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

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Abstract:

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 questions arises whether scientists have provided the right kind of advice to avoid the deterioration of the resources. 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 has its foundation in the assumption that scientists can make precise forecasts of stock development, based on estimates of current population size at age and on information on 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 an escalation of fishing mortality, partly through the deterioration of catch statistics undermining the accuracy of predictions. However, there is a growing recognition that, even if the recommended TACs had been strictly adhered to, they would not have produced the desired fishing mortality (Kell *et al.*, 2005).

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

These perceived limitations of the current advisory system - lack of communication of basic biological knowledge, the inherent uncertainty of absolute stock estimates and the unreliability of catch forcasts, and a 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 inform 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 in order to halt and hopefully reverse undesirable trends. The approach is intended to either be used on its own or to complement the traditional model-based methods, when sufficient data are available for the latter approach. We demonstrate the approach for two anglerfish stocks (*Lophius piscatorius* and *Lophius budegassa*) in the Bay of Biscay and Celtic Sea using bottom trawl survey data, and compare the recommendations derived with the advice provided by ICES for the final year (2005).

An indicator-based approach

·General concepts

The proposed indicator-based approach clearly separates the roles of scientists and managers (Figure 1). The first action is for managers to define their management objectives, for example, a specific level of landings or a specific average size of the fish caught (step 1 in the framework proposed by Rice and Rochet, 2005). Scientists then establish the state of the stock with respect to these objectives at some time in the past, called 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 this process is to categorise 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, in the reference year. Thus, the 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 (for example, an arbitrary percentage of the individuals in survey catches should be larger than a specific size or total mortality should be smaller than a certain value). The task of scientists is to actually 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 observed trends. Investigation of time trends of pressure indicators and additional information allows to refine the diagnosis for the possible causes driving the observed changes. Hence, suitable management measures might be proposed to mitigate potential negative effects of the fisheries on stock status.

·Comprehensive diagnosis and management recommendations

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

1. Select t_r and calculate time series of suitable population indicators;
2. Determine trends and status for each indicator in t_c relative to t_r;
3. Inspect additional information and combine results of different indicators to provide interpretation of observed changes
4. State final diagnosis including possible causes
5. Determine trends in fishing pressure and propose appropriate management actions given the diagnosis and taking account of stated objectives

For step 1, 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 requires additional age or growth data.

For step 2, 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 when 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 pertains to the managers. The selection of a suitable year range to detect recent changes is also up to the managers but has to be set in relation to t_r. However, in many cases relatively long time series (>20 years) are required to detect significant linear trends because of the usually large inter-annual 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 to identify 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 3, the results of several population indicators are combined. Several methods have been proposed, the traffic-light approach perhaps being 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 usually are given equal weights 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 $\overline{L}$, 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 observed changes. Furthermore, 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 to corroborate whether changes in fishing pressure could have been the major cause, before stating the final diagnosis (step 4).

The last step is then 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 on whether fishing pressure has 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 these 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 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 synthesis of practical experiences should allow to arrive at more refined measures.

Case study

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

Since 1997, a stratified, bottom-trawl survey covering the Bay of Biscay and Celtic Sea is carried out in autumn every year (Poulard *et al.*, 2003). Population indicators were calculated for the two anglerfish species for the period 1997 to 2004. In the absence of reliable age data, total mortality could not be estimated for either species. Total landings were taken as 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 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.

Based on landings and survey data for 1986-1997, the stocks of the two species in the Celtic Sea and Bay of Biscay were considered within safe biological limits at that time, although their spawning stock biomasses had decreased continuously from 1986 until 1993 (Table 3).

·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 of r=0.19 (Figure 2). For both species, estimated population abundances in the final year were among the highest observed, while 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 satisfactory (Table 3). In addition, the stability of total landings is interpreted to indicate 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 towards an increase in recruitment as a plausible cause, even though this should have come out 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* suggest that peaks to the left of these represent the recruiting year class. Tentative recruitment time series were then estimated using only individuals smaller or equal to these length limits (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. Thus, 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 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 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 as the two species are caught on the same grounds by the same fleets and their F-values are thus linked. Moreover, they are often not sorted by species when landed. For 2006, the maximum F in accordance with precautionary limits is 0.24 (that is, *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 two stocks separately differ somewhat from the ICES advice for the combined stocks. While 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* because of 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, as the ‘satisfactory’ state is assessed relative to precautionary rather than to desirable levels of exploitation. Therefore, a 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 in case their dynamics start to diverge in the 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 to traditional TAC-based advice, the indicator approach makes a more comprehensive use of basic biological knowledge, does not rely on absolute abundance estimates nor stock projections, and provides a non-normative, interactive advice. Actually, the advice provided is sometimes based on indicators, because TAC recommendations for stocks without enough information to carry out an analytical assessment are made based on trends in landings. Thus considering additional indicators could only improve the decision basis.

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

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 historic knowledge. VPA and TAC-based advice parameterise dynamic models to estimate the current state of the 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 backward 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 where time is non-reversible, relations and potentiality replace properties and identity of components, and dynamic models cannot be used to address real-world decisions (Haag and Kaupenjohann, 2001). However, foregoing prediction does not mean ignoring temporal changes. This is ground to focus on current trends as the best indication of what the near future will look like.

Building on trends also implies a different perspective on appropriate time frames. Currently, the ICES advice mainly addresses short-term developments (next year), although the process of gathering landings data, running stock assessments and reviewing the results takes two to three years, generating a strong inertia in the system. We suggest that the proposed procedure does not need to be run every year, but every few years. In the interim years monitoring and updating of current trends to check how agreed decisions affect system dynamics would suffice. Methods for detecting rapid changes, as mentioned in the methods section, would also have their role to play here.

Scientists would make their life much easier if they opted for forms of advice that clarify the respective responsibilities of managers (to decide objectives and policy measures) and of science (to spell out current trends and their causes, suggest relevant ranges of policy actions and monitor 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 monitor and evaluate the implementation of politically decided policies (Sarewitz, 2004). As recognition is growing 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 type of advice proposed explicitly give room for such stakeholder involvement. Allowing for 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. Users' involvement would be required at several steps of the procedure. First, for the formulation of objectives, which could be a practical target, easier to understand than a limit spawning stock biomass or limit fishing mortality. 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 effects mechanisms to decide on desirable combinations of trends. Fourth, their risk acceptance will determine the outcomes of trend tests; in the case of 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 a TAC recommendation, leaving room for learning-by-doing style management. In the first years of using the indicator based approach, past catches or TACs can be used as reference levels. Furthermore, 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 to identify the target fleets and to fine tune management measures. Second, empirical analysis of the relationship between biological indicators and pressure indicators might provide more quantitative guidelines. Thirdly, closely monitoring indicator changes following management decisions will enable scientists to advice on stronger or less stringent measures in subsequent years.

This contribution was mainly intended to set the principles of an indicator-based interactive advice, and the example considered is by no means comprehensive and only intended to illustrate these principles. Methods have to be developed for each of the steps identified, 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 this context.

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Table 1. Expected effects of different causes on population (Z: total mortality; ln-N: log-transformed total abundance; $\overline{L}$: mean length; $L_{25\%}$ and $L_{75\%}$: length distribution quartiles; R: recruitment; W_{age}: weight-at-age; CG: spatial centre of gravity) and fishing pressure (f) indicators and possible management measures for counterbalancing changes, depending on impacted and satisfactory reference state and changes in fishing pressure (Δ: change, —: no trend, ↗: increasing; ↘: decreasing).

Dominant cause	Z	ln-N	$\overline{L}$	$L_{25\%}$	$L_{75\%}$	Other	Management measures	
							reference state impacted or f increasing	reference state satisfactory and f non-increasing
↗ fishing mortality	↗	↘	↘	—	↘	f↗	−ΔF: reduction in overall fishing mortality	
↘ fishing mortality	↘	↗	↗	—	↗	f↘	*status quo*	+ΔF: increase in fishing mortality possible
↗ recruitment	—	↗	↘	↘	—	R ↗	*status quo*	+ΔTAC: increase in TAC possible
↘ recruitment	—	↘	↗	↗	—	R ↘	−ΔTAC: reduction in TAC	
Faster growth	—	—	↗	—	↗	W_{age} ↗	ΔS: increase selectivity to larger sizes	
Slower growth	—	—	↘	—	↘	W_{age} ↘	*status quo*	ΔS: selectivity could be decreased to smaller sizes
↘ population overlap with survey area	↗	↘	—	—	—	ΔCG	no recommendation possible	
↗ population overlap with survey area	↘	↗	—	—	—	•CG	no recommendation possible	
no change	—	—	—	—	—	none	−ΔTAC or -ΔF: reduction in fishing pressure	*status quo*

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

Trait	*Lophius budegassa*	*Lophius 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

Table 3. Comparative evaluation of *L. piscatorius* and *L. budegassa* in the Bay of Biscay and Celtic Sea by formal ICES stock assessment and by the indicator-based procedure (⇔:stationary; ↗: significantly increasing; $\alpha=0.05$).

Evaluation		*Lophius budegassa*	*Lophius 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	
Indicator-based evaluation			
1. Reference status		Within safe biological limits	Within safe biological limits
2. Time trends in indicators, 1997-2004	ln-*N*	⇔	↗
	$\overline{L}$	⇔	⇔
	$L_{25\%}$	⇔	⇔
	$L_{75\%}$	⇔	⇔
3. Time trend in recruitment	R	⇔	↗
4. Final diagnostic		No change	Increasing abundance due to increasing recruitment over last 8 years
5. Time trend in total landings, 1997-2004		⇔	⇔
Proposed management action		*Status quo*	Increase of TAC possible

Figure captions

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

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

Figure 3. Histogram of length frequency distributions cumulated across years (top; vertical lines separate recruits from sub-adults) and estimated recruitment time series (bottom) based on individuals ≤17 cm for *L. budegassa* (significant trend ln(recruits): p=0.04 r=0.3) and ≤26 cm for *L. piscatorius*.

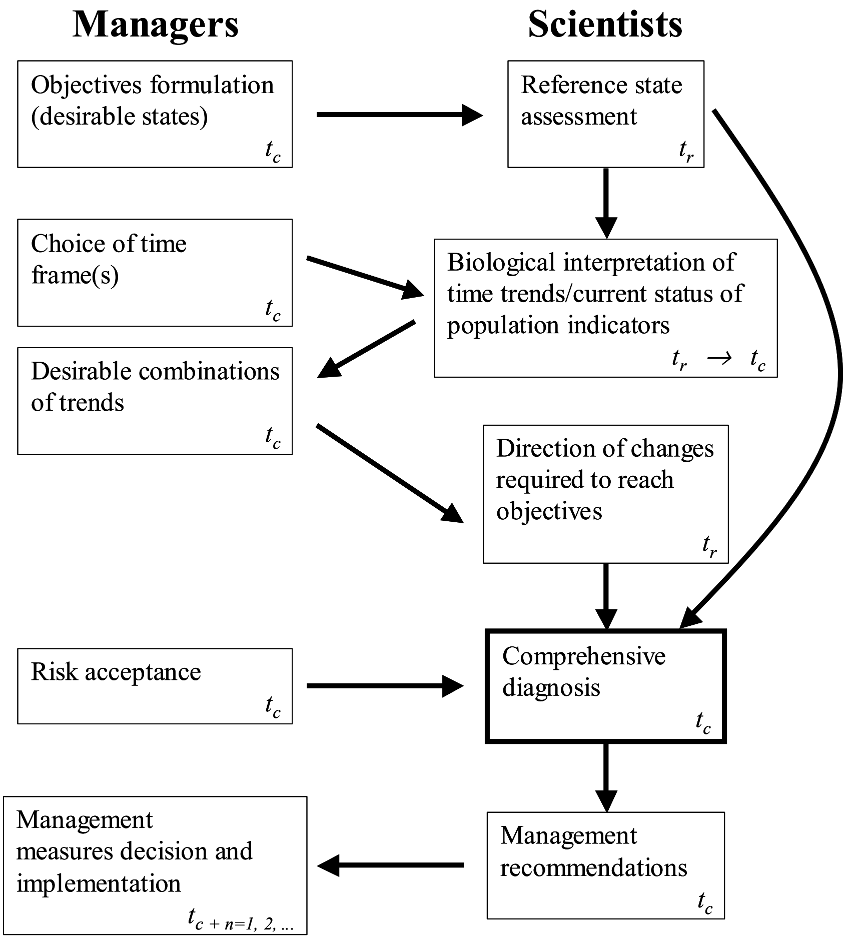
Managers
Scientists
Objectives formulation (desirable states)
t_c
Reference state assessment
t_r
Choice of time frame(s)
t_c
Biological interpretation of time trends/current status of population indicators
$t_r \rightarrow t_c$
Desirable combinations of trends
t_c
Direction of changes required to reach objectives
t_r
Risk acceptance
t_c
Comprehensive diagnosis
t_c
Management measures decision and implementation
$t_{c+n=1,2,\ldots}$
Management recommendations
t_c

Figure 1.

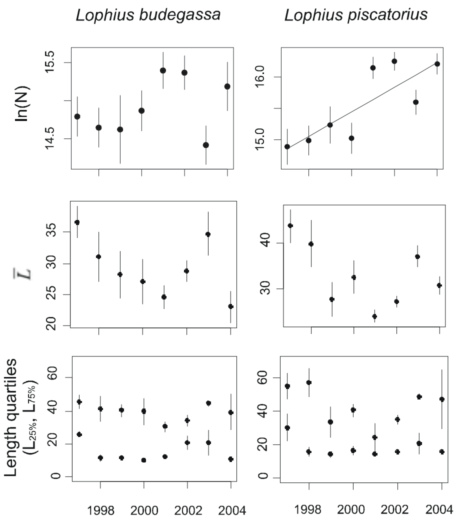
Lophius budegassa
Lophius piscatorius
ln(N)
15.5
14.5
16.0
15.0
$\bar{L}$
35
30
25
20
40
30
Length quartiles
(L25%, L75%)
60
40
20
0
60
40
20
0
1998
2000
2002
2004
1998
2000
2002
2004

Figure 2

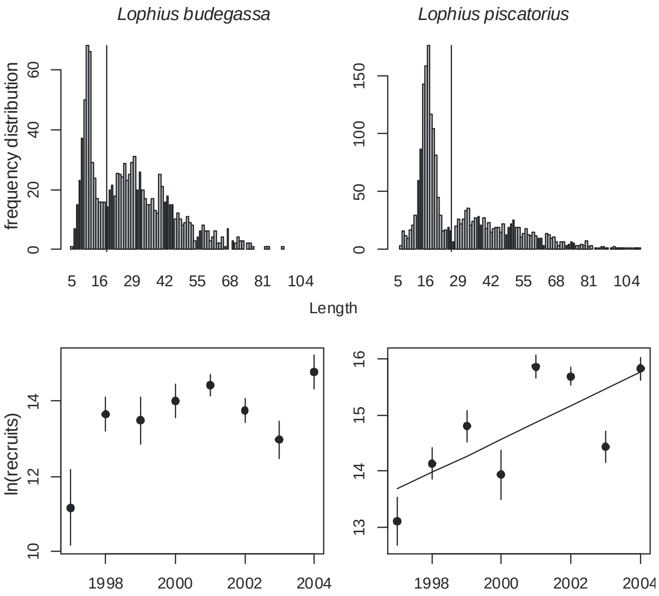
Lophius budegassa
Lophius piscatorius
frequency distribution
0
20
40
60
0
50
100
150
5
16
29
42
55
68
81
104
Length
ln(recruits)
10
12
14
13
14
15
16
1998
2000
2002
2004

Figure 3.