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From model-based prescriptive advice to indicator-based interactive advice

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Traditional advice for fisheries management, especially in the ICES world, focuses on short-term stock projections relative to reference points. Primarily, two numbers, spawning-stock biomass and fishing mortality rate, are considered in the advice, although a range of biological processes are included in the stock assessment models. We propose an alternative form of final advice that would not rely on stock predictions and only two numbers, but on a suite of indicators that are combined to provide stock assessment and management advice. For a single stock, the approach consists of monitoring a set of indicators of population state and fishing pressure. Stock reference status at some time in the past is assessed, based on these indicators and/or other available information. Changes in indicator values after this reference time are then estimated, interpreted, and finally combined into a diagnostic that highlights possible causes of the changes observed. After considering management objectives, appropriate management actions can then be proposed. The proposed approach is illustrated for anglerfish stocks in the Celtic Sea and the Bay of Biscay.

Keywords: fisheries management, indicators, scientific advice.

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Introduction

Many European stocks and fisheries are in poor shape and, retrospectively, the question arises whether scientists have provided the right type of advice to avoid resource deterioration. In the ICES culture, the advisory process culminates in the production of total allowable catch (TAC) recommendations (Rozwadowski, 2002) and a heavy machinery (from catch sampling and surveys, through dozens of working groups, to extensive reviews by the Advisory Committee on Fisheries Management) is operated each year just to serve the TAC system. This process is founded on the assumption that scientists can make precise forecasts of stock development, based on estimates of current population size at age and on information about incoming recruitment, and that TACs can be fine-tuned to meet management objectives (ICES, 1985; notably Annex 11). The sad fact is that for most demersal stocks, the TAC advisory and management system has not been able to curb escalation of fishing mortality, partly through the deterioration of catch statistics undermining the accuracy of the predictions. However, there is growing recognition that, even if the recommended TACs had been adhered to strictly, they would not have produced the desired level of fishing mortality (Kell *et al.*, 2005).

It is to be regretted that this advice, based on number crunching, sidelines and fails to educate the clients about the basic laws of biology and ecology under which marine resources function. In effect, emphasis is placed on some inevitably uncertain numbers rather than on firm knowledge established by the broader marine scientific community. Moreover, TAC advice is perceived as being too normative, and scientists are suspected of imposing their own objectives and values on managers and the industry. Ultimately, the present form of advice can lead to confusion among stakeholders and the public at large about the respective roles of managers and scientists in the decision-making system, scientists appearing to have the key role and attracting the blame for management failure.

These perceived limitations of the current advisory system, i.e. a lack of communication of basic biological knowledge, the inherent uncertainty of absolute stock estimates, the unreliability of catch forecasts, and too normative advice, led us to propose a change in the type of scientific advice offered to managers (Rochet *et al.*, 2005). Here, we describe a stock assessment approach based on indicators derived from scientific survey data that provide information on the state of a stock. In combination with predefined management objectives, these indicators are used to diagnose if and which population processes (recruitment, demographic structure, etc.) are changing, and in what direction fishing impacts need to be modified by managers to halt and, it is to be hoped, reverse undesirable trends. The approach is intended to be used either independently or to complement traditional model-based methods, when sufficient data are available for the latter approach. We demonstrate the approach for two anglerfish stocks (*Lophius piscatorius* and *L.budegassa*) in the Bay of Biscay and the Celtic Sea, using bottom-trawl survey data, and comparing the recommendations derived from the last available ICES advice (ICES, 2005a).

An indicator-based approach

General concepts

The proposed indicator-based approach comprised of clearly separates the roles of scientist and manager (Figure 1). The first action

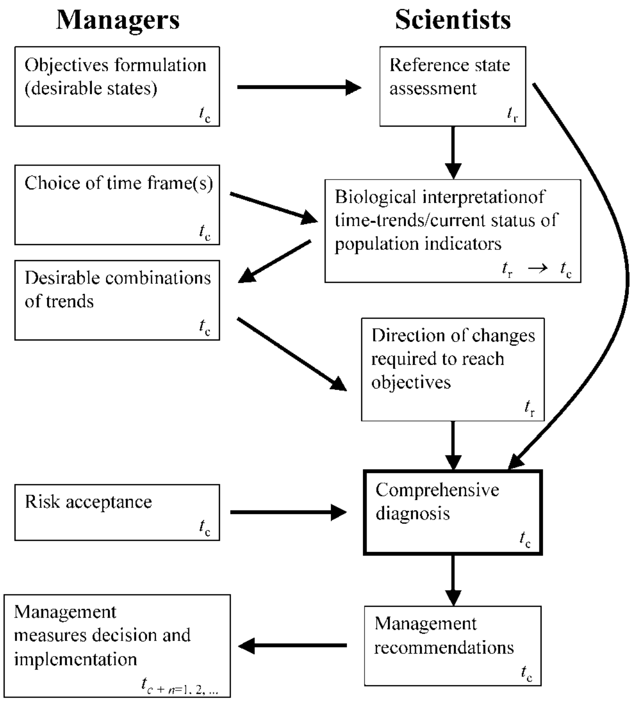

Figure 1. Schematic representation of the indicator-based interactive advice approach, with the roles of managers and scientists (t_c, current year; t_r, reference year; t_{c+n}, future years).

is for managers to define their management objectives, e.g. a specific level of landings or a specific average size of caught fish (step 1 in the framework proposed by Rice and Rochet, 2005). Scientists then establish the state of the stock in relation to these objectives as they stood at some time in the past, referred to as the reference state, based on all available information. The starting year of a survey time-series (or any other year if that is considered more appropriate) might be taken as the reference year (t_r in Figure 1). The aim of the process is to categorize the population state in the reference year as being either satisfactory or unsatisfactory. This defines the direction of trends in population indicators required for the status in the current year t_c to be equally satisfactory as, or more satisfactory than, that of the reference year. Therefore, current status is assessed by considering the direction of change in population indicators in preceding years. Some management objectives might be used directly as reference points (e.g. an arbitrary percentage of the fish in survey catches should be larger than a specific size or total mortality should be smaller than a specified value). The task of scientists is to estimate the temporal trends in population indicators from t_r to t_c. The combination of actual trends in different indicators relative to their required directions allows a comprehensive diagnosis of the recent evolution of stock status, given a biological interpretation of the processes that could be held responsible for the trends observed. Investigation of time-trends of pressure indicators and additional information allows scientists to refine the diagnosis in terms of the possible causes driving the changes observed. Hence, suitable management measures might be proposed to mitigate potentially negative effects of fisheries on stock status.

Comprehensive diagnosis and management recommendations

The process of creating a comprehensive set of diagnostics can be divided into several steps:

(i) select t_r and calculate time-series of suitable population indicators;

(ii) determine trends and status for each indicator in t_c relative to t_r;

(iii) evaluate additional information and combine the results of different indicators to provide an interpretation of the changes observed;

(iv) state a final diagnosis, including possible causes;

(v) determine trends in fishing pressure and propose appropriate management action, in light of the diagnosis and stated objectives.

For Step (i), many authors have proposed and tested indicators derived from survey estimates (Gangl and Pereira, 2003; Rochet and Trenkel, 2003; Ault *et al.*, 2005). Ln-abundance, mean length, and the quartiles of the length distribution are easily and generally precisely estimable. Total mortality is another informative indicator, but it requires additional data on age or growth.

For Step (ii), uncertainty and natural variability in the survey data can be accommodated through a hypothesis-testing framework. A hypothesis test involves two types of error, the type-I error of detecting a trend where there is none and the type-II error of not detecting an existing trend. Whereas the α-risk of type-I errors may be arbitrarily selected, the probability of type-II errors increases as α decreases. Because of the trade-off between the type of error to be avoided, the selection of α is the task of managers. The selection of a suitable year range to detect recent changes is also up to managers, but it has to be set in relation to t_r. However, in many cases, relatively long time-series ($>$20 y) are required to detect significant linear trends because of the generally large interannual variations in population indicators (Nicholson and Jennings, 2004). Even within a multi-annual approach, it is desirable to detect drastic changes to allow measures to be taken rapidly. Alternative methods for identifying degrading situations include cumulative sum (CUSUM) charts (Page, 1961; Hawkins and Olwell, 1997) and methods based on the second derivative of the indicator time-series (Fewster *et al.*, 2000) that allow identification of changes in the underlying dynamics. For certain indicators such as total mortality rate, absolute reference points have been proposed (Die and Caddy, 1997). The final aim of this step is to determine the direction of the most recent changes for each indicator (i.e. decreasing, stable, or increasing).

In Step (iii), the results of several population indicators are combined. Several methods have been proposed, the traffic-light approach being perhaps the most widely known (Halliday *et al.*, 2001; Caddy, 2002). Depending on how many indicators are in an undesirable state (red), the overall status is evaluated. For this approach, the different indicators are usually given equal weight, but they could just as well be weighted based on some *a priori* criteria.

Rochet *et al.* (2005) proposed an alternative approach, based on combining population and community indicators based on their biological meaning. Here, we extend this approach for the case of five population indicators: log-transformed abundance ln(N), mean length $\bar{L}$, length quartiles $L_{25\%}$ and $L_{75\%}$, and total mortality Z. Starting from the expected effects that both anthropogenic and natural factors might have on each indicator, the expected combination of indicator trends for each cause is established (Table 1). Additional biological information (e.g. recruitment estimates, mean weight-at-age) should be sought to clarify the causes of the changes observed. Moreover, investigation of time-trends in indicators for fishing pressure such as days-at-sea or fishing mortality (F) (Piet *et al.*, 2007), but also catches or landings, will allow corroboration of whether changes in fishing pressure could have been the major cause, before stating the final diagnosis [Step (iv)].

The last step then is to propose possible management measures that are linked to each diagnosis of cause (Table 1). The proposed measures depend on whether the reference state was considered satisfactory or unsatisfactory, and whether fishing pressure had increased since the reference year. An impacted initial state and increasing fishing pressure are considered to be equivalent in terms of management measures required. As the diagnosis is qualitative, so are the proposed management measures: the advice provides the direction of appropriate measures rather than prescribing them in quantitative terms, leaving the final decision to managers, who should be guided by past experience. The measures proposed seem suitable for different human and natural biological causes (Table 1), and they relate to F and TAC. *Status quo* means to keep TAC or F at recent levels, i.e. to halt any increase in fishing pressure. The measures listed are not intended to be exhaustive. Clearly, more dialogue with interested parties and a synthesis of practical experiences should lead to more-refined measures.

Case study

The distributions of two anglerfish species in the Northeast Atlantic, *L. piscatorius* and *L. budegassa*, partly overlap, but the former is generally found in more northern and deeper waters (Quéro, 1984). *Lophius piscatorius* attains a larger size and lives longer than *L. budegassa*, but it matures younger (Table 2; Quincoces *et al.*, 1998a, b). The two species are often caught together in mixed fisheries, mainly by trawlers and gillnetters.

Since 1997, a stratified, bottom-trawl survey covering the Bay of Biscay and Celtic Sea has been carried out annually in autumn (Poulard *et al.*, 2003). Population indicators were calculated for the two anglerfish species for the period 1997–2004. In the absence of reliable age data, total mortality could not be estimated for either species. Total landings were taken as a pressure indicator (ICES, 2005a), owing to the lack of suitable effort data.

We use these data to illustrate the indicator approach to providing management advice. However, not all steps of the comprehensive assessment could be performed satisfactorily because of the lack of interaction with managers to decide on suitable objectives.

Reference state assessment

We take 1997 as the reference year and assume that the status of the two stocks was satisfactory at that time, based on ICES (1998, 1999) advice. On the basis of landings and survey data for the period 1986–1997, the stocks of the two species in the Celtic Sea and the Bay of Biscay were considered within safe biological limits at that time, although their spawning-stock biomasses (SSBs) had decreased continuously from 1986 to 1993 (Table 3).

Table 1. Expected effects of different causes on a fish population and fishing pressure (f) indicators and possible management measures for counterbalancing changes, depending on impacted and satisfactory reference states and changes in fishing pressure.

Dominant cause	Z	ln(N)	$\bar{L}$	$L_{25\%}$	$L_{75\%}$	Other	Management measures	
							Reference state impacted or f increasing	**Reference state satisfactory and f not increasing**
↗ Fishing mortality	↗	↘	↘	—	↘	f↗	$-\Delta F$, reduction in overall fishing mortality	$-\Delta F$
↘ Fishing mortality	↘	↗	↗	—	↗	f↘	*Status quo*	$+\Delta F$, increase in fishing mortality possible
↗ Recruitment	—	↗	↘	↘	—	R↗	*Status quo*	$+\Delta$TAC, increase in TAC possible
↘ Recruitment	—	↘	↗	↗	—	R ↘	$-\Delta$TAC, reduction in TAC	$-\Delta$TAC
Faster growth	—	—	↗	—	↗	W_{age} ↗	ΔS: increase selectivity to larger sizes	ΔS
Slower growth	—	—	↘	—	↘	W_{age} ↘	*Status quo*	ΔS, selectivity could be decreased to smaller sizes
↘ Population overlap with survey area	↗	↘	—	—	—	ΔCG	No recommendation possible	No recommendation possible
↗ Population overlap with survey area	↘	↗	—	—	—		No recommendation possible	No recommendation possible
No change	—	—	—	—	—	None	$-\Delta$TAC or $-\Delta F$, reduction in fishing pressure	*Status quo*

Z, total mortality; ln(N), log-transformed total abundance; $\bar{L}$, mean length; $L_{25\%}$ and $L_{75\%}$, length distribution quartiles; R, recruitment; W_{age}, weight-at-age; CG, spatial centre of gravity, Δ, change; —, no trend; ↗, increasing; ↘, decreasing.

Table 2. Life history traits of *L. piscatorius* and *L. budegassa* in the Bay of Biscay (after Quéro, 1984; Quincoces *et al.*, 1998a, b).

Trait	*L. budegassa*	*L. piscatorius*
Latitudes	0–55°N	20–75°N
Depth (m)	50–800	20–1000
$L_{infinity}$ (cm)	100	150
Length at 50% maturity (females) (cm)	65	73
Age at 50% maturity (females) (y)	10	7

Indicator-based assessment

Using a conventional value of $\alpha = 0.05$, only the ln(N) time-series for *L. piscatorius* showed a significant trend ($p = 0.01$) over the entire survey period (1997–2004), abundance having been increasing at a rate, *r*, of 0.19 (Figure 2). For both species, estimated population abundances in the final year were among the highest observed, and estimates of mean length in the survey catches were among the lowest. For *L. budegassa*, we arrive at the diagnosis of no overall change since the reference year, when status was considered to be satisfactory (Table 3). In addition, the stability of total landings is interpreted to mean stability in fishing pressure. As current TAC management has apparently been able to keep the stock in a satisfactory state, the recommendation might be *status quo* management. For *L. piscatorius*, the combination of observed trends points to an increase in recruitment as a plausible cause, even though this should have been evident more clearly as a decline in mean length. To examine whether recruitment can be held responsible, the accumulated length frequency distributions over all years were plotted (Figure 3, top panels). The clear dip around 17 cm for *L. budegassa* and around 26 cm for *L. piscatorius* suggests that peaks to the left of these represent the recruiting year class. Tentative recruitment time-series were then estimated using only fish smaller than or equal to these lengths (Figure 3, bottom panels). For *L. piscatorius*, the increase in recruitment was significant ($p = 0.04$; slope = 0.3), corroborating our diagnosis. Again, total landings were stable. Therefore, our final assessment for this species is that population size has increased since the reference year, owing to an increasing trend in recruitment, while fishing pressure has remained stable. Consequently, our recommendation would be that some increase in catch (TAC) might be allowed (Table 3).

ICES advice

The recent advice states that both stocks are at full reproductive capacity (ICES, 2005b): *L. budegassa* is considered to be harvested sustainably, whereas *L. piscatorius* is at increased risk of being harvested unsustainably (fishing mortality being at around its precautionary reference point). ICES (2005b) also states “So far the stocks have developed synchronously but this may not be so in the future in which case they should be managed separately”. This would be problematic, because the two species are caught on the same grounds by the same fleets and, therefore, their *F*-values are linked. Moreover, they are often not sorted by species when landed. For 2006, the maximum *F* in accordance with precautionary limits is 0.24 (i.e. *status quo* for *L. piscatorius*) and 0.23 (*L. budegassa*). The advice is not to increase the TAC for the two species combined above the agreed TAC for 2005 (ICES, 2005a).

Discussion

The management recommendations we arrive at for the two anglerfish stocks in 2005 by applying the proposed indicator-based assessment method for the stocks separately differ somewhat from the ICES advice for the combined stocks. Although we would recommend no change for *L. budegassa*, in agreement with an unchanged TAC advocated by ICES, we would allow some increase in TAC for *L. piscatorius* based on signs of recent good recruitment, which is not mentioned in the ICES advice. These recommendations are conditional on the evaluation of satisfactory population states in the reference year. Basing our reference state assessment on the 1999 ICES advice was probably not conservative, because the “satisfactory” state is assessed relative to precautionary rather than desirable levels of exploitation. Therefore, a

Table 3. Comparative evaluation of *L. piscatorius* and *L. budegassa* in the Bay of Biscay and the Celtic Sea by formal ICES stock assessment and by the indicator-based procedure.

Evaluation	*L. budegassa*	*L. piscatorius*
ICES evaluation		
Reproductive capacity	Full ($B > B_{pa}$)	Full ($B > B_{pa}$)
Harvesting	Sustainable ($F < F_{pa}$)	Increased risk of unsustainable harvest ($F = F_{pa}$)
Recommendation	Do not increase common TAC	Do not increase common TAC
Indicator-based evaluation		
Reference status	Within safe biological limits	Within safe biological limits
Time-trends in indicators, 1997–2004		
ln(N)	⇔	↗
$\bar{L}$	⇔	⇔
$L_{25\%}$	⇔	⇔
$L_{75\%}$	⇔	⇔
Time-trend in recruitment R	⇔	↗
Final diagnostic	No change	Increasing abundance owing to increasing recruitment over past 8 y
Time-trend in total landings, 1997–2004	⇔	⇔
Proposed management action	*Status quo*	Increase of TAC possible

⇔ , stationary; ↗, increasing significantly; $\alpha = 0.05$.

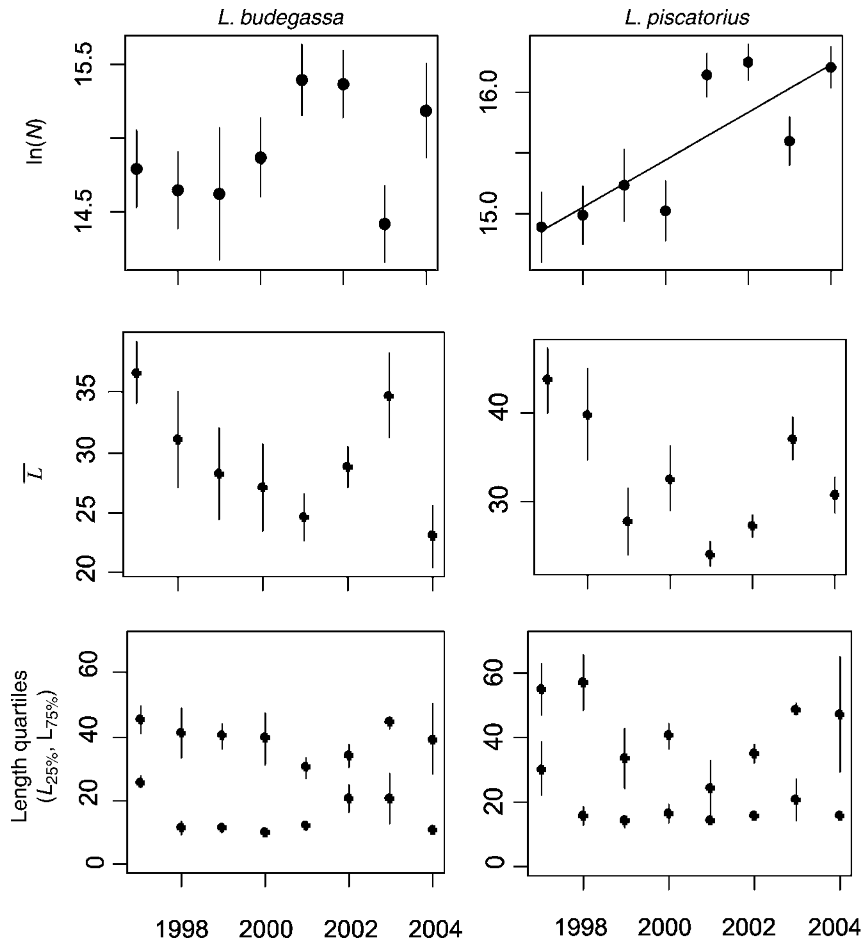

Figure 2. Time-series of indicators (significant trend for *L. piscatorius* ln(N): $p = 0.013$, $r = 0.19$).

more appropriate method for assessing the reference state appears to be required. The ability to provide separate advice for the two species might be useful if their dynamics start to diverge in future. Although separate management may not be easy to implement, advantage might be taken of the differences in their distributions and sizes when devising separate policies (if required).

Compared with traditional TAC-based advice, the indicator approach makes a more comprehensive use of basic biological knowledge, relies on neither absolute abundance estimates nor stock projections, and provides non-normative, interactive advice. Actually, the advice provided is sometimes based on indicators, because TAC recommendations for stocks without sufficient information to carry out an analytical assessment tend to be made based on trends in landings. Therefore, considering additional indicators could only improve the basis of decision-making.

The example presented to illustrate the method relies on a too narrow range of indicators. Including additional factors that describe fishing pressure or environmental change would improve the assessment by incorporating more stock-specific knowledge of key factors determining population dynamics. This knowledge cannot always be incorporated formally in a population model, because the data available do not contain sufficient information to estimate the associated parameters (Parma and Deriso, 1990; Rochet, 2000). This does not mean, though, that this knowledge should not be used or would not be useful.

As an alternative to error-prone stock projections and absolute catch predictions, we based our assessment on trends, which can be estimated more reliably than absolute values. Statistical tests provide a straightforward way of taking account of unavoidable uncertainty and variability in the data. This implies a different way of using historical knowledge. Virtual population analysis- and TAC-based advice parameterizes dynamic models to estimate the current state of a stock and project likely consequences of policy actions as point estimates. This relies on the traditional view of time being reversible, where any past and future system state can be computed forward or backwards along the same trajectory, and causality is transparent, strong, and linear (Haag and Kaupenjohann, 2001). In view of the complexity of ecological systems, this paradigm tends to be replaced by a new one in which time is irreversible, relations and potentiality replace the properties and identity of components, and dynamic models cannot be used to address the real-world decisions (Haag and Kaupenjohann, 2001). However, dispensing with prediction does not mean ignoring temporal change. This is the basis for focusing on current trends as the best indication of how the near future will appear.

Building on trends also implies a different perspective on appropriate time frames. Currently, the ICES advice addresses

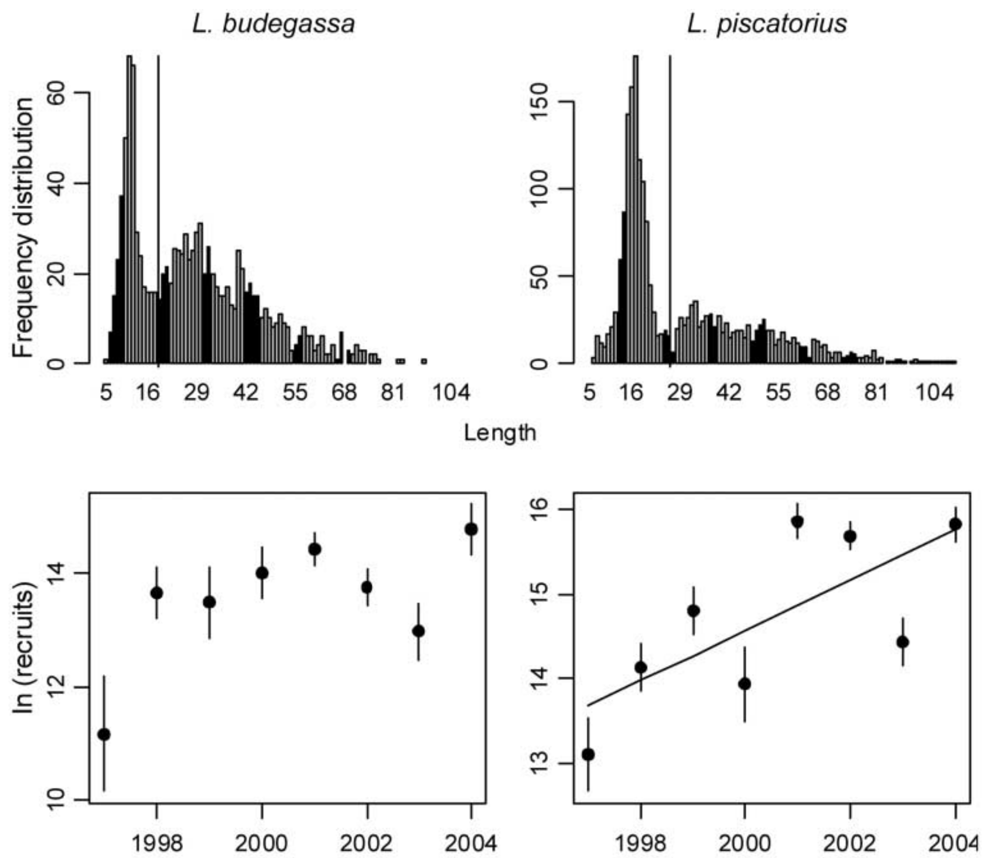

Figure 3. Length frequency distributions cumulated across years (top; vertical lines separate recruits from sub-adults) and estimated ln (recruits) time-series (bottom) based on fish $\leq$ 17 cm for *L. budegassa* and $\leq$ 26 cm for *L. piscatorius* (significant trend: $p = 0.04$, $r = 0.3$).

mainly short-term developments (next year), although the process of gathering landings data, running stock assessments, and reviewing the results takes 2–3 y, generating strong inertia in the system. We suggest that the procedure we propose would not need to be run every year, but rather every few years. In interim years, monitoring and updating of current trends to check how agreed decisions affect system dynamics would suffice. Methods for detecting rapid change, as mentioned in the Comprehensive diagnosis and management recommendations section above, would also play a role here.

Scientists would make life easier for themselves if they opted for forms of advice that clarified the respective responsibilities of managers (to decide objectives and policy measures) and of scientists (to spell out current trends and their causes, to suggest relevant ranges of policy actions, and to monitor the effects of those enacted). We suggest that clearly separating their roles both allows and requires more interaction: science will not deliver prophecies to guide policy choices, but can monitor and evaluate the implementation of politically decided policies (Sarewitz, 2004). With the growing recognition that stakeholders should be more involved in management (Garcia and Cochrane, 2005) and that management targets and measures should be negotiated in participatory settings to enhance the legitimacy and efficacy of management (Degnbol, 2005), the assessment procedure and the type of advice proposed explicitly give room for such stakeholder involvement.

Implementing an interactive process does not mean that decisions should be taken *ad hoc*. On the contrary, a formal process with clearly separated steps is called for. User involvement would be required at several steps of the procedure. First, for the formulation of objectives, a practical target could be easier to understand than a limit SSB or limit *F*. Second, relevant time frames have to be decided: when should the objectives be reached, and how far in the past do we look to determine what are current trends? Third, users have to understand and endorse the possible cause-and-effect mechanisms to decide on desirable combinations of trends. Fourth, risk acceptance will determine the outcomes of trend tests; for anglerfish, increasing the α-risk to 0.1 to increase power does not change the assessment, but decreasing it to 0.01 to avoid false alarms removes the signal of increasing abundance for *L. piscatorius*. Finally, advice is given as a recommended direction rather than as a TAC recommendation, leaving room for learn-by-doing style management.

In the first years of using an indicator-based approach, past catches or TACs can be used as reference levels. Moreover, scientists can assist managers in making necessarily quantitative decisions in several ways. First, detailed analysis of fishing pressure by métier, such as partial fishing mortalities (Rijnsdorp *et al.*, 2006), will allow the identification of target fleets and fine-tuning of management measures. Second, empirical analysis of the relationship between biological indicators and pressure indicators might provide more quantitative guidelines. Third, closely monitoring indicator changes following management decisions will permit scientists to advise on stronger or less stringent measures in subsequent years.

This contribution was mainly intended to set the principles of indicator-based interactive advice, and the example considered is by no means comprehensive and is only intended to illustrate the principles. Methods have to be developed for each of the steps, including reference state assessment, trend assessment, trends combination, and provision of management recommendations in an interactive management framework. The modalities and practicalities of the interactive part still need to be devised and tested. We exemplified these principles for managing individual stocks, but they may prove even more useful in an ecosystem approach to fisheries management, because the use of indicators seems unavoidable in that context.

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References

Ault, J. S., Smith, S. G., and Bohnsack, J. A. 2005. Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. ICES Journal of Marine Science, 62: 417–423.

Caddy, J. F. 2002. Limit reference points, traffic lights, and holistic approaches to fisheries management with minimal stock assessment input. Fisheries Research, 56: 133–137.

Degnbol, P. 2005. Indicators as a means of communicating knowledge. ICES Journal of Marine Science, 62: 606–611.

Die, D. J., and Caddy, J. F. 1997. Sustainable yield indicators from biomass: are there appropriate reference points for use in tropical fisheries? Fisheries Research, 32: 69–79.

Fewster, R. M., Buckland, S. T., Siriwardena, G. M., Baillie, S. R., and Wilson, J. D. 2000. Analysis of population trends for farmland birds using generalized additive models. Ecology, 81: 1970–1984.

Gangl, R. S., and Pereira, D. L. 2003. Biological performance indicators for evaluating exploitation of Minnesota's large-lake walleye fisheries. North American Journal of Fisheries Management, 23: 1303–1311.

Garcia, S. M., and Cochrane, K. L. 2005. Ecosystem approach to fisheries: a review of implementation guidelines. ICES Journal of Marine Science, 62: 311–318.

Haag, D., and Kaupenjohann, M. 2001. Parameters, prediction, post-normal science and the precautionary principle—a roadmap for modelling for decision-making. Ecological Modelling, 144: 45–60.

Halliday, R. G., Fanning, L. P., and Mohn, R. K. 2001. Use of the traffic light method in fishery management planning. CSAS Research Document 2001/18. 41 pp.

Hawkins, D. M., and Olwell, D. H. 1997. Cumulative Sum Charts and Charting for Quality Improvement. Springer, New York. 247 pp.

ICES. 1985. Report of the Fifth Dialogue Meeting, 4 October 1985. ICES Cooperative Research Report, 139. 86 pp.

ICES. 1998. Report of the ICES Advisory Committee on Fishery Management, 1997. ICES Cooperative Research Report, 223, Part 2. 365 pp.

ICES. 1999. Report of the Advisory Committee on Fishery Management, 1998. ICES Cooperative Research Report, 229, Part 2. 446 pp.

ICES. 2005a. Report of the ICES Advisory Committee on Fishery Management and Advisory Committee on Ecosystems, 2005. ICES Advice, 5. 242 pp.

ICES. 2005b. Report of the Working Group on the Assessment of Hake, Monk and Megrim (WGHMM). ICES Document CM 2006/ACFM: 01. 875 pp.

Kell, L. T., Pilling, G. M., Kirkwood, G. P., Pastoors, M., Mesnil, B., Korsbrekke, K., Abaunza, P. *et al.* 2005. An evaluation of the implicit management procedure used for some ICES roundfish stocks. ICES Journal of Marine Science, 62: 750–759.

Nicholson, M. D., and Jennings, S. 2004. Testing candidate indicators to support ecosystem-based management: the power of monitoring surveys to detect temporal trends in fish community metrics. ICES Journal of Marine Science, 61: 35–42.

Page, E. S. 1961. Cumulative sum control charts. Technometrics, 3: 1–9.

Parma, A. M., and Deriso, R. B. 1990. Dynamics of age and size composition in a population subject to size-selective mortality: effects of phenotypic variability in growth. Canadian Journal of Fisheries and Aquatic Sciences, 47: 274–289.

Piet, G. J., Quirijns, F. J., Robinson, L., and Greenstreet, S. P. R. 2007. Potential pressure indicators for fishing, and their data requirements. ICES Journal of Marine Science, 64: 110–121.

Poulard, J-C., Blanchard, F., Boucher, J., and Souissi, S. 2003. Variability in the demersal fish assemblages of the Bay of Biscay during the 1990s. ICES Marine Science Symposia, 219: 411–414.

Quéro, J. C. 1984. Les Poissons de Mer des Pêches Françaises. Grancher, Paris. 394 pp.

Quincoces, I., Lucio, P., and Santurtun, M. 1998a. Biology of black anglerfish (*Lophius budegassa*) in the Bay of Biscay during 1996–1997. ICES Document CM 1998/O: 47. 28 pp.

Quincoces, I., Santurtun, M., and Lucio, P. 1998b. Biological aspects of white anglerfish (*Lophius piscatorius*) in the Bay of Biscay (ICES Division VII a, b, d) in 1996–1997. ICES Document CM 1998/O: 48. 29 pp.

Rice, J. C., and Rochet, M-J. 2005. A framework for selecting a suite of indicators for fisheries management. ICES Journal of Marine Science, 62: 516–527.

Rijnsdorp, A. D., Daan, N., and Dekker, W. 2006. Partial fishing mortality per fishing trip: a useful indicator of effective fishing effort in mixed demersal fisheries. ICES Journal of Marine Science 63: 556–566.

Rochet, M-J. 2000. Does the concept of spawning per recruit make sense? ICES Journal of Marine Science, 57: 1160–1174.

Rochet, M-J., and Trenkel, V. M. 2003. Which community indicators can measure the impact of fishing? A review and proposals. Canadian Journal of Fisheries and Aquatic Sciences, 60: 86–99.

Rochet, M-J., Trenkel, V. M., Bellail, R., Coppin, F., Le Pape, O., Mahé, J-C., Morin, J. *et al.* 2005. Combining indicator trends to assess ongoing changes in exploited fish communities: diagnostic of communities off the coasts of France. ICES Journal of Marine Science, 62: 1647–1664.

Rozwadowski, H. M. 2002. The Sea Knows No Boundary: A Century of Marine Science Under ICES. ICES, in association with University of Washington Press, Seattle. 420 pp.

Sarewitz, D. 2004. How science makes environmental controversies worse. Environmental Science and Policy, 7: 385–403.

doi:10.1093/icesjms/fsm006