precise reference points that need regular adjustment or major data gathering exercises, seems less than convincing.

One suggestion to management could help counteract the usual 'effort ratchet' principle (Caddy, 1984) whereby effort continues to increase despite declining resource status. This would be to require that annual quota increases in response to good news not exceed (say) by 20% the last year's quota, whereas evidence for declining resource abundance would be required to trigger a decrease in quotas of no less than (say) 40%. This would add a degree of precaution to the management response and a greater readiness to reduce exploitation in the light of unfavourable conditions, as well as offering more opportunities for light on the 'traffic-light board' to change from red to green again.

Following initial experience with such a suite of LRPs, management may agree with stakeholders to adjustments to the cut off points. These can either consist of modifying the LRP so as to reduce or increase the degree of precaution, and/or changing the severity of management response when LRPs are exceeded. Such decisions should ideally be taken in a transparent way, as allowed for in the FAO Code of Conduct for Responsible Fisheries. It will of course be desirable that scientific monitoring of the performance of such a management

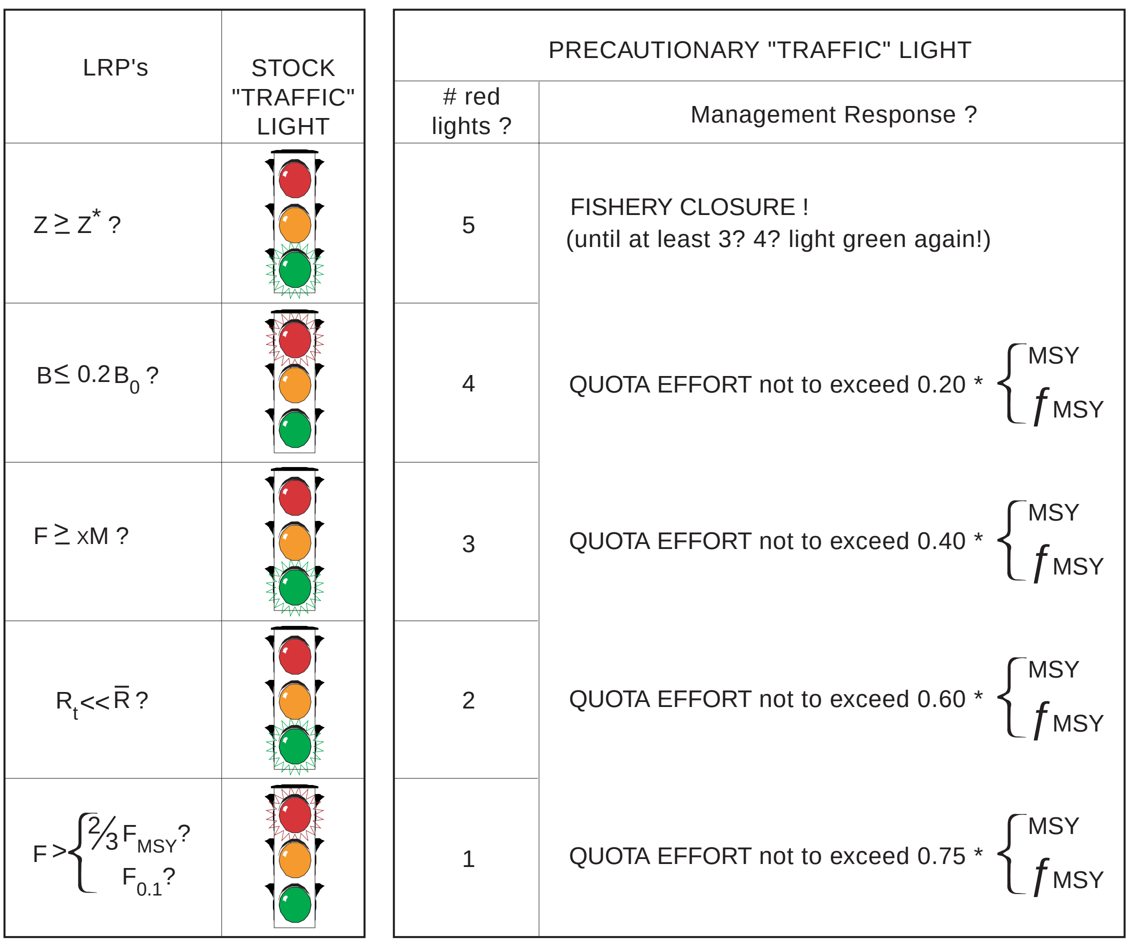

Fig. 3. A harvest law based on multiple LRPs integrated into a feedback loop incorporating gradated management responses. Here, 5 examples of LRP's (left) are tested against data from annual fishery analyses. The LRP's represent agreed limits to dangerous conditions. If the inequalities to the left are contravened, these manifest as 'red' lights on a precautionary 'traffic light'. The number of red lights lit determines the severity of the (pre-negoitated?) management response; (modified from Caddy, 1999)

system be provided in parallel; especially in the early stages of application.

It was suggested in Caddy (1999) and Seijo and Caddy (in press), that a 'traffic-light' approach to the use of such limit reference points could be feasible, and more easily understandable at all levels in the fishery management system (Fig. 3). Management responses are assumed to be calibrated to be progressively more severe as the reference points pass from green to orange to red conditions. Scorings of Tables 1–4 could be incorporated into such a multi-reference system. For example, if 75% or more of the scores in Tables 1–4 are in the green or orange category, an overall green scoring might be agreed to; if less than 50% of the scorings are green, an overall red or warning score might be used in the traffic light control panel. Of course such cut-off points would need to be discussed in the light of the particular situation that applies, and it may be preferable to use the tables simply to indicate the general level of precaution required, or to suggest what type of LRP is most appropriate.

Such a feed-back control system seems testable by simulation and this could still be feasible in relatively data-poor conditions using a Monte Carlo approach (e.g. Seijo and Caddy, in press). An analogy can be made to systems of fuzzy logic which are progressively finding applications in control systems, and further developments in this area (e.g. Saila, 1997) seem worth pursuing.

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