Estimating EAF indicators from scientific trawl surveys: theoretical and practical concerns

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Under the context of an ecosystem approach to fisheries (EAF), there is keen interest in providing insights into the evolution of exploited ecosystems using simple ecosystem indicators. Many nations have long-term scientific research surveys, originally driven by conventional approaches in fisheries assessment and management. The aim of this study is to address the practical concerns linked to current objectives of monitoring simple EAF indicators, using data from surveys that were not historically designed for the purpose. Based on the results of an expert survey designed to collect expert knowledge on research surveys from scientists working on different ecosystems worldwide, a list of challenges faced during indicator estimation is highlighted, along with associated concerns and constraints. The work provides additional information useful in the interpretation of the results obtained on the state and trends of ecosystems using EAF indicators by the IndiSeas WG. Further, the related discussion provides potential pathways that could be useful for future research and development aiming to improve the ecosystem indicator approach in the operational context of EAF. The question of the utility for EAF of using historical dataseries of scientific trawl series is also discussed. Such long-term series are concluded to be useful, that they are even inescapable (since the past cannot be resamplied), and that EAF therefore brings a supplementary reason for continuing such monitoring and to incorporate new insights in how research surveys may be conducted.

Keywords: EAF, ecological indicators, ecosystem effect of fishing, historical data, trawling surveys.

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Introduction

The impacts of fishing on marine ecosystems have been reported widely (Pauly *et al.*, 1998; Jackson *et al.*, 2001; Lotze *et al.*, 2006), and the consequent poor status of many exploited marine ecosystems has led to the adoption of ecosystem considerations in fisheries management (Gislason *et al.*, 2000; Murawski, 2000; Link, 2002a, b, 2005; Walters *et al.*, 2005), and the ongoing development of an ecosystem approach to fisheries (EAF; Garcia *et al.*, 2003; Pikitch *et al.*, 2004). EAF has gained currency as a conceptual reference framework, but it is recognized that it is an evolving area and further methodological development is needed to improve its implementation and to render it operational (Sainsbury *et al.*, 2000; Link, 2005). Among the different EAF approaches under development, an ecosystem indicator approach is promising and has been widely explored (Jennings *et al.*, 2002; Cury *et al.*, 2005; Daan *et al.*, 2005; Fulton *et al.*, 2005; Link, 2005; Piet and Jennings, 2005; Trenkel *et al.*, 2007; Libralato *et al.*, 2008; Levin *et al.*, 2009).

Indicators serve four basic functions: simplification, quantification, standardization, and communication UNEP (2003). Their value is that they can simplify information by summarizing data from different datasets and present it in a form with a clear interpretation to a wider audience. There is a large literature on the development of ecosystem indicators (see contributions in Daan *et al.*, 2005) which has provided a diverse range of indicators, ranging from simple ones such as abundance of a "canary" species to integrated indicators such as mean length in the community (Fulton *et al.*, 2005). However, an indicator approach to management requires large quantities of comparable data with associated statistical measures. Moreover, multidecadal time-series of data can provide an essential historical perspective of the evolution of marine ecosystems and of the complexity of ecosystem dynamics. Fortunately, many scientific fisheries research surveys are carried out worldwide and have been used to estimate ecosystem indicators (Methratta and Link, 2006). However, such research surveys have been driven principally by data requirements for conventional single-species management, so may not be ideal for deriving ecosystem indicators. Here, we explore how historical data from scientific research surveys can be used to estimate ecosystem indicators for EAF. In particular, we address three questions: (i) what difficulties are encountered in the calculation of EAF indicators with conventional scientific survey data, not designed for the purpose; (ii) how can the difficulties encountered in the calculation of simple EAF indicators from historical (and also from current) scientific trawl-survey data be resolved, and (iii) are scientific trawling surveys data still useful in the EAF context and should they be continued in future?

The present study is a contribution to the EurOceans IndiSeas Working Group (www.indiseas.org), which has developed a suite of ecosystem indicators to evaluate the exploitation status of marine ecosystems in a comparative framework (Shin and Shannon, 2010; Shin *et al*., 2010a). Experts from more than 19 nations worked collaboratively to provide the data required for this suite of ecosystem indicators (Appendix). The data were derived from a worldwide set of case studies involving diverse ecosystems, scientific research surveys, models, and fisheries data with different survey protocols and institutional origin. This situation is typical of any large-scale study that attempts to compare ecosystems. Given this, the present work has six specific objectives:

- (i) to identify the main challenges associated with the estimation of ecosystem indicators from scientific survey data;
- (ii) to evaluate the impact of these challenges;
- (iii) to provide information to improve interpretation of the ecosystem indicators considered in the IndiSeas suite and to complement the results and discussions related to the analysis of their states and trends (Blanchard *et al*., 2010; Bundy *et al*., 2010; Coll *et al*., 2010; Shannon *et al*., 2010; Shin *et al*., 2010b);
- (iv) to propose methods to improve the use of traditional survey-based indicators for EAF;
- (v) to explore how well the IndiSeas indicators are estimated by the various research survey data available;
- (vi) to discuss whether, in the context of future EAF management, the current fishery-independent resource monitoring based on periodical scientific trawl-survey series is the optimal way to proceed.

Methodology

The datasets used to calculate the IndiSeas indicators for the ecosystems included in the analysis are large and complex: each local or national database includes a time-series of surveys (which are often multidecadal, with one or more surveys per year), tens to hundreds of stations, sampling tens to hundreds of species, and with the collection of various data collected for each species (e.g. weight, length, maturity, age, diet data). Therefore, it is a large task to interrogate each of these data sources empirically to address the objectives listed above. Instead, we adopted a method using an expert knowledge survey. Experts were identified as scientists who had accumulated a store of knowledge of the ecosystems on which they worked, the sampling methodologies and protocols used and the changes that may have occurred over time and knew the specifics of their databases. The experts are all members of the IndiSeas WG and are considered experts on the ecosystems for which they provided the data. They are not, however, necessarily involved in the data collection (but are always in position to consult the persons who are involved in it and/or to access the local technical paper describing it).

We surveyed the scientific experts using a questionnaire to collect their expert knowledge and practical experience as well as any additional information relevant to the estimation of simple EAF indicators from scientific trawl surveys. Two types of information were collected: (i) descriptions of the data used to calculate the IndiSeas indicators and the sampling protocols associated with them, providing the metadata for the IndiSeas database; and (ii) the expert's opinion of the impact of the methodological challenges on the values estimated for each indicator. This assessment is only a first attempt, and its limits are explored later.

Development of the expert survey questionnaire

The development of the expert survey questionnaire involved the steps below.

1. Identification of the list of methodological issues, i.e. the points that could present potential challenges to the calculation of ecosystem indicators based on scientific survey data, and which may involve additional choices or decisions.
2. Formulation of the question(s) associated with each of the issues identified in Step (i) and preparation of the questionnaire to be completed by the science experts for each ecosystem. The questionnaire was first tested on a subset of ecosystems from western Africa and adaptations made based on feedback at that stage. An option was included to add issues additional to those identified in Step (i).
3. Sending of the questionnaire to the experts in charge of IndiSeas case studies (the list of ecosystems is provided in Shin and Shannon, 2010), completion of the questionnaires by the experts for each ecosystem, and compilation of their results in synthetic tables and graphs and analysis of results.

The questionnaire

The questionnaire consisted of a short information section followed by three sections corresponding to three distinct tables. In the information section, the following was requested: identity of the expert(s), the name of the ecosystem, and the temporal coverage of the sampling surveys used (first year and last year).

Part 1

This section included questions relating to ecosystem delimitation (Q1 and Q2), survey protocol (Q3–Q9), and the quality of the species determination (Q10 and Q11; Table 1). In the original form of the questionnaire (not presented here), there were two areas to be completed for each question. The first was a direct answer to the question posed (Yes or No, or a code from 1 to 6; see Table 1). The second, entitled justification or comment, was a free text area, without a limit on size, where the experts were invited to provide comments about their response. As stated in a short guideline attached to the form, this additional column was provided as a source of additional information that could aid in

Table 1. Questionnaire part 1: methodological issues in estimating the IndiSeas scientific survey indicators.

Issue	Question
1 = Delimitation of your ecosystem (a)	Q1: Did the scientific survey data available for your ecosystem influence your choice concerning the spatial delimitation of your ecosystem?
2 = Delimitation of your ecosystem (b)	Q2: Does this theoretical spatial delimitation of your ecosystem correspond exactly to the spatial coverage of the sampling design of the scientific survey used in the indicators calculations for your ecosystem?
3 = Type of scientific survey	Q3: What type of scientific survey data did you use in the calculation of the set of indicators for your ecosystem? 1, bottom trawl surveys; 2, pelagic trawl surveys; 3, acoustic surveys (pelagic); 4, a mix of the preceding ones (to be specified in the comment section below)
4 = Sampling vessel	Q4: Did the research vessel (or sampling vessel) remain the same throughout the series of surveys used for your indicator calculations? 1, Yes;, only one vessel; 2, No, at least two vessels; 3; don't know
5 = Sampling gear	Q5: Did the sampling gear remain the same for the whole series of surveys used for your indicator calculations? 1, Yes, only one gear; 2, No, at least two gears; 3, don't know
6 = Temporal sampling design	Q6: Did the temporal sampling design change during the series of surveys used for your indicator calculations (i.e. irregular frequency of surveys: variable number of surveys each year, surveys not done in the same month or seasons each year, etc.)? If yes, please specify in the comment section what you have then chosen to do (e.g. to use the data as they are or to select some surveys in order to make the temporal design more regular and comparable from year to year, etc.)
7 = Type of spatial sampling design	Q7: Did the type of sampling design, i.e. full random design, stratified random design, systematic design (transect or regular grid, for example) etc., remain the same throughout the series of surveys used for your indicator calculations? 1, Yes, only one type of design; 2, No, at least two designs; 3, don't know
8 = Spatial coverage	Q8: Did the spatial coverage of each survey remain the same throughout the series of surveys used for your indicator calculations? 1, Yes; 2, No; 3, don't know
9 = Number of stations per survey	Q9: Did the number of sampling station (hauls or acoustic location) of each of the survey remain the same throughout the series of surveys used for your indicator calculations? 1, Yes; 2, No; 3, don't know.
10 = Precision of species determination	Q10: Can you specify the precision of the specific determination encountered in the survey data you used for your indicators calculations? 1, Species determination fully exhaustive (the whole fauna sampled determined specifically); 2, Species determination not fully exhaustive but constant over time and a lack of precision only for rare species; 3, Species determination not fully exhaustive and a lack of precision also for non-rare species, but constant over time; 4, Species determination inconsistent over time but problems only for rare species; 5, Species determination inconsistent over time and problems also for non-rare species; 6, Don't know
11 = Generic groups	Q11: Were some generic groups (e.g. family, genus, various, spp.) present in the determination levels encountered in the survey data you used for your indicator calculations?
12 = Additional item 1 Etc.	$Qa_{1:}$ Potential additional question 1 = empty field to be completed by experts; see text for detail

the interpretation of the response. The questionnaire was designed to be open-ended by including an option for respondents to identify additional issues that may have challenged the calculation of ecosystem indicators from survey data (Table 1, Qa_1).

Part 2

This section of the questionnaire asked the experts to provide an evaluation of the impact of each of the issues identified in Table 1 on the estimation of the IndiSeas survey-based indicator estimates (Appendix). In the original questionnaire sent to the experts, this part was presented in the same way as Table 2. The guidelines attached to the form requested responses to be coded as follows: 0, no impact; 1, low impact; 2, strong impact; 3, no idea (undetermined).

Part 3

The objective of the third part of the questionnaire was to explore the methodologies used to estimate the indicators. The questions (Q12–Q19; Table 3) refer to situations where the expert had to decide on the method to apply (or to define a protocol) for the practical calculation of the indicator based on the nature of the available data. The science experts were asked to complete three responses to each question: the first was a direct answer to the question, the second an assessment of the impact of the question on the results of the estimates (cf. Table 2), and the last a justification or comment (cf. Table 1).

Results

List of the ecosystems involved in the expert survey

Experts from almost 50% of the ecosystems included in the IndiSeas project completed the science expert survey (see Table 4 for further details of each ecosystem, and Shin *et al.*, 2010a, Table 1, and associated Supplementary Material). Geographically, responses were from Atlantic ecosystems, the Northwest Atlantic, the Northeast Atlantic, the eastern central Atlantic, and the Mediterranean Sea (with two case studies). One exception was from the South Pacific. All case studies have more than 20 years of data: the longest time-series began in 1970 (the eastern Scotian Shelf) and the shortest in 1985 (Guinea EEZ). Therefore, all provide a good basis from which to respond to the questionnaire.

Questionnaire part 1

The first part of the questionnaire asked a series of questions related to the potential challenges associated with the calculation of the IndiSeas indicators from scientific sampling surveys (Table 5). Usually (six of nine; Q1, Table 5) the spatial extent of the scientific survey data influenced the defined boundaries of the target ecosystem. In five of nine cases (Q2, Table 5), therefore, the theoretical spatial boundaries of the ecosystem used for IndiSeas case studies did not correspond exactly to the spatial coverage of the sampling design of the scientific surveys. Regarding the survey methods used, two-thirds of the ecosystems used exclusively bottom-trawl

Table 2. Questionnaire part 2: evaluation of the impact of each issue defined in Table 1 on each indicator.

Question/indicator	Total biomass	Biomass of retained species	Proportion of predators	Mean lifespan	Proportion of exploited biomass	Proportion of improved species
2 = Delimitation of your ecosystem						
3 = Type of scientific survey used						
4 = Sampling vessel						
5 = Sampling gear						
6 = Temporal sampling design						
7 = Type of spatial sampling design						
8 = Spatial coverage						
9 = Number of stations per survey						
10 = Precision of species determination						
11 = Generic groups						
12 = Additional item 1						
13 = Additional item 2						
Etc.						

The following guidelines were provided with this table in the original form of the questionnaire: Fill the table with your "expert" estimation of the specific impact of each item (from Table 1) on each of the indicators (from the IndiSeas list and related to survey data) in your case study (ecosystem). This impact should be coded as follows: 0, no impact; 1, low impact; 2, strong impact; 3, no idea.

surveys, and the remaining one-third used a mix of surveys from bottom trawls, pelagic trawls, and acoustic surveys (Q3, Table 5). There was a lack of consistency in the survey vessels used in most ecosystems over time (Q4, Table 5: usually, i.e. seven of nine, at least two different research vessels were used during the time-series). The situation is similar for the sampling gear, where at least two types of sampling gear were used during the course of the survey in seven of the eight ecosystems where this was known (Q5, Table 5). There was less change in temporal sampling design of the surveys (e.g. annual, same time each year), but five of nine ecosystems experienced some change (Q6, Table 5). Similarly, in nearly half the cases (four of nine; Q7, Table 5), the type of spatial sampling design (e.g. random stratified, systematic) was known to have changed through the series. There was less clarity with respect to changes in spatial coverage; it changed in three systems, did not change in three others, and in the other three systems, it was not known if there were changes (Q8, Table 5). The number of stations per survey changed during the course of the survey time-series in eight of nine ecosystems and was unknown in one (Q9, Table 5).

The final two questions concerned the biological protocols used to sample the catch. The level of taxonomic detail used to identify the catch was highly variable among the surveys of the nine ecosystems. Only two surveys identified the whole catch to species level, whereas species identification was inconsistent through time for five surveys (Q10, Table 5). Most of the ecosystems (eight of nine) used generic groups derived from the survey data for estimation of the IndiSeas indicators (Q11, Table 5). The respondents were also given the option to identify addition challenges or issues, but no additional questions were identified. This indicates that the issues identified during Step (i) of the development of the questionnaire were considered relevant and complete. This also implies that the issues identified as relevant at a regional scale (West Africa) were confirmed to be applicable also at a broader global scale.

Questionnaire part 2

The results of the expert assessments of the potential impacts of the issues on the estimation of the ecosystem indicators (Table 2) were synthesized as pie charts (Figure 1). For each issue–indicator pair, the pie chart summarizes the results from the nine ecosystems listed in Table 4, where each pie segment represents the total numbers of each response (0 = no impact to 3 = high impact). In addition, an average impact value for each issue–indicator pair was quantified as the average of the nine expert responses for that pair. In cases where there was no information, a mid-value of 1.5 was used.

The type of scientific research survey used had the most impact across all indicators. The temporal consistency of sampling gear used and the spatial sampling coverage of the survey over time were also perceived as issues with significant impact across all indicators. The number of stations in the surveys, and more precisely its variation through time (Issue 9), was perceived as having an impact on every indicator (no green area in the related pie charts), but this impact was assessed to be low.

If we consider the differences of impacts between indicators for any given issue, most indicators are impacted in similar ways (Figure 1). One exception is that Issues 6 (temporal sampling design) and 8 (spatial coverage) were assayed to have a stronger impact on total biomass and biomass of retained species than they have on the other indicators of the IndiSeas suite. Globally, those two indicators seem to be the most sensitive to the issues identified in the present study.

Questionnaire part 3

The final section of the questionnaire explored specific issues associated with four of the IndiSeas indicators (total biomass, biomass of retained species, mean length, and proportion of predators; Table 6). These results are analysed by indicator and specific question (Q12–Q19), taking into account the additional information provided by the experts in the justification or comment section of the questionnaire. The additional information is reported below in quotation marks.

Q12: total biomass

Specific catchability coefficients were used to estimate total biomass in four cases. The use of catchability coefficients was assayed to have had a strong impact on the results by more than half the experts (five of nine), and a low impact in three cases (none which used specific catchabilities to estimate total biomass). One response was reported as unknown. Interestingly, in two cases where specific catchability coefficients were not used, the respondents reported that "this choice was made for practical consideration but it would be better to use such coefficients to improve the indicator estimates".

Table 3. Questionnaire part 3: specific questions related to indicators.

Indicator	Question
Total biomass	Q12: It is well known that all species do not behave in the same way with the sampling gear: they are more or less catchable according to their general behaviour (benthic, pelagic), size, speed of swimming, burial ability, etc. To take (or not) this fact into account: did you use differential catchability coefficient between species to calculate the total biomass indicator on the basis of your survey data?
Biomass of retained species	Q13: Did you use a differential catchability coefficient between species to calculate the biomass of retained species indicator on the basis of your survey data?
Mean length (1)	Q14: Which method did you use to calculate the mean length indicator? 1, direct method, using available length data; 2, indirect method, using (i) specific mean weight data (as estimated through numbers and biomass, exhaustively available for each surveyed species), and (ii) length–weight relationships
Mean length (2)	Q15: The length measurement in your survey dataset concerns: 1, all species surveyed; 2, a large and representative proportion of the species surveyed; 3, a low proportion of the species surveyed; 4, there is no length measurement in your survey data; 5, don't know
Mean length (3)	Q16: In your case study, the selection of the measured species has remained the same over time (throughout the whole survey series): 1, yes; 2, no; 3, no idea
Mean length (4)	Q17: The spatial coverage of the samples used for length measurement is representative of the spatial coverage of your ecosystem? 1, yes; 2, no; 3, no idea
Mean length (5)	Q18: Because individual measurements are time-consuming, the theoretical data requested for a mean length indicator assumed to be representative at the ecosystem or community level are difficult to obtain in practice (see the preceding questions on this indicator). Considering this, how do you estimate the adequacy between the length data you use for mean length estimation in your case study and the information theoretically requested: 1, low adequacy; 2, moderate adequacy; 3, high adequacy; 4, no idea
Proportion of predators	Q19: How did you distinguish predator species from others in order to calculate the proportion of predator indicator? 1, you used a threshold of trophic level (specify which one in the comment section); 2, you used another method (specify which one in the comments section)

Q13: biomass of retained species

Logically, the responses concerning the use of catchability coefficients for estimating the biomass of retained species were exactly the same as for total biomass. This confirms the coherence of the estimates provided on these two indicators.

Table 4. Ecosystems involved in the present study.

Ecosystem	Geographic area	Temporal coverage
1. Eastern Scotian Shelf	Northwest Atlantic	1970–2007
2. Southern Catalan Sea	Northwest Mediterranean	1978–2003
3. North-central Adriatic Sea	Central Mediterranean	1975–2002
4. Australia[a]	South Pacific—South Indian	–
5. Guinean EEZ	Eastern central Atlantic	1985–2008
6. North Sea	Northeast Atlantic	1983–2006
7. Mauritanian EEZ	Eastern central Atlantic	1982–2007
8. Senegalese EEZ	Eastern central Atlantic	1981–2005
9. Portuguese EEZ	Northeast Atlantic	1981–2005

[a]This ecosystem, a recent addition the IndiSeas project, has not yet completed the estimation of the IndiSeas suite of indicators. Nevertheless, that was not an obstacle to Australia's expert completing our science expert survey and hence contributing an additional informative case study.

Q14–Q18: mean length

Q14—Usually (six of nine) the mean length indicator was estimated using an indirect method (Table 3). In those cases, this methodological alternative (use of a direct vs. an indirect method) is always reported as potentially having a strong impact on the results (five of six). For the three ecosystem studies using direct length measurements, the experts believed that the concern had low (two of three) or undetermined (one of three) impact. Experts for two ecosystems (southern Catalan Sea and north-central Adriatic Sea) reported an absence of length measurements in their publicly available research survey data demonstrated that the use of the indirect method is not always a methodological choice, but can be simply a methodological constraint.

Q15—Two of the nine ecosystems had no length data and were not considered further in this question or for Q16–Q18 below. Of the remaining seven ecosystems, a small proportion of surveyed species was measured in three, and a large proportion or all surveyed species was measured in the other four. The impact of a small proportion of surveyed species with length data on the estimation of mean length was considered to be high by the three experts from ecosystems with a small proportion of surveyed species with length data, two considered the impact to be low, and one did not know.

Q16—The selection of measured species remained the same through time in most surveys (six of seven). The potential impact of this issue was estimated variously by experts as low (three of seven), undetermined (one of seven), or strong (three of seven).

Q17—The spatial distribution of the samples used for length measurements is representative of the spatial coverage of the ecosystem for four of the ecosystems. In the remaining three ecosystems, it was reported as not representative (two of seven) or unknown (one of seven). The potential impact of this distribution was estimated as evenly low (three of seven), undetermined (two of seven), or strong (two of seven).

Q18—The adequacy of the length data available compared with the information theoretically requested was high for two ecosystems. In four other cases, this adequacy was estimated as moderate, and in one case low. The potential impact of this issue is estimated to be strong in general (four of seven), unknown (two of seven), or low (one of seven).

Table 5. Responses to part 1 of the questionnaire.

	Ecosystem								
Issue	**ESS**	**SCS**	**NCAS**	**Aus**	**Gui**	**N Sea**	**Mau**	**Sen**	**Por**
Q1: Delimitation of the ecosystem (a)	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes
Q2: Delimitation of the ecosystem (b)	Yes	No	Yes	No	No	No	Yes	No	Yes
Q3: Type of scientific survey	1	4	4	4	1	1	1	1	1
Q4: Sampling vessel	2	1	2	2	2	2	2	2	1
Q5: Sampling gear	2	2	3	2	2	2	2	2	1
Q6: Temporal sampling design	No	No	No	Yes	Yes	No	Yes	Yes	Yes
Q7: Type of spatial sampling design	1	3	2	2	2	1	3	3	2
Q8: Spatial coverage	1	3	3	2	2	1	3	2	1
Q9: Number of stations per survey	2	2	2	2	2	3	2	2	2
Q10: Precision of species determination	5	1	2	6	5	4	3	4	1
Q11: Generic groups	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Qa_1: Additional issue 1	–	–	–	–	–	–	–	–	–

ESS, eastern Scotian Shelf; SCS, southern Catalan Sea; NCAS, north-central Adriatic Sea; Aus, Australia; Gui, Guinean EEZ; N Sea, North Sea; Mau, Mauritanian EEZ; Sen, Senegalese EEZ; Por, Portuguese EEZ. See Table 1 for full description of the items, the related questions (Q1–Q12), and the signification of the codes used for responses (Yes, No, 0, 1, 2, 3, 4).

Q19: proportion of predators

The IndiSeas WG developed the following criterion for defining predatory fish: a predator is not largely planktivorous, is mainly piscivorous or feeds on invertebrates >2 cm. This category also included predatory invertebrates. In three cases, this criterion was applied using expert knowledge based on stomach contents data. In the other six cases, a threshold value of the trophic level, derived from Fishbase (www.fishbase.org; Table 3), was used to calculate the proportion of predator indicator in the ecosystem case studies. When reported, this minimal TL threshold varied between 3.5 and 4.0. The potential impact of using a threshold trophic level to define predators was estimated to be strong (four of nine), unknown (one of nine), or low (four of nine).

Discussion

We have identified a reference list of the main methodological challenges encountered when using scientific survey data as a source for estimating ecosystem indicators. The 11 issues identified in Table 1, characterized in Table 5, and evaluated in Figure 1 are associated with four main challenges: (i) the delimitation of the targeted ecosystem, (ii) the generic type of scientific survey used as a data source, (iii) the change in sampling techniques and protocols through time, and (iv) the consistency and taxonomic level of species identification.

Each of these points is discussed below, successively, along with the methodology used in the present study, in an attempt to evaluate, in a second step, which general knowledge, potential direction, or recommendation could be drawn from them, for both future research and operational implementation of ecosystem indicators in an EAF context.

Delimitation of the targeted ecosystem

Ecosystems are found at different spatial and temporal scales and in practice, we can only access and refer to sampled ecosystems. At best, ecosystems have fuzzy boundaries and our understanding is limited by what can be sampled. In an ecosystem-based approach, the delimitation of the targeted ecosystem is an initial step that is often challenging because of incomplete understanding and knowledge of the system and data availability. This does not prevent inference of ecosystem dynamics and functioning, but it does imply a need to document the key points of the underlying methodological protocols carefully, to keep assumptions in mind during the interpretation of indicator estimates or indicator observed values. The need to take note of assumptions was already important at the population level in traditional fisheries science, and we suggest that this concern is increased in an EAF context.

In six of the nine ecosystems included in our study, delimitation of ecosystem boundaries was influenced by the available survey data. Definition of ecosystem boundaries is therefore often the result of a compromise between existing knowledge and available data. This can be complicated by variation in spatial and temporal survey coverage when considering multidecadal series, so the coherence between survey data and the theoretical ecosystem delimitation is not always optimal or constant through time. Consequently, there is a small but often inevitable disparity between theory (i.e. the posited delimitation of the targeted ecosystem) and practice (i.e. the field data used in the calculation of the indicators). This relates back to the fact that these surveys were not initially intended for EAF. However, in considering a pragmatic implementation of a data-based indicator approach in an EAF context, this study has shown that this disparity was not perceived as a major problem.

Type of scientific survey used as a data source

Monitoring marine ecosystems is perhaps one of the most challenging aspects of an EAF; various types of survey provide information about different components of the ecosystem. There is no ideal solution for which method to choose, but based on our results, bottom trawling is the most frequently used. The integration of several types of sampling survey (and hence of several sampling techniques, such as trawling and echo-integration) into comparable datasets seems to be rarely experienced in practice, even when the opportunity does exist. This result tends to demonstrate that the way of combining data from different sources raises difficulties at least as large as that related to the biases induced by using a single sampling method.

A way forward is a modelling exercise, in which different data from trawl and other scientific studies are combined to obtain a view of the ecosystem as a whole. It is important that these studies are pursued; they provide an opportunity to combine modelling results, scientific assessments, and catch data to assess

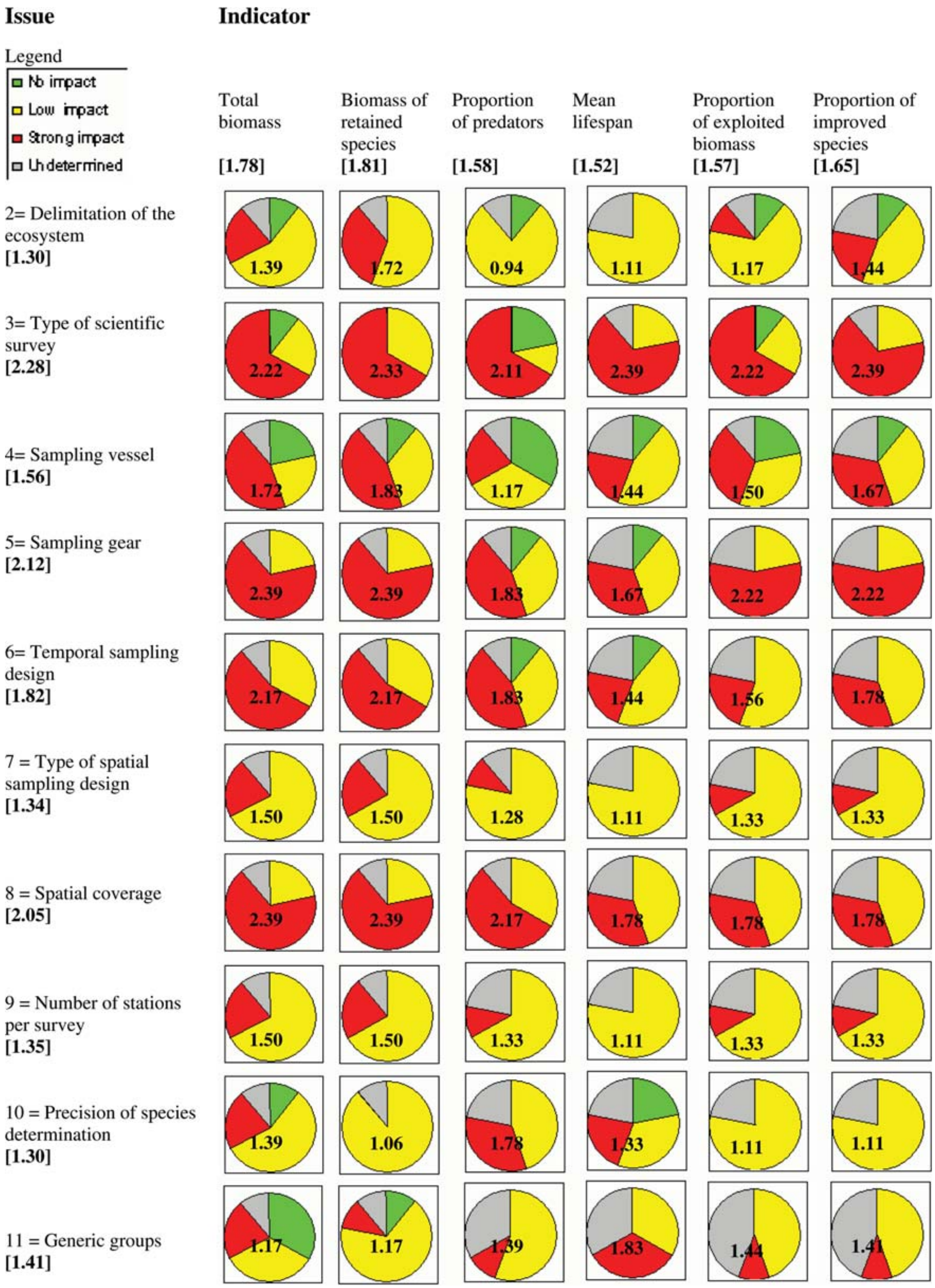

Figure 1. Pie charts representing summaries of the responses to part 2 of the questionnaire. For each issue–indicator pair, the pie chart summarizes the results over the nine ecosystems listed in Table 4, where each pie segment represents the total number of each response (0 = no impact to 3 = high impact). Emboldened values on the pie charts represent the impact averaged over the nine ecosystems, where no impact = 0, low impact = 1, high impact = 3, and undetermined = 1.5. Emboldened values in square brackets represent the impact averaged over each row or column. See text for detail.

Table 6. Responses to part 3 of the questionnaire.

Ecosystem	Total B (Q12)	B-RS (Q13)	ML (Q14)	ML (Q15)	ML (Q16)	ML (Q17)	ML (Q18)	Prop-Pred (Q19)
Describing the situation								
1: eastern Scotian Shelf	No	No	1	1	1	1	3	2
2: southern Catalan Sea	Yes	Yes	2	4	NA[a]	NA[a]	NA[a]	1
3: north-central Adriatic Sea	Yes	Yes	2	4	NA[a]	NA[a]	NA[a]	1
4: Australia	Yes	Yes	2	3	1	2	2	2
5: Guinean EEZ	No	No	2	3	1	2	2	1
6: North Sea	Yes	Yes	1	1	1	1	3	2
7: Mauritanian EEZ	No	No	2	2	1	1	2	1
8: Senegalese EEZ	No	No	2	3	2	3	1	1
9: Portuguese EEZ	No	No	1	1	1	1	2	1
Estimating the impact								
1: eastern Scotian Shelf	1	1	1	2	2	2	2	1
2: southern Catalan Sea	2	2	2	NA	NA	NA	NA	1
3: north-central Adriatic Sea	2	2	2	NA	NA	NA	NA	1
4: Australia	2	2	2	2	1	1	2	2
5: Guinean EEZ	2	2	2	2	2	2	2	2
6: North Sea	3	3	3	3	3	3	3	3
7: Mauritanian EEZ	1	1	1	1	1	1	1	2
8: Senegalese EEZ	2	2	2	2	2	2	2	2
9: Portuguese EEZ	1	1	1	1	1	1	2	1

[a]Not available because no length measurements were made. See Table 3 for full description of the questions (Q12–Q19) and the significance of the codes used for responses (Yes, No, 0, 1, 2, 3, 4). Total B, total biomass; B-RS, biomass of retained species; ML, mean length; Prop-Pred, proportion of predators. In the lower panel: 0, no impact; 1, low impact; 2, strong impact; 3, not known.

marine ecosystems and to compare the results (Bundy, 2001; Fulton *et al*., 2005).

Changes in sampling techniques and protocols through time

Based on the present study, a certain level of change or inconsistency in sampling techniques through time is a recurring characteristic of survey series worldwide, especially if the time-series exceeds 20 years. Further, our results suggest that these technical changes should be seen as one of the main practical difficulties in the indicator approach. Concerns regard: a change in the sampling vessel in the course of the series; changes in the sampling gear; variations in the temporal sampling design, such as changes in the number and distribution of annual surveys; changes in the spatial sampling design, such as alternation between random and systematic designs; variations in the spatial coverage between surveys; and variation in the number of sampling stations by survey. Among these issues, those concerning the boat, gear, and the number of sampling stations appear to be particularly frequent at the temporal scale considered here (20 years and more). Attention should be paid to all these issues because none is rare and the results of this study indicate that their potential impact on estimation of ecosystem indicators could be high.

Consistency and taxonomic level of species identification

The use of generic taxonomic categories together with some degree of unreliability or inconsistency in the species identification of the samples is the fourth type of difficulty identified here. It is an almost universal concern in scientific survey series. Fortunately, though, the problem was generally limited to rare or very rare species in the ecosystems studied, so its impact on the ecosystem indicators assayed here was not considered to be high. However, its impact on other ecosystem indicators such as biodiversity indicators (e.g. species richness or evenness, or taxonomic diversity) or community indicators (such as assemblage composition or keystone species indicators) is likely to be greater.

Utility of this analysis

Despite the useful patterns emerging at the end of this study that will improve further discussions on the subject, the present study must nevertheless be considered a pilot one and its results as preliminary. Indeed, to provide greater value, the current results have to be enhanced by increasing the sample size (i.e. the number of case studies and the number of respondents) and by further development of the questionnaire with additional requests for greater detail and justification of the responses provided (including citation and reference to local technical papers and grey literature).

Given this, there are a few key areas where the responses were consistent and sufficient to allow further discussion on several aspects, which are reported below. An additional result of the present study was a demonstration of the feasibility, and the relevance, of an expert-knowledge-based methodological approach. Here also, the results of our study should be considered as a useful pilot study before future implementation on a larger scale of a comparable but more complete investigation, in a science (aquatic biology) where this way of sampling is still unusual, even if not new (Nielsen and Scott, 1994).

The use of expert knowledge

Two types of expert knowledge were collected from our expert survey process: descriptive information about the data, the sampling process and the data processing, and expert evaluation of the impact of these concerns on the results (in terms of IndiSeas indicators).

Concerning the first aspect, the recourse to local expertise is a way to synthesize and/or to target some specific information generally dispersed in technical reports in local grey literature. Some of the required information can be very difficult to access in practice, perhaps being found in reports that are no longer available or that may require specific interrogation of the local databases. Therefore, at the scale of the present global comparative study, a science expert survey was the most efficient method for acquiring the required information.

The second aspect is more subjective and needs some comment to avoid misinterpretation. First, expert evaluation is not intended to be a quantitative assessment of the precision of the estimates of indicators, so one can indeed dispute the representivity of this type of information based on expert knowledge and appreciation as opposed to that based on experimental data. However, even if it must be interpreted with prudence, we think that such expertise is probably not completely unfounded (made by scientists involved in the local database and/or data collection). Further, where no other information is available, it is important to collect expert knowledge rather than having no idea about the potential range and sources of sampling uncertainties. Otherwise, the data may be used in meta-analysis without considering the uncertainly involved.

Considering both aspects, the expertise can be useful to plan how to analyse past data (better interpret them, better fit data processing to existing data structure, etc.), and also to identify future improvements in the ecosystem indicator approach, including how future EAF-orientated scientific trawl-survey results (some aspects are discussed below) should be incorporated. The expertise can also help to identify the specific studies required to estimate and/or minimize the sources of variability affecting the indicator sampling process, and hence to shape future ecosystem monitoring routines. It allows also better estimation, for future EAF monitoring, of what seems possible and what seems not possible, considering field constraints.

Stock assessment-orientated vs. EAF-orientated surveys

We stressed up front that scientific surveys were not initially carried out for EAF purposes but for conventional stock assessment purposes, a perspective also stressed by Trenkel and Cotter (2009), who refer (p. 121) to "surveys that were designed historically for special purposes, e.g. for assessing abundances of two or three target species, or for tuning VPAs". This returns us to the difference between stock assessment-orientated surveys (conventional surveys) and EAF-orientated surveys. In fact, no clear theoretical difference can be made between the two. Historically, research surveys were designed to encompass ecosystem considerations and to complement data from fisheries-dependent sources. In addition to collecting information on specific commercial species, many surveys also collected data for other species caught in the survey. Differences between conventional surveys and EAF-orientated surveys are more practical than theoretical. The results of the present study show that some conventional surveys only subject species of commercial interest that undergo stock assessments to detailed biological sampling (i.e. length, sex, maturity, stomach contents, etc.), even if the whole catch is counted and weighed by species. The lack of biological sampling of other species often refers to less abundant or rarer species, which are sometimes grouped (included in miscellaneous or other taxa groups). Species are also grouped because they belong to multispecies commercial categories (fish species grouped under the same commercial names) or are so close in appearance that it is too time-consuming to identify them to species level.

From the above, we can draw general characteristics of how an EAF-orientated research survey would look. The same biological data would be collected systematically for all species, commercial and non-commercial, and all species would be identified to species level if possible to permit analysis of the multispecies composition of commercial assemblages. Moreover, this would enhance our ability to understand the key roles that some species play in ecosystem functioning. Finally, the surveys should be integrated into long-term sampling plans, designed to minimize spatial and temporal bias, and simplifying indicator data processing and periodic monitoring.

Most conventional surveys have the capacity to adapt to become more ecosystem-orientated. Globally, they are considered as conveniently designed for EAF requirements (Cotter *et al.*, 2009), but in practice, this varies from case to case (Cotter, 2009a; Trenkel and Cotter, 2009). Nevertheless, it seems that historical scientific trawl data represent useful and even inescapable sources of information for an EAF management (Cotter *et al.*, 2009). To further enhance an EAF, this information should be made publicly available to the scientific community for ecosystem-based studies.

The ecosystem indicator approach and potential future improvement

Other general concerns are suggested by the results of the present study of the ecosystem indicator approach as a contribution towards potential future improvement, and some are listed below.

(i) *Standardization in the EAF indicator context*. The results of our study show the necessity to standardize data collection and also data processing, because different ways exist to estimate the same indicator. Therefore, when faced with complex databases, it is not always obvious what is the best method (as suggested by our results from part 3 of the questionnaire; Table 6).

(ii) *Documentation of historical data and constitution of integrated historical databases at the scale of each ecosystem*. To achieve this goal, a general reflection on standards and guidelines (in terms of data documentation and integration) should be an initial step, a step that should be supported by exhaustive analysis of the current situation, in line with the objectives of the present study, and possibly by way of studies involving similar expert surveys.

(iii) *Complex data requirements for simple ecosystem indicators*. Our results have suggested that there is no really simple ecosystem indicator when considering data requirements. Indeed, the ecosystem (or community) indicators that may appear as simplest, when considering their theoretical definition and ecological interpretation, often require complex data sampling and/or complex data processing for their firm (i.e. not too biased) estimation. Clearly, complementary discussions on the concept of an indicator, the potential use (and definition) of similar indicators (or proxies) to investigate the same natural or ecological phenomena (e.g. in fish size evolution), the ecosystem indicator approach in data-poor ecosystems, and the identification of statistical methods for trawl-survey data-processing (Cotter, 2009b) are relevant here.

It will be interesting to investigate further each of these aspects in future, and we suggest that analysis similar to the present one, but involving more questions, could be a way to achieve such an objective.

Conclusions

This study has highlighted some of the consequences of using data from conventional surveys designed to evaluate specific stocks to estimate ecosystem indicators for an EAF. Based on the results, two complementary conclusions emerged. First, data-based ecosystem indicator studies using long-term survey series seem always to have to deal with a certain range of biased information, regardless what ecosystem is being analysed. Second, most of the survey characteristics that have been identified as potential sources of bias were not assessed to have a great impact on the assayed IndiSeas ecosystem indicators.

Although limitations have been identified in scientific survey data, there are also several ways to improve their use in future in aiming for an EAF (see Cotter, 2009b). Our analysis has shown that these data are informative for ecosystem studies; in their absence, many ecosystem studies would not be possible. Taking this into account, the results emerging from our study, and the related discussions, should be seen as an attempt to provide potential directions that could be useful for future research and development aiming to improve the ecosystem indicator approach in the operational context of ecosystem-based fishery management. In the short term, a clear and practical recommendation can be addressed to managers, to continue fisheries-independent scientific trawling surveys including the sampling and classification of all organisms captured and to provide clear information about the survey. The recent EAF requirements do not question the current utility of such surveys. On the contrary, they provide reasons for continuing and strengthening them, as suggested also by Cotter *et al*. (2009).

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Appendix

The IndiSeas simple indicators suite minimum list used for establishing the IndiSeas dashboard diagnosing marine ecosystems (adapted from Shin *et al.*, 2010a).

Indicator	Data source	Calculation, notations, units	Indicator directly influenced by the present study (i.e. data source involving scientific surveys)
Mean length of fish in the community	Fisheries- independent surveys (i.e. scientific surveys)	$\bar{L} = \sum_i L_i / \sum_i N_i$ (cm)	Yes
Mean lifespan of fish in the community	Fisheries-independent surveys	$\bar{A}_{max} = \sum_s (A_{s,max} B_s) / \sum_s B_s$ (years)	Yes
Total biomass of species in the community	Fisheries-independent surveys	B_s (t)	Yes
Proportion of predatory fish in the community	Fisheries-independent surveys	Proportion of predatory fish[a] = biomass of predatory fish/ biomass surveyed	Yes
Trophic level of landings	Commercial landings and estimates of trophic level (empirical and fishbase)	$\overline{TL} = \sum_s (TL_s Y_s) / Y_{Total}$	No
Proportion of under- and moderately exploited stocks	FAO database and local expertise (WG reports)	Number of under- and moderately exploited stocks/total number of stocks considered	No
Survey biomass/landings	Commercial landings and fisheries-independent surveys	B_{rs}/Y retained species[b] (i.e. inverse fishing pressure[c])	Yes
$1/CV$ of total biomass	Fisheries-independent surveys	Mean (total B for the past 10 years)/ s.d. (total B for the past 10 years)	Yes

N_s, total abundance of sampled species estimated from the research survey (as opposed to species sampled in catches by fishing vessels), including species of demersal and pelagic fish (bony and cartilaginous, small and large), as well as commercially important invertebrates (squids, crabs, shrimps, etc). Intertidal and subtidal crustaceans and molluscs, such as abalones and mussels, mammalian and avian top predators, and turtles, are excluded. Surveyed species are those that are considered by default in the calculation of all survey-based indicators. L, length (cm); i, individual; s, species; N, total abundance; B, total biomass; Y, landings (t); A_{max}, mean lifespan of the community; $A_{s,max}$, species-specific maximum expected age; Y_s and Y_{total}, landings of each species and total landings, respectively; TL_s, trophic level of each species; TL, mean trophic level of landings (adapted from Shin *et al.*, 2010a); B_s, biomass of species sampled by researchers during routine surveys; B_{rs}, biomass of surveyed species retained by the fishery.

[a]Predatory fish are considered to be all fish species surveyed that are not largely planktivorous (i.e. phytoplankton and zooplankton feeders excluded). A fish species is classified as predatory if it is piscivorous, or if it feeds on invertebrates larger than the macrozooplankton category (>2 cm). Detritivores are not classified as predatory fish.

[b]Retained species are species caught in fishing operations and landed. Retained species are those that are considered by default in the calculation of all catch-based indicators.

[c]Fishing pressure is inverted so that it will decrease under increasing fishing pressure, so theoretically varying in the same direction as the other indicators in the selected suite.

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