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Abstract

Fisheries have had major negative impacts on marine ecosystems, and effective fisheries management and governance are needed to achieve sustainable fisheries, biodiversity conservation goals and thus good ecosystem status. To date, the IndiSeas programme (Indicators for the Seas) has focussed on assessing the ecological impacts of fishing at the ecosystem scale using ecological indicators. Here, we

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explore fisheries 'Management Effectiveness' and 'Governance Quality' and relate this to ecosystem health and status. We developed a dedicated expert survey, focused at the ecosystem level, with a series of questions addressing aspects of management and governance, from an ecosystem-based perspective, using objective and evidence-based criteria. The survey was completed by ecosystem experts (managers and scientists) and results analysed using ranking and multivariate methods. Results were further examined for selected ecosystems, using expert knowledge, to explore the overall findings in greater depth. Higher scores for 'Management Effectiveness' and 'Governance Quality' were significantly and positively related to ecosystems with better ecological status. Key factors that point to success in delivering fisheries and conservation objectives were as follows: the use of reference points for management, frequent review of stock assessments, whether Illegal, Unreported and Unregulated (IUU) catches were being accounted for and addressed, and the inclusion of stakeholders. Additionally, we found that the implementation of a long-term management plan, including economic and social dimensions of fisheries in exploited ecosystems, was a key factor in successful, sustainable fisheries management. Our results support the thesis that good ecosystem-based management and governance, sustainable fisheries and healthy ecosystems go together.

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Introduction

The oceans provide critical ecosystem services (Alcamo *et al.* 2003; MEA 2005; Liquete *et al.* 2013), among which are food provisioning and food security, traditionally accessed by fishing at multiple scales, from local subsistence fishing to small-scale artisanal fisheries, and to larger scale industrial operations. Harvesting marine living resources at all scales has the potential to alter marine ecosystem structure and functioning, and thus, impact the services that seas and oceans provide. Therefore, how we manage and govern human activities in our oceans has a direct impact on their overall health and ability to provide the benefits that we derive from them now and into the future.

This link between management, governance and ecosystem health is reflected by the evolving nature of fisheries management and the widespread recognition of the need for an ecosystem-based approach to fisheries (FAO 2003). Over the last two decades, in an attempt to highlight and service this need, there has been substantial effort to evaluate the ecological status of marine ecosystems, through initiatives such as the Scientific Committee on Ocean Research/Intergovernmental Oceanographic Commission (SCOR/IOC) Working Group (WG) on Quantitative Ecosystem Indicators for Fisheries Management (Cury and Christensen 2005), International Council for the Exploration of the Sea (ICES) Working groups such as the ICES WG on Ecosystem Effects of Fishing Activities (WGECO, ICES 2015a), the ICES WG on Biodiversity Science (WGBIODIV, ICES 2015b), and the IndiSeas (Indicators for the Seas) programme (Shin *et al.* 2010, 2012; Bundy *et al.* 2012). However, evaluation of the human dimensions of fisheries has received relatively less attention although they are explicitly recognized as a key element of ecosystem-based fisheries management, EBFM (Leslie and McLeod 2007; De Young *et al.* 2008). Economic outcomes have garnered some regional to global research efforts (e.g. Browman *et al.* 2005; Sumaila *et al.* 2006, 2011) while social well-being has been considered in some locations (e.g. Coulthard *et al.* 2011; Coulthard 2012). With respect to management and governance, some studies have been conducted to evaluate the effectiveness of governance overall (Pitcher *et al.* 2006, 2009a; Mora *et al.* 2009; Coll *et al.* 2013), but there is a lack of specific studies that link governance to ecosystem status.

Understanding the status and effectiveness of management and governance can provide important insights and linkages to the ecological status of marine ecosystems. In a global study, Pitcher *et al.* (2006, 2009a) assessed the extent to which 53 fishing nations, accounting for 96% of the global marine catch in 1999, complied with the Food and Agriculture Organization of the United Nations (FAO) Code of Conduct for Responsible Fisheries (CCRF, FAO 1995). Their evaluation method, comprised of 44 questions, was based on Article 7 of the CCRF and the rapid appraisal technique, Rapfish (Pitcher, 1999, Pitcher *et al.* 2013). They developed a two-stage process whereby the authors initially scored the 53 nations based on available literature, including grey reports. In the second stage, their assessment was externally validated by independent experts, although this only included 33 nations (Pitcher *et al.* 2006). They concluded that globally, compliance was poor: no country reached their 'good' status and 28 countries failed 'unequivocally'; the three best performing countries were Norway, USA and Canada. In a further study, Pitcher *et al.* (2009b) used the previous 2006 results to score how well EBFM was being implemented worldwide, again concluding that no country rated as 'good', and over half received failing grades. Coll *et al.* (2013) took these results further by exploring the relationship between compliance with the CCRF and different measures of ecosystem health, and they concluded that greater compliance does result in greater ecosystem sustainability. They based their approach on the 'Psust' indicator, that is the probability of the ecosystem to be sustainably fished (Libralato *et al.* 2008). Their results linked compliance by country to ecosystem sustainability of fisheries, highlighting that countries with a higher level of compliance with the FAO Code of Conduct in 2008 experienced an increase in fisheries sustainability from the 1990s to 2000s.

In another global study, Mora *et al.* (2009) evaluated the management effectiveness of marine fisheries using an expert elicitation approach through an online survey. They developed their survey questions based on six factors: scientific robustness, transparency, enforcement compliance, fishing capacity, subsidies and foreign fishing. They contacted over 13 000 fisheries experts, with a 9% success rate (1188 responses) covering 236 EEZs, although only 209 were used in their final statistical analyses (see Mora *et al.* 2009 for further details). Like Pitcher *et al.* (2006), they concluded that fisheries management was poor overall: only 7% of nations surveyed had management policies that were based on rigorous scientific assessment, very few had participatory and transparent processes for converting scientific recommendations into policy (1.4%), and less than 1% had sufficient mechanisms to ensure compliance with regulations. They then assessed the relationship between their results with the sustainability of reported fisheries catches (Libralato *et al.* 2008). They concluded that 'the conversion of scientific advice into policy, through a participatory and transparent process, is at the core of achieving fisheries sustainability, regardless of other attributes of the fisheries' (Mora *et al.* 2009).

Cullis-Suzuki and Pauly (2010) explored how well regional fisheries management organizations (RFMOs) comply with a code of best practices for RFMOs by analysing available information from reports. They concluded that, on paper, and based on empirical evidence related to stock status, the RFMOs scored poorly on average. They also concluded that there is a gap between what was intended on paper and material outcomes. Similarly, Skern-Mauritzen *et al.* (2016) evaluated the degree to which ecosystem processes were included in the scientific information provided for management decisions and advice regarding catch levels. They discovered that ecosystem considerations were included less than 2% of the time. As such, the implementation of the EBFM is deemed lagging and concerns for management effectiveness remain.

The FAO has adopted the general survey approach proposed by Pitcher *et al.* (2006), and since 2013, it has surveyed member States, Regional Fisheries Bodies and International Non-Governmental Organizations using a web-based platform, 'Progress in the Implementation of the Code of Conduct for Responsible Fisheries and Related Instruments' (http://www.fao.org/fishery/topic/166326/en). Results are published in annual reports, at an aggregated level (e.g. FAO 2014a,b).

These studies underscore the importance of looking beyond the ecological status of marine ecosystems to include management and governance, which are key drivers of fishery systems. However, the studies cited above (Pitcher *et al.* 2006, 2009a,b; Mora *et al.* 2009; Cullis-Suzuki and Pauly 2010; Coll *et al.* 2013) were all conducted at national or larger spatial scales, and information was collected and analysed remotely by the authors of the studies. Although National Fisheries policies do apply at these scales, in practice fisheries governance and management generally occur at smaller, more regional scales, such as at the fishery or stock scale (e.g. ICES Divisions, North Atlantic Fisheries Organization [NAFO] Divisions, coastal fisheries such as 'lobster fishing areas'). More recently, with growing interest in ecosystem-based fisheries management, there has been increased recognition of the need for management at the ecosystem level, a scale that often does not match jurisdictional boundaries, which may be broader than the scale of individual stocks or fisheries, but may better account for ecological processes (Link 2010). Here, we define 'ecosystem scale' as the spatial scale that encompasses the majority of the species and fisheries interactions within a region (Garcia and Charles 2008). Obviously due to differences between regions, the size and demarcation of an ecosystem will be context dependent. However, to the extent possible, it is important to try to match ecosystem, jurisdictional and management boundaries (Garcia and Charles 2008), and this usually occurs at spatial scales smaller than large marine ecosystems (Fogarty and Rose 2013). Co-design and co-creation of knowledge is increasingly recognized as a robust and meaningful approach to Science (e.g. Mauser *et al.* 2013). Here, we propose to explore the relationship between management, governance and ecosystem status at the ecosystem scale, including expert knowledge in the survey design, survey completion and interpretation of the survey data.

The IndiSeas programme (www.indiseas.org) has conducted comparative analyses across many of the world's marine ecosystems to quantify the impact of fishing using a suite of ecological indicators that are robust over diverse and contrasting conditions and a combination of data driven and ecosystem modelling approaches (e.g. Shin *et al.* 2010, 2012; Bundy *et al.* 2012; Shannon *et al.* 2014; Fu *et al.* 2015; Coll *et al.* 2016). Although the original focus of the IndiSeas programme was on the ecological status of exploited ecosystems, it has since extended its scope to include the human dimensions of fisheries in marine ecosystems, recognizing that management and governance effectiveness is likely to be linked to the status of the exploited ecosystem and that the importance and contribution of fisheries to society and community well-being should be evaluated.

A key emphasis of the IndiSeas programme has been on comparative analyses at the ecosystem scale for EBFM, matching the scale of the analysis to the scale of the system, and critically, the use of local survey data, and local expert knowledge to provide information and to interpret results: IndiSeas members include experts from all IndiSeas ecosystems. The IndiSeas approach, which tries to extract patterns from complex local realities, is hence fully complementary to existing global meta-data analyses. For each ecosystem included in the IndiSeas programme, an ecosystem expert defines the scale of the ecosystem, which currently range in size from 1000 to 3 700 000 km^2 (for further details see www.indiseas.org). In this study, we assess management and governance at the ecosystem scale across a broad suite of ecosystems using expert knowledge, explore how management and governance relates to the ecological status of exploited ecosystems, and identify what factors are important for success. We do this by developing a parsimonious expert survey questionnaire, using evidence-based criteria, to evaluate the 'Management Effectiveness' and 'Governance Quality' of ecosystems included in the IndiSeas programme at the ecosystem level. Further, we explore how the results of this survey relate to other factors and indicators of ecosystem and stock status, and test the hypothesis that ecosystems with better management and governance are more sustainable, with higher scores for ecosystem and stock status. We use the results of this analysis to identify potential ways to improve fisheries management and governance and the sustainability of exploited ecosystems.

Methods

Survey questionnaire

An expert elicitation approach was used to assess fisheries management effectiveness and governance quality in exploited ecosystems included in the IndiSeas programme. Expert elicitation has been widely used to gather information in the social and natural sciences (e.g. Lenton *et al.* 2008; Choy *et al.* 2009; Runge *et al.* 2011). An expert is defined as someone who is a knowledge integrator (representing broad expertise), has professional integrity (representing consensus, rather than just their own opinion) and has skills in analytical judgment, with particular knowledge of a given topic or area (Burgman *et al.* 2011). For this analysis, we targeted fisheries managers and scientists who are closely involved with providing fisheries management advice in each of the ecosystems analysed. Specific guidelines were developed to define who was eligible to complete the survey, based on the definition of an expert given above. The surveys were initially sent to the ecosystem representatives on the IndiSeas programme, who were then asked to use their expert judgement to select additional relevant experts to complete the survey template. Information about the experts completing the survey was collected to assess their expertise (Table 1). The reference time period for the survey is over recent years (e.g. 2005–2012), to be coherent with the ecological indicators.

Generally speaking, we consider routine activities and those of a technical nature, with well-specified targets and goals, as part of management. Governance, on the other hand, is a broader concept that emphasizes the importance of processes, the roles of institutions, the legal mandate and authority to govern, and the involvement of actors and stakeholders. The aims of governance also go beyond achieving certain objectives to providing mechanisms that enable relevant sectors to articulate their interests, establishing institutions that allow them to exercise their rights and meet their obligations, and formulating principles and values that serve as a basis for mediating differences and making decisions affecting society (Kooiman *et al.* 2005; Chuenpagdee 2011).

We used the questions from Pitcher *et al.* (2006) as a starting point to develop a

Table 1 Information required about ecosystem and fisheries experts completing the Management Effectiveness and Governance Quality Survey.

Expert Information	Fishery/Sector Information
Name	Name of country
Affiliation	Name of ecosystem
Job title and description	Number of different fisheries/fisheries sectors in the ecosystem
Specialization	Name of fishery or fishery sector
Highest degree	Year of current management plan
Number of years in this job	Number of different fisheries included in this sector
Number of years' experience in Fisheries	Total number of targeted species in this sector
Number of years' experience in related field (e.g. sociological research/fisheries management)	Annual total catch for this fishery or fishery sector from most recent year (indicate year)
International experience (Yes/No, Where?)	
Member of IndiSeas (Yes/No)	

parsimonious, short survey of management effectiveness and governance quality of exploited ecosystems in the IndiSeas programme. To this end, by means of an iterative process, we selected a subset of questions using the following criteria: the question should be clearly stated, objective, supportable by evidence and address management effectiveness or governance quality. Of the 44 questions used by Pitcher *et al.* (2006), 13 were initially selected for this study. These were then tested using a subset of IndiSeas ecosystems and revised based on the feedback of the local experts completing the questionnaire (i.e. the survey was co-designed by IndiSeas and a subset of local ecosystem experts). The survey was then completed for 23 IndiSeas ecosystems and the results presented to the larger IndiSeas membership during the annual 2011 and 2012 IndiSeas meetings. The survey was revised, to further reduce subjectivity and ambiguity in the questions, based on feedback from the participants of the annual meetings. The final survey consisted of 11 questions (Table 2), encompassing 18 of the 44 questions in Pitcher *et al.* (2006), and all surveys were completed by 2013.

Of the 11 questions, six were related to management effectiveness and five to governance quality (Table 2). Management effectiveness questions were focussed on specific details of fish stock and ecosystem management, such as reference points and whether ecosystem impacts are addressed. The governance quality questions were focussed on whether the social and economic dimensions of fisheries were addressed in their longer term governance plans and whether there is transparency in decision making. Some questions were focussed at the species/stock level, and others reflect an ecosystem perspective. By combining these two aspects, we have developed a parsimonious survey that details the essential elements required for EBFM.

A glossary of terms (see Table S1) was provided to ensure that all questions were fully understood, and experts were asked to provide references as evidence to support their responses. The 11 questions were framed as multiple choice questions, with five or six possible responses scored on a 5-point scale, where 5 was the highest score. In the few cases where there was a sixth option, it was considered equivalent to option 5 for comparative purposes (see Table S1 for a full version of the Survey Questionnaire and guidelines).

To capture the majority of fisheries that contribute to the landings from the ecosystem, experts were asked to complete the survey for all the fisheries that account for a minimum of 80% of the total landings by volume. If separate management plans existed for the different fisheries, experts were asked to complete the questions for each main management plan. Groupings could therefore be by target species, sector or management type or by gear type – for example small-scale longline, small-scale trap fishery and mid-water trawl fishery. A single score for each question was calculated as the average of all fisheries/sectors, weighted by their total landings.

In many cases, several experts representing the different fisheries/sectors in the ecosystem completed the survey. In cases where more than one expert independently completed the survey for the same fishery or sector and the scores were markedly different, the experts were contacted again, and a consensus approach was used to arrive at a single response.

Data analysis

Survey results

The Management Effectiveness and Governance Quality Survey results (the Survey results henceforth) were first explored to evaluate and summarize the information provided by the survey respondents about their expertise and experience to provide contextual information to help evaluate the quantitative analyses described below.

The responses to the 11 questions were then explored to elucidate the major patterns in the data and to summarize and rank results. Finally, the rank order of the IndiSeas ecosystems, using the average of the 11 questions, was compared with the rank order based on compliance with the CCRF (Pitcher *et al.* 2009a). In cases where an ecosystem straddled more than one national jurisdiction, the CCRF scores for each country bordering the ecosystem were averaged, using their total average annual landings from the ecosystem (2000–2010) as a weighting factor, to estimate an average ecosystem compliance score – see Table S2 for further details.

Multivariate analysis

A range of multivariate methods was used to explore the results of the Survey using the statistical package PRIMER (6.1.2, PRIMER-E Ltd, Plymouth, UK).

Table 2 Management Effectiveness and Quality of Governance Survey questions. Right-hand column indicated the question numbers from Pitcher *et al.* (2006) to which the survey questions relate.

Assess the Effectiveness of Management	Pitcher *et al.* (2006)
1. How frequently are stock assessments* carried out in your fishery or fishery sector?	na
i. No stock assessments are being carried out ii. Infrequent for less than 50% of commercial stocks iii. Infrequent for more than 50% of commercial stocks iv. Every 1–5 years for less than 50% of commercial stocks v. Every 1–5 years for more than 50% of commercial stocks	
2. Are limit reference points*, thresholds*, or other targets*, set and used for the management of commercial stocks and/or species at risk?	1,19,20
i. No reference points exist ii. Reference points exist for less than 50% of stocks/species but are not implemented iii. Reference points exist for less than 50% of stocks/species and are implemented iv. Reference points exist for more than 50% of stocks/species and are implemented v. Reference points exist for more than 50% of stocks/species are implemented and regularly reviewed	
3. Are depleted stocks* or species* being successfully rebuilt?	5, 32
i. No ii. The intention to rebuild is in the management plan, but there is no mechanism in place to enable rebuilding iii. Rebuilding effort occurs, but it is not effective iv. Effective rebuilding* of less than 50% of depleted stocks/species v. Effective rebuilding of more than 50% depleted stocks/species vi. No depleted stocks or species caught in this fishery or fishery sector	
4. Are management measures* being reviewed frequently enough to maximize the prospect that the management intentions* are met?	23
i. No review ii. Infrequent review and management intentions not being met iii. Infrequent review, but some management intentions being met iv. Frequent enough review to maximize the prospect that most management intentions are met v. Frequently enough review to maximize the prospect that all management intentions are met	
5. Are ecosystem impacts* of fishing assessed, and are they being addressed?	8,25
i. No ecosystem impact assessment ii. Some ecosystem impact assessment, but no impacts are being addressed iii. Some ecosystem impact assessment, and some impacts are being addressed iv. Comprehensive ecosystem impact assessment, and some impacts are being addressed v. Comprehensive ecosystem impact assessment, and all impacts are being addressed	
6. Is Illegal*, Underreported* and Unregulated* (IUU) fishing being addressed by management?	42,43
i. No ii. The intention to address IUU is in the management plan, but there is no mechanism in place to enable action iii. Some mechanisms to address IUU are in the management plan, but they are not effective iv. Mechanisms to address IUU are in the management plan, and they are partly effective v. Mechanisms to address IUU are in the management plan, and they are effective vi. Not applicable (i.e. there is no IUU)	

Table 2 Continued.

Assess the Effectiveness of Management	Pitcher *et al.* (2006)
Assess Quality of Governance	Pitcher *et al.* (2006)
7. Is this fishery managed so as to minimize conflict* with other fishery sectors?	33
i. Conflict is not acknowledged ii. Conflict is acknowledged but not addressed iii. Conflict is addressed, but has little effect iv. Conflict is addressed, but only partly effective v. Conflict management is very effective vi. Not applicable	
8. Does the fishery or fishery sector management plan have long-term objectives*?	12
i. no long-term objectives in management plan ii. yes, but no specific ecological, social or economic long-term objectives iii. yes, but only with one of the following long-term objectives: ecological, economic or social iv. yes, but only with two of the following long-term objectives: ecological, economic or social v. yes, with ecological, economic and social long-term objectives	
9. Are the social impacts of the fisheries management plan considered and formally evaluated in management decisions?	34,35,37
i. Social impacts not considered ii. Social impacts considered, but not formally evaluated* iii. Social impacts formally evaluated, but with no change to management decisions iv. Social impacts formally evaluated, with some required changes reflected in management decisions v. Social impacts formally evaluated, with all required changes reflected in management decisions	
10. Are economic impacts of the fisheries management plan considered and evaluated in management decisions?	16,36
i. Economic impacts not considered ii. Economic impacts considered, but not formally evaluated* iii. Economic impacts formally evaluated, but with no change to management decisions iv. Economic impacts formally evaluated, with some required changes reflected in management decisions v. Economic impacts formally evaluated, with all required changes reflected in management decisions	
11. Is the participation of the harvesting sector a requirement in fisheries management?	13,14
i. No requirement ii. Required but limited to information provision to harvesting sector iii. Required and includes some two-way information exchange iv. Required and involves full exchange of information v. Required, involves full exchange of information and input to management decisions	

*Asterisks denote terms that are explained in the glossary - see Table S1 for further details.

Prior to analysis, the Survey data were standardized using the 'normalize' routine in PRIMER. Survey results were first examined using Draftsman plots to assess skewness in the data and Spearman rank-order correlations were used to test for correlations between the 11 questions: the maximum Spearman rank correlation was 0.82, with an average of 0.46, so all questions were used in the analysis.

The Survey data were then explored using a standard principle components analysis (PCA) and a hierarchical agglomerative cluster analysis based on Euclidean distance. The group average option was used to link clusters, which is based on the mean similarity between all samples in two groups. Significance of the cluster results was tested using the 'SIMPROF' permutation test, which examines whether the similarities observed in the data are smaller and/or larger than those expected by chance (Clarke *et al.* 2008). We used 1000 permutations and an alpha of 5%.

Relationship to additional ecosystem characteristics

In order to place the Survey results in a broader context, and to gain understanding of the resulting patterns and groupings, we explored their relationship with national social, economic and governing conditions and with ecosystem status. There is a wealth of potential indicators to measure these conditions, and we initially selected thirteen commonly used and accepted indicators of national social, economic and governing conditions, available at the global scale from a range of sources, and three indicators of ecosystem status and ecosystem size. Where possible the data were extracted for 2005–2012 (see Table S3 for further details) and standardized using the 'normalize' routine in PRIMER. Spearman rank-order correlations were used to evaluate whether there were any correlations between these additional ecosystem characteristics, using a coefficient of 0.85 as a threshold. Of the 17 additional ecosystem characteristics (Table S3), most were highly correlated with at least one other indicator (Table S4). Redundant ecosystem characteristics were removed, reducing the number of additional ecosystem characteristics to eight (Table 3): two socioeconomic indicators – the Human Development Index (HDI, http://hdr.undp.org/en, accessed February 2016) and Research and Development (R and D, http://hdr.undp.org/en, accessed February 2016), two broad governance indicators – Bad Fisheries Subsidies (B-SUBS, Khan *et al.* 2006) and Political Stability and Absence of Violence/Terrorism (PS, Kaufmann *et al.* 2011), three indicators of ecosystem status – Sustainable Stocks (SS, Shin *et al.* 2010; Coll *et al.* 2016), Non-Declining Exploited Species (NDES, Kleisner *et al.* 2015), and an IndiSeas aggregate indicator of ecosystem status (ES, Bundy *et al.* 2012), and Ecosystem Size (Size). See Table S3 for further details.

The PRIMER BEST routine was used to investigate whether there was a relationship between the results of the multivariate analysis of the Survey data and the nine ecosystem characteristics. It selects the ecosystem characteristics that globally best explain the variability in the Survey data. Specifically, it calculates the correlation coefficients between the similarity matrices of the Survey data and the ecosystem characteristics and identifies the combination of ecosystem characteristics that maximize the correlation between the two similarity matrices. Some of the additional ecosystem characteristics were transformed; all were standardized prior to analyses. The statistical significance of the results of the BEST analyses was assessed using a permutation test (Clarke *et al.* 2008).

The social, economic, governing and size indicators were available for all ecosystems, but the additional IndiSeas ecological indicators, SS, NDES and ES, were only available for a subset of the total of the ecosystems included in the Survey. To fully explore all the ecological indicators, and maximize the number of ecosystems in the analysis, four separate BEST analyses were explored:

1. BEST 1: All ecosystems, excluding, SS, NDES and ES (n = 27)
2. BEST 2: Only ecosystems with SS data, excluding NDES and ES indicators (n = 25)
3. BEST 3: Only ecosystems with SS and NDES data excluding ES indicator (n = 18)

Table 3 Social, economic, governance and ecological indicators used in the BEST analyses.

Social, Economic and Ecological Indicators	Source	Number of ecosystems
1. Ecosystem Size (Size)	IndiSeas 2	27
2. Human Development Index (HDI)	International Human Development Indicators – UNDP	27
3. Research and Development (% of GDP): average 2006–2012 (R&D)	http://hdr.undp.org/en (accessed Feb 2016)	
4. Bad Fisheries Subsidies – % GDP (Bad-SUBS)	Sumaila and Pauly (2006)	27
5. Political Stability and Absence of Violence/Terrorism (PS)	The Worldwide Governance Indicators www.govindicators.org (accessed Feb 2016)	27
6. Sustainable Stocks – Proportion of moderately and underexploited species (SS)	IndiSeas, Shin *et al.* (2010); Coll *et al.* (2016)	25
7. NDES: Non-Declining Exploited Species	IndiSeas, Kleisner *et al.* (2015)	18
8. ES: Ecosystem Status (−1, 0, +1)	IndiSeas, Bundy *et al.* (2012)	13

4. BEST 4: Only ecosystems with all additional ecological indicators (n = 11)

These four analyses differed in the number of ecosystems and ecological indicators included. As a statistical check to ensure that any differences in results between the four BEST analysis were due to the combination of indicators and not the difference in number of ecosystems included in the analysis, BEST 1, 2, 3 and 4 were rerun as BEST 1a, 2a and 3a without the ecological indicators SS, NDES and ES.

Results

Management effectiveness and governance quality survey results

Background experts and ecosystem data

Survey templates were completed by 61 experts from 27 IndiSeas ecosystems (Fig. 1, Table 4). On average, there were 2.3 experts per ecosystem survey template, although in 15 cases only one expert completed the survey (Table 5). In the 12 cases where more than one expert completed the survey, most responses were for different fishery sectors. In cases where more than one expert provided information for the same sector, a consensus approach was used in one case, and an average taken in the other cases as the differences were minor. Each expert had an average of 18 years of experience in fisheries, and 13 years in sociological research and/or fisheries management. Over half (40) of the experts were from government institutions, 20 from academia and 1 from an NGO. All experts were university educated, with most having PhDs or MScs, and most were senior researchers or above (Table 5b).

The 27 systems ranged in size from 1000 to 3 700 000 km^2, with an average size of 346 000 km^2 and a median size of 89 000 km^2 (Tables 4 and 5c). Four ecosystems were defined at the same scale as the country's EEZ (Portugal, Guinea, northern Humboldt and Senegal), and the rest were either ecosystems within the EEZ including the two largest ecosystems, south-east Australia and the West Coast USA, or were ecosystems that straddled national boundaries. The respondents were asked to define the number of different fisheries or fisheries sectors in the ecosystem, which varied from one to fifteen, with a median value of four. The survey was subsequently completed for each of these sectors. In practice, experts were only required to complete the survey for sectors that contributed to a minimum of 80% of the landings by volume, so the maximum number of sectors in any ecosystem for

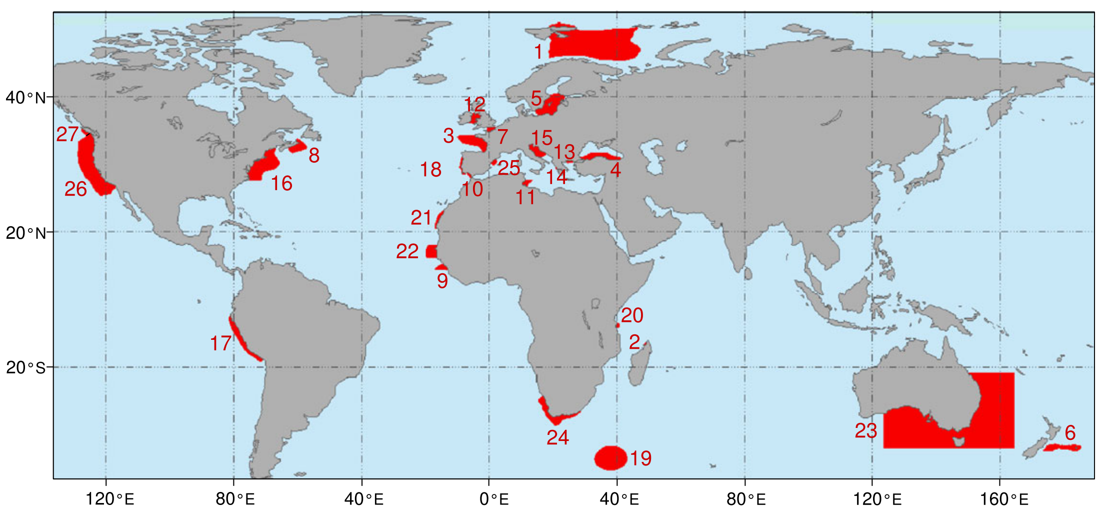

Figure 1 Map showing the location and size of the 27 IndiSeas ecosystems included in this analysis. 1 = Barents Sea, 2 = Bay of Ambaro, 3 = Biscay Bay, 4 = Black Sea (Turkish Waters), 5 = Central Baltic Sea, 6 = Chatham Rise, 7 = Eastern English Channel, 8 = Eastern Scotian Shelf, 9 = Guinean Shelf, 10 = Gulf of Cadiz, 11 = Gulf of Gabes, 12 = Irish Sea, 13 = North Aegean Sea, 14 = North Ionian Sea, 15 = North-central Adriatic Sea, 16 = North-east USA, 17 = Northern Humboldt Current, 18 = Portugal, 19 = Prince Edward Islands, 20 = Rufiji-Mafia Channel, 21 = Sahara Coastal Morocco, 22 = Senegalese Shelf, 23 = South-east Australian Shelf, 24 = Southern Benguela Current, 25 = Southern Catalan Sea, 26 = West Coast USA, 27 = West Coast Vancouver Island. Map prepared by Hervé Demarcq, IRD, France. [Colour figure can be viewed at wileyonlinelibrary.com].

Table 4 List of 27 exploited marine ecosystems included in the IndiSeas Survey, additional ecosystem characteristics and indication of the availability of data to calculate the indicators in each ecosystem.

	Ecosystems	Label	Ocean/Sea	Ecosystem type	SIZE (km^{2*1000})	HDI	Subs	WGI	SS	NDES	IndiSeas
1	Barents Sea	BAREN	NE Atlantic	High latitude	677	Y	Y	Y	Y	Y	Y
2	Bay of Ambaro, Madagascar	MADAG	SW Indian	Tropical	5	Y	Y	Y	na	na	na
3	Biscay Bay	BISCA	NE Atlantic	Temperate	202	Y	Y	Y	Y	Y	na
4	Black Sea (Turkish Waters)	BLCK	Black Sea	Temperate	18.4	Y	Y	Y	Y	Y	na
5	Central Baltic Sea	BALTI	NE Atlantic	Temperate	248	Y	Y	Y	na	Y	Y
6	Chatham Rise	CHATH	SW Pacific	Temperate	167	Y[1]	Y	Y	Y	na	na
7	Eastern English Channel	CHANN	NE Atlantic	Temperate	26	Y	Y	Y	Y	Y	na
8	Eastern Scotian Shelf	ESS	NW Atlantic	Temperate	89	Y	Y	Y	Y	Y	Y
9	Guinean Shelf	GUINE	E Central Atlantic	Tropical	47	Y[2]	Y	Y	Y	Y	Y
10	Gulf of Cadiz	CADIZ	NW Atlantic	Temperate	8.9	Y	Y	Y	Y	Y	na
11	Gulf of Gabes	GABES	C Mediterranean Sea	Temperate	36	Y[3]	Y	Y	Y	na	na
12	Irish Sea	IRISH	NE Atlantic	Temperate	58	Y	Y	Y	Y	Y	Y
13	North Aegean Sea	AEGEA	E Mediterranean Sea	Temperate	8	Y	Y	Y	Y	Y	na
14	North Ionian Sea	IONIA	C Mediterranean Sea	Temperate	1	Y	Y	Y	Y	Y	na
15	North-central Adriatic Sea	ADRIA	C Mediterranean Sea	Temperate	55.5	Y	Y	Y	Y	Y	Y
16	North-east USA	NEUS	NW Atlantic	Temperate	297	Y	Y	Y	Y	Y	Y
17	Northern Humboldt Current	NHUMB	SE Pacific	Upwelling	149	Y	Y[4]	Y	Y	Y	Y
18	Portugal	PORTU	NE Atlantic	Upwelling	24	Y	Y	Y	Y	Y	Y
19	Prince Edward Islands	PE_IS	S Indian	High latitude	431	Y	Y	Y	Y	na	na
20	Rufiji-Mafia Channel, Tanzania	TANZA	SW Indian	Tropical	1.2	Y	Y	Y	Y	na	na
21	Sahara Coastal Morocco	SAHAR	E Central Atlantic	Upwelling	57	Y	Y	Y	Y	na	na
22	Senegalese Shelf	SENEG	E Central Atlantic Ocean	Upwelling	159	Y	Y	Y	Y	na	Y
23	South-East Australian Shelf	AUST	SW Pacific Ocean	Temperate	3700	Y	Y	Y	Y	na	na
24	Southern Benguela Current	SBENG	SE Atlantic Ocean	Upwelling	244	Y[5]	Y	Y	Y	Y	Y
25	Southern Catalan Sea	CATAL	NW Mediterranean Sea	Temperate	5	Y	Y	Y	Y	Y	Y
26	West Coast USA	NWUS	NE Pacific Ocean	Upwelling	2000	Y	Y	Y	Y	Y	na
27	West Coast Vancouver Island	WCVI	NE Pacific Ocean	Upwelling	4.7	Y	Y	Y	Y	Y	Y

[1]No IHDI or HDI-loss data for New Zealand, so values from Australia were used, pro-rated by the ratio of their HDI values (0.98).

[2]No Research and Development data were available so the average for Africa was used.

[3]No IHDI or HDI-loss data for Tunisia for 2012, so values from 2014 were used.

[4]No UNDP Research and Development data were available, so the value from Chile was used, pro-rated by the ratio of their HDI values (0.9).

[5]No IHDI or HDI-loss data for New Zealand for 2012, so values for 2014 were used.

Table 5 (a) Summary of metadata from Management Effectiveness and Quality of Governance Survey: responses from Experts Part 1: average of numerical responses. (b) Summary of responses from Experts Part 2: count of categorical responses. (c) Summary of information about the ecosystems.

	Total number of experts	Number of years in this job	Number of years of experience in Fisheries	Number of years' experience in related field (e.g. sociological research/fisheries management)
(a)				
Average	2.3	14.2	18.0	13.5
Mode	1	6.0	19.0	0.0
Min	1	3.0	3.0	0.0
Max	8	35.0	35.0	35.0
# >1	12	26	25	20
No response		1	2	2
SUM	61			

Option	Job title and description: 1 = Government; 2 = Academic; 3 = NGO; 4 = other;	Seniority[1]: 1 = head scientist; 2 = senior scientist/professor; 3 = lead researcher/manager; 4 = researcher; 5 = postdoc/student	Highest degree[1]: 1 = PhD; 2 = MSc, 3 = BSc, 4 = other:	International experience[1] (Yes/No, Where?) 1 = widely 2 = ICES/STECF/PICES; 3 = Y, some in region; 4 = N0
(b)				
1	40	3	18	6
2	20	8	7	6
3	1	8	0	11
4	0	8	1	4
5	na	0	na	na
No response	0	0	1	0

	Number of fisheries/ fisheries sectors	Number of fisheries/ fisheries sectors defined	Year of current management plan	Number of different fisheries	Total number of targeted species	Annual total catch for most recent year (indicate year)	Size (km^2*1000)
(c)							
Min	1	1	1994	1	1	84	1
Max	15	8	2013	21	60	1 500 0000	3700
Average	5	4	2009	7	23	1 012 547	346
Median	4	4	2011	6	20	80 822	89

[1]For Surveys completed by more than one expert an average was used. Therefore, these columns sum to the total number of ecosystems, 27.

which the survey was actually completed was eight (Table 5c).

Survey results

All questions received a wide range of responses (Fig. 2 and Table S5), most spanning the range of options. Of the six questions focussed on Management Effectiveness, the highest scores were obtained for Q1, which asked 'How frequently are stock assessments carried out in your fishery or fishery sector?', and the lowest scores were for Q2, which asked 'Are limit reference points, thresholds, or other targets, set and used for the management of commercial stocks and/or species at risk?' and Q5, which asked 'Are ecosystem impacts of fishing assessed, and are they being addressed?'.

Questions 3, 4 and 6 had similar average scores of around 3.4. Of the five Governance Quality questions, Q7 (Is this fishery managed so as to minimize conflict with other fishery sectors?) achieved the highest score and Q9 (Are the social impacts of the fisheries management plan considered and formally evaluated in management decisions?) and Q10 (Are the economic impacts of the fisheries management plan considered and formally evaluated in management decisions?) received the lowest scores (Fig. 2).

Overall, the Governance Quality questions received lower scores ($\mu = 2.88$, $\sigma = 0.88$) than the Management Effectiveness questions ($\mu = 3.37$, $\sigma = 1.0$), and Question 1 had the highest score overall. Further, the greatest variation of responses was for Governance Quality Q8 (Does the fishery or fishery sector management plan have long-term objectives?) ($\mu = 2.88$, σ=1.49), and the narrowest range of responses was for Q5 ($\mu = 2.59$, $\sigma = 0.64$).

No ecosystem received an average score of 5 over the 11 questions, and only 6 scored 4 or over, Fig. 3. When rank ordered, the three ecosystems with the highest scores across all questions were the south-east Australian Shelf, the West Coast USA and the Barents Sea, and the three lowest were the southern Catalan Sea, the Guinean Shelf and north Ionian Sea (Fig. 3). When the Survey results were ranked separately as Management Effectiveness and Governance Quality, the ecosystems with the lowest three scores did not change, but the rank order of other ecosystems did, including the ecosystems with the top three scores. For Management Effectiveness, the top three scores were for the south-east Australian Shelf, the Barents Sea and Prince Edward Islands, and for Governance Quality it was West Coast Vancouver Island, the south-east Australian Shelf and the West Coast USA. In general, systems with low average scores for Management Effectiveness and Governance Quality questions combined had low scores for the Management Effectiveness or Governance Quality questions. This was not necessarily the case for systems with high scores for Management Effectiveness and Governance Quality. Most of the ecosystems had lower scores for Governance Quality than Management Effectiveness (22 ecosystems), 11 of which were lower by more than 20%, and, in the case of the Irish Sea, 50%. On the other hand, the score for Governance Quality for West Coast Vancouver Island was much higher than Management Effectiveness (which was also relatively high).

The rank order of the IndiSeas ecosystems from this Survey was compared with the rank order using the compliance with the Code of Conduct for Responsible Fisheries scores from Pitcher *et al.*

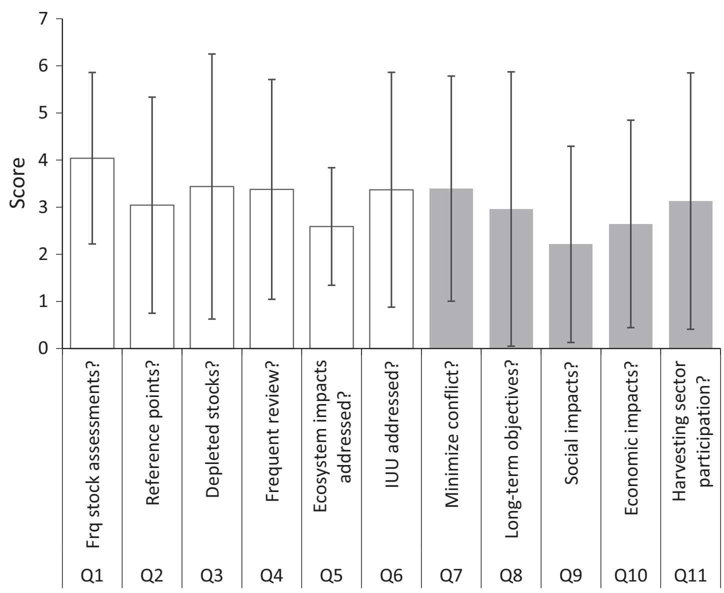

Figure 2 Responses averaged over the 27 ecosystems for each of Survey Questions with 95% confidence limits. White bars refer to Management questions; grey bars refer to Governance questions.

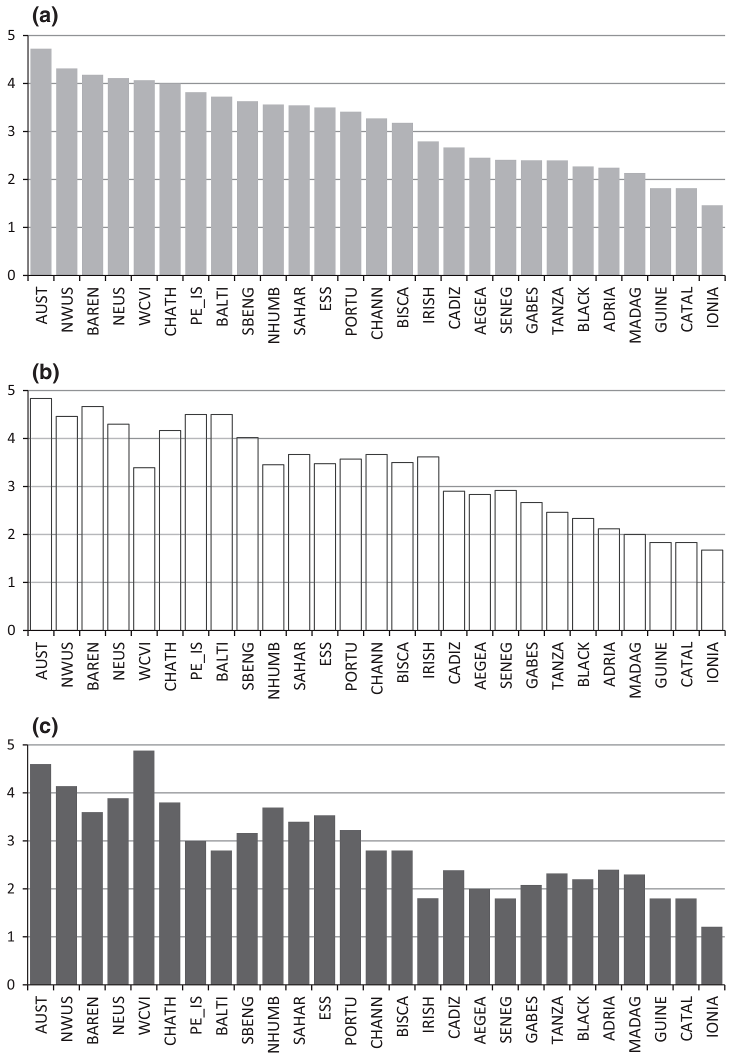

Figure 3 Results of the Management Effectiveness and Governance Quality Survey ranked by (a) the score averaged over all questions per ecosystem, (b) the average scores for Management Effectiveness and (c) the average scores for Governance Quality. For acronyms, see Table 4.

(2009a) for the 22 IndiSeas ecosystems for which there were compliance scores available. The countries with the six top scores for each survey (Fig. 4) were comparable, with two exceptions. The eastern Scotian Shelf (Canada) had a lower ranking in our Management Effectiveness and Governance Quality Survey, and the Barents Sea (Norway and Russia) had a higher one. However, there were more differences in the rank order of the rest of the ecosystems, in some cases substantially, as illustrated in Fig. 4. For example, the northern Humboldt (Peru) and Sahara Coastal Morocco were ranked among the lowest three using the scores from Pitcher *et al.* (2009a), but were ranked in the middle of the range in this analysis. Other ecosystems were given a lower ranking by our Management Effectiveness and Governance Quality Survey, such as the Catalan Sea and the north-central Adriatic Sea.

Multivariate analysis

The first three principle components of the PCA accounted for 53, 15 and 8% of the variation in the data, a total of 76%. All survey questions had high scores (positive (>0.3) or negative (<−0.3)) on at least one principle component (PC); thus, all were useful in defining the clusters (Table 6). The

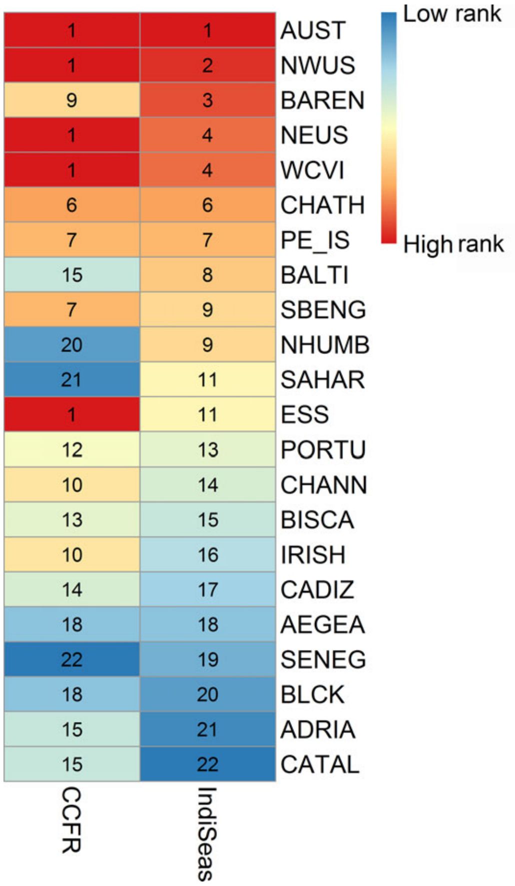

Figure 4 Heat Map showing the relative rankings of 22 IndiSeas ecosystems based on results from the Management Effectiveness and Governance Quality Survey. Also shown (left column) are the rankings from the Pitcher *et al.* 2006 CCFR Survey. Shading from highest rank (1 = red) to lowest rank (22 = blue). Note that they are ranked based on the IndiSeas rankings. For acronyms, see Table 4. [Colour figure can be viewed at wileyonlinelibrary.com].

Cluster Analysis divided the 27 systems into two large clusters and one unitary cluster (Fig. S1), which were superimposed on the PCA (Fig. 5a). Cluster 1 and West Coast Vancouver Island were separated from Cluster 2 along PC1. As all survey questions scored negatively on PC1, in general, systems to the left of PC1 in Fig. 5 scored better on all questions than those to the right side of the figure. In particular, the defining questions for PC1 (those with the highest negative scores) were Q2 (Reference points), Q4 (Frequency of review), Q6 (IUU (Illegal, Underreported and Unregulated) fishing addressed) and Q11 (Harvesting sector participation), Table 6.

Table 6 Scores of variables on the first three principle components of the PCA of 27 IndiSeas Ecosystems based on the Management Effectiveness and Quality of Governance Survey results. Bold numbers indicate higher loadings on the principle components.

	Survey Question	PC1	PC2	PC3
1	Frequency of stock assessments?	−0.249	−0.19	−**0.473**
2	Reference points?	−**0.363**	−0.098	−0.003
3	Depleted stocks?	−**0.305**	−0.251	0.112
4	Frequency of review?	−**0.387**	−0.05	0.041
5	Ecosystem impacts addressed?	−0.228	−0.098	−**0.674**
6	IUU addressed?	−**0.347**	−0.021	−0.044
7	Minimize conflict?	−**0.315**	−0.226	**0.378**
8	Long-term objectives?	−**0.311**	0.187	0.107
9	Social impacts?	−0.119	**0.708**	0.033
10	Economic impacts?	−0.257	**0.54**	−0.153
11	Harvesting sector participation?	−**0.338**	−0.007	**0.356**

PC2 was largely defined by Q9 and Q10 (Are the social (economic) impacts of the fisheries management plan considered and formally evaluated in management decisions?), with high positive scores on PC2 (Table 6), providing a strong signal that separated systems with some form of long-term social and economic management objectives (such as north-east USA and West Coast Vancouver Island, systems at the top of Cluster 1), from those without. The Irish Sea stands out from the rest of Cluster 2, due to its low scores on Q8–Q11. PC3 is characterized by high positive scores on Q7 (Minimize conflict?) and Q11 (Harvesting sector participation?) and high negative scores on Q5 (Ecosystem impacts addressed?) and Q1 (Frequency stock assessments?). When PC2 was plotted against PC3, the separation of the West Coast Vancouver Island from the other ecosystems was very clear (Fig. 5b), due to its high scores on PC2 (Q9 and Q10) and PC3 (Q7 and Q11), and its lower scores on Questions 1 and 5 (PC3, Fig. 5b).

Although the questions were divided into Management Effectiveness and Governance Quality in the survey, they did not completely group this way in the PCA: Governance Qs 8, 9 and 10 all scored positively on PC2, but Governance Q11 (Harvesting sector participation?) grouped with the Management Effectiveness questions. In addition to the survey questions that separate Cluster 1 and West Coast Vancouver Island from Cluster 2, it is notable that Cluster 1 is largely comprised of

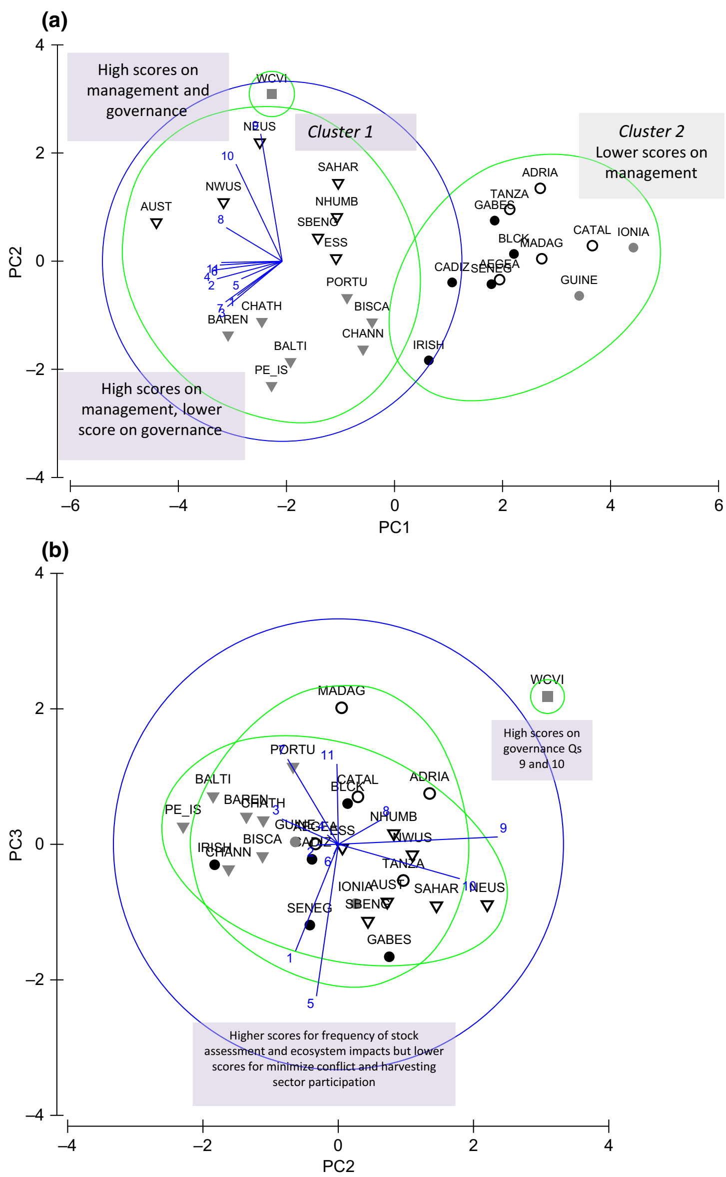

Figure 5 PCA of 27 ecosystems using Management Effectiveness and Governance Quality results. (a) PC1 vs. PC2 and (b) PC2 vs. PC3. Blue lines represent the scores of the survey questions on the principal components; length of line reflects the importance of the loading, where a longer line indicates greater loading. For acronyms, see Table 4. [Colour figure can be viewed at wileyonlinelibrary.com].

systems from Europe, North America, and the Pacific, whereas Cluster 2 is mainly comprised of systems from the Mediterranean and Africa, suggesting a geographic divide that may be related to other social and economic factors, explored below.

Relationship to other ecosystem characteristics – BEST Analysis

Size was consistently selected as one of 2–3 external ecosystem characteristics that best explained the variability of the Survey data across all four BEST analyses (Table 7) and political stability (a proxy for the World Governance Indicators) was selected in BEST 1, 2 and 3. In BEST analyses 2–4, where the ecological indicators were added, the latter were always selected (SS in BEST 2, SS and NDES in BEST 3, and SS, NDES and ES in BEST 4). All results were significant, and the highest correlations between the ecosystem characteristics and the survey data resemblance matrix were for

Table 7 Results of the BEST analysis. For ecosystem characteristics abbreviations, refer to Table 3.

BEST Analysis	Number of Systems	Number of ecosystem characteristics	Ecosystem characteristics	ρ	Significance % level	BEST ecosystem characteristics
BEST 1	27	5	Size, HDI, Bad-SUBS, RandD, PS	0.459	0.1	Size; Political Stability
BEST 2	25	T6	Size, HDI, Bad-SUBS, RandD, PS, SS	0.507	0.1	Size; Political Stability; SS
BEST 3	18	7	Size, HDI, Bad-SUBS, RandD, PS, SS, NDES	0.562	0.1	Size; Political Stability; SS; NDES
BEST 4	11	8	Size, HDI, Bad-SUBS, RandD, PS, SS, NDES, ES	0.583	3.7	Size; HDI; SS; NDES; ES
BEST 1a	11	5	Size, HDI, Bad-SUBS, RandD, PS	0.407	13.3	Size; HDI
BEST 2a	11	6	Size, HDI, Bad-SUBS, RandD, PS, SS	0.558	3.7	Size; HDI, SS;
BEST 3a	11	7	Size, HDI, Bad-SUBS, RandD, PS, SS, NDES	0.570	3.4	Size; HDI, SS, NDES

BEST 4, for ecosystem characteristics Size, HDI, SS, NDES and ES. The results of Best 1a-3a confirm that the correlation results observed in BEST 4 were not the result of the smaller number of ecosystems in this analysis (Table 7): that is, BEST 4 still resulted in the highest significant correlation between the Survey data and the additional ecosystem characteristics. Therefore, there was a strong relationship between the ecological indicators and the Survey data.

To visually compare the results of BEST 4 to the results of the Survey, a PCA was run for the 11 ecosystems from BEST 4 using the five best ecosystem characteristics (Fig. 6, Table 8). PC1 explained 54% of the variation in the data, and was defined by SS, NDES and ES, that is, the ecological status of the ecosystem. PC2 explained 26% of the variation in the data and was primarily defined by size and HDI (Table 8). The results are comparable to the PCA that used all 27 systems (Fig. 5). There were three main clusters (although not significant (SIMPROF test)), but the same ecosystems grouped together in each cluster. These results indicate that the main pattern observed in the Survey results can be reproduced based largely on the ecosystem indicators, that is, SS, NDES and ES, again illustrating the strong relationship between management, governance and ecosystem status. West Coast Vancouver Island, north-east USA and the Barents Sea were located to the left of all PCA plots, whether the Survey data or the ecological and human

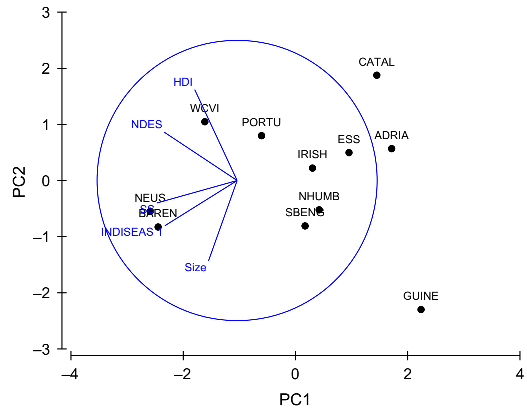

Figure 6 PCA of 11 ecosystems using the five best ecosystem characteristics from BEST4. Blue lines represent the scores of the ecosystem characteristics on PC1 and PC2; length of line reflects the importance of the loading, where a longer line indicates greater loading. For acronyms, see Table 4. [Colour figure can be viewed at wileyonlinelibrary.com].

dimensions indicators were used; the southern Catalan Sea, north-central Adriatic Sea and Guinea were always located on the right-hand side of the PCAs and the Irish Sea, northern Humboldt Current, Portugal and southern Benguela Current were located in the middle (Figs 5 and 6). Only the eastern Scotian Shelf, which moved to the right of the PC1, closer to the southern Catalan Sea, the north-central Adriatic Sea and Guinean Shelf in Fig. 6, changed position. Given the explanatory power of PC1, it can be concluded

Table 8 Results of the PCA of the 11 systems from BEST 4: Percentage variation explained (top row) and scores of variables on principal components in subsequent rows. For ecosystem characteristics abbreviations, refer to Table 6.

	PC1	PC2	PC3
% variation	53.9	26.1	14.9
Variable			
Size	−0.204	−0.574	0.78
HDI	−0.303	0.649	0.46
SS	−0.574	−0.16	−0.16
NDES	−0.520	0.345	−0.009
ES	−0.516	−0.323	−0.392

that there is a strong relationship between systems with high (low) scores for Management Effectiveness and Governance Quality and good (poor) ecosystem and stock status. Size and HDI have less influence on results, principally along PC2 and PC3. Guinea's low HDI, for example, separated it from the other systems along PC2 (Fig. 6).

Discussion

Many nations are adopting or are considering the adoption of EBFM; 67% of member States reporting to FAO's Committee on Fisheries indicate that they are implementing some form of an ecosystem approach to fisheries (FAO 2014a,b), which requires thinking, planning and acting at the ecosystem scale. The analysis presented here represents the first real exploration of the relationship between management, governance and ecosystem status at the ecosystem scale. The main conclusion was that higher scores for Management Effectiveness and Quality of Governance were observed in the ecosystems with better ecosystem and stock status, suggesting that good ecosystem-based management and governance, and healthy ecosystems go together. This is coherent with the results of Coll *et al.* (2013) and Mora *et al.* (2009) studies conducted at much broader scales, without local experts involved in providing the information and data, interpreting the analysis, and providing a more hands-on understanding of management and governance in these ecosystems. The benefit of the finer scale analysis conducted here is that a more nuanced understanding of how management and governance contribute to ecosystem health was achieved. Specifically, our results enabled the identification of aspects of the management and governance that are important to ensure good ecosystem status and also to specify, for different systems, which aspects may need to be improved.

Responses to three questions related to Management Effectiveness (Q2 (Reference points?), Q4 (Frequency of review?) and Q6 (IUU addressed?) and Governance Quality Q11 (Harvesting sector participation?), were key to distinguishing between the 27 ecosystems. Responses to Governance Quality questions Q9 and Q10, regarding inclusion of social and economic impacts in management plans, led to further differentiation between these systems. Q11, concerning harvesting sector participation in fisheries management, was classed as a governance question, but it aligned with the responses to the Management Effectiveness questions in the PCA. Stakeholder participation in resource management generally (Beierle 2002; Reed 2008) and fisheries management specifically (e.g. Jentoft and McCay 1995; Pomeroy *et al.* 2001; Beddington *et al.* 2007; Mora *et al.* 2009) have been previously identified as important for sustainable fisheries management and this is reinforced by our results. Our question about stakeholder participation was quite simple; others have noted the realities and complexities in engaging stakeholders in fisheries research and decisions making (e.g. Gray and Hatchard 2008; Pita *et al.* 2010; Mackinson *et al.* 2011).

Two questions, Q1 (Frequency of stock assessments) and Q5 (Ecosystem impacts addressed), had little influence on overall results, despite their widely perceived importance in EBFM. Most ecosystems scored well on Q1, but poorly on Q5, suggesting positively that stock assessments were generally being conducted frequently enough but that ecosystem impacts were not yet being adequately addressed. However, of the six ecosystems with the highest rankings (averaged over the 11 questions), five had high scores (>3) for addressing ecosystem impacts, underscoring that high performing management systems tend to include consideration of ecosystem impacts.

These overall results are consistent with analyses conducted at the National or High Seas level (Pitcher *et al.* 2006, 2009a,b; Mora *et al.* 2009; Cullis-Suzuki and Pauly 2010; Coll *et al.* 2013); however, our survey differed in several important ways. We used a parsimonious set of 11 questions that were empirically tried and tested prior to finalizing the survey, questions were designed to be objective, and documented evidence in support of the responses was required. Although the questions were adapted from Pitcher *et al.* (2006), our intent was not to assess how well nations complied with the Code of Conduct for Responsible Fisheries, but to assess how well fisheries were managed and governed, and to what extent ecosystem considerations, including social and economic aspects, were incorporated into long-term management plans. Notably, few ecosystems scored well on the latter questions, indicating an opportunity for improvement within the management and governance arena (Skern-Mauritzen *et al.* 2016). This is consistent with Pitcher *et al.* (2009a,b) who observed that countries scored poorly on questions concerned with ecosystem-based management. However, in contrast with the Pitcher *et al.* (2009a) analysis, our results produced higher overall scores for control of illegal fishing, suggesting that some progress may have been made in this area. This is confirmed by a recent FAO report on 'Progress in the Implementation of the Code of Conduct for Responsible Fisheries and Related Instruments' (FAO (2014a), which indicates that following the recognition of IUU fisheries as a problem in 90% of member states, most have taken measures to combat this threat.

The results of our ranking were generally coherent with those of Pitcher *et al.* (2009a), with a couple of exceptions; the Catalan Sea and the north-central Adriatic Seas received notably lower scores in this analysis, and the northern Humboldt and Sahara Coastal Morocco received visibly higher scores. We do not interpret this as a contradictory result as the earlier large-scale analyses do not necessarily reflect what is happening at the smaller ecosystem scale (e.g. Marshall *et al.* 2015). In the Pitcher *et al.* (2009a) analysis, the Catalan Sea and the north-central Adriatic Seas were classified with the rest of Spain and Italy respectively, whereas in this analysis, they were assessed at much smaller scale. Both are highly exploited ecosystems, so a lower ranking at this scale compared to the country level makes sense. Notably, the Catalan Sea and the north-central Adriatic Seas, both Mediterranean systems, received similar scores. It is well recognized now that, in general, Mediterranean marine ecosystems lack management and of those stocks with data, more than 90% are over-exploited (Colloca *et al.* 2013; Smith and Garcia 2014; Vasilakopoulos *et al.* 2014). For the northern Humboldt, Peru received a 'fail' grade of less than 40% for 'compliance with the code of conduct for use of reference points' and 'controlling illegal fishing' in the Pitcher *et al.* (2009a) analysis whereas the northern Humboldt (representing Peru here) received scores >50% in the Management Effectiveness and Quality of Governance Survey for the comparable questions Q2 and Q6. In January 2009, a new management regime of individual vessel quotas was put in force in the Peruvian anchoveta (*Engraulis ringens*, Engraulidae) fishery. The overall effect of this new system appears to have been positive in terms of economic and ecological sustainability (Tveteras *et al.* 2011). Interestingly, the phrasing of Q2 was discussed at length during the development of the Survey to ensure that it recognized different forms of limit reference points. Morocco also received a lower rank by Pitcher *et al.* (2009a), whereas Sahara Coastal Morocco was ranked in the top 10 in this survey. Although Morocco is still at the early stages of implementing EBFM (Kifani *et al.* 2008), in 2009 the Moroccan government launched Plan HALIEUTIS, a strategy to enhance long-term sustainability of its fisheries (http://www.maroc.ma/fr/content/halieutis). There is now consideration of the social and economic dimensions of fisheries, even if they are not specifically incorporated in the long-term management objectives. One example is the redirection of the freezing industry from common octopus (*Octopus vulgaris*, Octopodidae) to small pelagic fish after the collapse of octopus in 2003.

As with all surveys, the potential subjectivity of respondents cannot be ignored, and differences between different survey results may be due to subjectivity (Okoli and Pawlowski 2004). Here, we tried to minimize this effect by selecting questions based on fact, not opinion; we asked for documentary evidence and encouraged the completion of the survey by multiple experts. The level of coherence with the results of Pitcher *et al.* (2009a) suggests that this has been successful.

In general, the ecosystems surveyed received better scores for the Management Effectiveness questions than the questions about Governance Quality, although there is a linear relationship between their average scores ($r^2 = 0.55$, not shown). As the Management Effectiveness questions speak more to everyday fisheries management, and the Governance Quality questions to longer term strategic thinking and an explicitly ecosystem approach to fisheries, this result is not too surprising as few systems have yet fully implemented EBFM (Arkema *et al.* 2006; Long *et al.* 2015; Patrick and Link 2015). This is also highlighted by the poor scores across all ecosystems for Q5 (Are ecosystem impacts addressed). A few systems, the West Coast Vancouver Island in particular, did have better results for Governance than Management. This was due to lower scores for Management Effectiveness questions Q1 (Frequency of stock assessments), Q3 (Depleted stocks) and Q5 (Ecosystem impacts addressed). There were several reasons for these lower scores: (i) Fisheries and Oceans Canada is moving towards providing multiyear advice for some species (e.g. shrimp), thereby reducing the frequency of stock assessments (http://www.dfo-mpo.gc.ca/fm-gp/sdc-cps/multi-year-pluriannuels-eng.htm, accessed 28 March 2016), although multiyear advice for groundfish species preceded implementation of this policy; (ii) groundfish, which accounted for more than 85% of landings and comprised approximately 36 species, had a lower score for Q1, which reduced the overall average and (iii) effective rebuilding (Q3) is difficult to judge for long-lived species, such as rockfish (*Sebastes* spp., Sebastidae).

Overall, the ranking results and the results of the multivariate analysis were consistent; the multivariate analysis separated four of the six top-ranked ecosystems from the rest and clustered the lowest ranking ecosystems together.

Relationship to other ecosystem characteristics

The results above, together with the higher overall scores for Management Effectiveness, highlight the difference between single-species management and EBFM. Fisheries management bodies have been practising single-species fisheries management for decades, and although their success is debatable, in some ecosystems good single-species fisheries management can be effective, especially for assessed species of high commercial value (e.g. Dickey-Collas *et al.* 2010; Ricard *et al.* 2012; Methot *et al.* 2013; Flood *et al.* 2016) and where fisheries are the major pressure on the stock (as is the case for many deep water offshore species, such as orange roughy (*Hoplostethus atlanticus*) in Australia). Developing and operationalizing EBFM is a lengthy process, and even when practised, management actions under EBFM take time to adopt and implement, let alone to show effect (Link 2010; Tallis *et al.* 2010; Skern-Mauritzen *et al.* 2016).

However, our results support the thesis that strong ecosystem-based management and governance, and healthy ecosystems go together: whenever an ecological indicator was included in the BEST analysis, it was selected as one of two to three factors that best described the survey data, even when adjusted for sample size. Ideally, all 27 ecosystems, and all nine ecosystem characteristics, would be included in this analysis, but these data were not available for all systems. However, the fact that one of the ecological indicators was always an explanatory variable, even when 25 ecosystems were included, and had the highest loadings on PC1, underscores the relationship between effective fisheries management and governance and sustainable, healthy ecosystems.

Our results also indicated that broader physical, social and economic factors such as size, political stability and the human development index (HDI) are related to fisheries management and governance, although that relationship is weaker than for the ecological indicators. This relationship was also apparent from the analysis of the Survey data, which showed some geographic clustering of ecosystems, although location was not an input: south-east Australia, north-west USA, north-east USA and West Coast Vancouver Island were all located in the top left quadrant, indicating good scores on both Management Effectiveness and Governance Quality. The Mediterranean ecosystems and most African ecosystems were all located to the right of the PCA, with low scores for Management Effectiveness and Governance Quality. These are systems with contrasting values for HDI and political stability. This is typified by Guinea, on the one hand, which has low HDI and was separated from the other 10 ecosystems in BEST 4, and West Coast Vancouver Island, which has a high HDI.

The relative influence of political stability and HDI shifted in the results when the number of ecosystems changed in the different BEST analyses, for example compare BEST 2 and BEST 4 (Table 7). This is because there was greater contrast in the HDI values across the 11 ecosystems than there was among the values for 'Political Stability and Absence of Violence/Terrorism' across the 25 systems; therefore, it had more influence. In effect, there is a fairly strong relationship between 'Political Stability and Absence of

Violence/Terrorism' and HDI, with a correlation coefficient of 0.75. Most of the additional social and economic factors that were explored for the BEST analysis were highly correlated for the countries included in this analysis, which does raise questions concerning how these data are used for other purposes. For example, using multiple indicators with the same trend can lead to an overemphasis on the property that they represent.

Ecosystem size was consistently selected as an explanatory variable in the BEST analysis: the seven ecosystems with greater than average size (>230 000 km^2) were among the nine ecosystems with the highest scores on PC1, suggesting that fisheries in larger ecosystems are better managed and that these ecosystems have better ecological status. Further, for the 27 ecosystems, there was a strong linear relationship between Survey score and size ($r^2 = 0.54$, $P < 0.001$, Fig. S2). The two exceptions to the trend were the West Coast Vancouver Island and Chatham Rise ecosystems, which were below the average ecosystem size (<230 km^2), but had high PC1 scores. In the case of the Chatham Rise, a high proportion of the landed biomass is from migratory species (e.g. *Macruronus novaezelandiae*, Merlucciidae), which are managed over larger spatial scales than Chatham Rise ecosystem. The West Coast Vancouver Island includes transboundary stocks, such as Pacific salmon (*Oncorhynchus spp.*, Salmonidae) and Pacific hake (*Merluccius productus*, Merlucciidae). In both cases, management decisions for these species relate to these larger areas.

The general result that larger ecosystems are better managed may be related to the portfolio effect (Schindler *et al.* 2015). This is where for large ecosystems there is the possibility to switch target species or relocate effort. Smaller ecosystems may have less capacity to easily redirect pressure to other locations to give species, or habitats, a release from fishing pressure and time to recover. However, managing fisheries at the large scale of south-east Australia or Barents Sea ecosystems is an expensive undertaking, requiring good institutional structure and lengthy time investment. This underscores that successful EBFM takes time.

Although the ecosystems included in this study had a wide size range, all, with the exception of south-east Australia, were smaller than the LME scale and most were smaller than EEZ. However, as larger ecosystems did achieve higher rankings for management effectiveness and governance quality, this does raise the question of whether larger ecosystems would always result in a higher ranking, or whether there is an upper limit to this relationship. Factors such as complexity of the fisheries and the number of national jurisdictions generally increase with ecosystem size and would be likely to compromise fisheries management effectiveness and governance quality. The results of this analysis indicate that complexity of fisheries does affect Management Effectiveness and Governance Quality: the ecosystems that were more multispecies, multisector and, therefore, more complex (e.g. Mediterranean and Guinean ecosystems) had the lowest survey scores. In contrast, the Barents Sea, which had high scores, is a high latitude ecosystem with a relatively simple species composition and fisheries sector, which may make it easier to map, monitor and manage. On the other hand, survey scores for the five multijurisdictional ecosystems that were included in this assessment (the central Baltic Sea, the Barents Sea, the eastern English Channel, the Irish Sea and the north-central Adriatic) ranged from high to low. Interestingly, with the exception of the north-central Adriatic, all multijurisdictional ecosystems scored poorly on the Governance Questions, especially related to whether social or economic impacts of the fisheries management plan were considered and formally evaluated in management decisions. Therefore, incorporating social and economic consideration may be more difficult to enact in multijurisdictional ecosystems. To explore the question of the relationship of ecosystem size with complexity of the fisheries and the number of national jurisdictions would require a large number of ecosystems with ecological indicators representing all possible combinations of size, HDI and fisheries complexity and number of jurisdictions.

A more nuanced view of the results

We have used simple indicators for this comparative study, which have proven useful for ranking and assessment purposes. This approach necessarily aggregates a lot of information, and it misses some of the nuances and detail of individual systems. It would be a mistake to assume that these results tell the whole story and that all is well with the high-ranking ecosystems, and all is wrong with the low-ranking ecosystems. The southern Benguela, for example, was ranked in the top third of ecosystems in this and other assessments cited here, which may be considered 'good enough' for a developing society. A closer look, however, reveals that some of its important fisheries are problematic with respect to governance issues, such as stakeholder representation (Hara *et al.* 2014; Norton 2014), transparent and defensible rights allocation process, for example, in small-scale fisheries (see, e.g. Norton 2014 and Gammage 2015 for overviews) and mistrust among stakeholders (Hara *et al.* 2014; Duggan *et al.* 2014; Ragaller 2012). Further, economic objectives override social objectives in the large fisheries (e.g. Cooper *et al.* 2014) without explicit consideration of trade-offs, and spatial management is slow to be implemented in the small pelagics fishery (Howard *et al.* 2007; Coetzee *et al.* 2008). Overlaid with expected changes due to climate change (e.g. Jarre *et al.* 2015) and political instability (Nel *et al.* 2007; Petersen *et al.* 2010; Norton 2014), these weaknesses may well compromise the ability of the southern Benguela to provide important ecosystem services into the future.

Here, we explore some of the details that underlie the results of the Management Effectiveness and Governance Quality Survey and, in doing so, underscore the need for the involvement of local experts in the interpretation of the result of global assessments. The existence of long-term management plans and consideration of ecosystem impacts is typical of ecosystems with the highest scores for both Management Effectiveness and Governance Quality. However, even with effective management, governance quality varied. For example, the West Coast Vancouver Island had high Governance Quality scores whereas the Barents Sea had lower scores. This difference was largely due to the degree to which social and economic impacts were included in long-term management plans (Qs 9 and 10). The West Coast of Vancouver Island fisheries are managed by Fisheries and Oceans Canada (DFO), and Canada's National Acts, regulations, and policies require that DFO consults with industry, non-government organizations, and First Nations through consultative boards or committees. In the Barents Sea, fisheries management has formally existed since the 1930s (Grønnevet 2015). Since 2005, all Norwegian EEZ ocean areas have established management plans that include economic and social information, but there is not a focus on their impacts. Therefore, there is still a room for improvement of the governance of the Barents Sea, as shown in this study, and previously suggested by the European Union project 'Monitoring and Evaluation of Spatially Managed Areas' (Stelzenmüller *et al.* 2013).

Two major eastern boundary current upwelling systems, southern Benguela and northern Humboldt, were ranked 9th and 10th, respectively, in this Survey; they had similar values for size, HDI, SS and ES, although NDES was higher (better) in the southern Benguela, and they were located adjacent to one another in the PCA analyses. The similarity of their results is perhaps not surprising as they share many characteristics such as relatively low species diversity and fisheries for small pelagics (historically anchovies (Engraulidae) and sardines (Clupeidae)) and hakes (*Merluccius* spp. Merlucciidae) that dominate other fisheries by volume and value, and which have international markets. Despite the developing status of their societies and hence limited government support for marine science, the management of these large fisheries has for decades attracted government support and the attention of the international fisheries science community. These large fisheries, in contrast to many smaller fisheries in these countries, are therefore better managed than may be apparent from their HDI values. However, one key difference between them is the higher economic contribution of anchovy to society in northern Humboldt (FAO, 2010). This may explain why the northern Humboldt achieved higher scores for minimizing conflict in fisheries, and hence Governance Quality, due to the importance its fisheries.

The Portuguese EEZ, another upwelling system, ranked 13th in this survey, had similar scores to the two upwelling systems, the eastern Scotian Shelf, Bay of Biscay, and the eastern English Channel. This mostly reflects implementation of the European Common Fisheries Policy with long-term management plans, reference points and targets (EU 2008, 2015), as well as the Marine Framework Strategy Directive (MSFD, 2008/56/EC), which requires consideration of the ecosystem impacts of fishing. In Portugal, stakeholders are increasingly included in developing management plan objectives as in the case of the Portuguese-Iberian sardine fishery, which has a management plan with a strong national stakeholder participation and social impacts considered (DGRM 2012).

Although also part of the European Union and therefore subject to the European Common Fisheries Policy, the Irish Sea was somewhat separated from the other ecosystems in the Survey PCA. This was caused by its low scores on the Governance Quality questions, largely due to the lack of long-term, multispecies management plans. Fisheries management to date has been almost entirely single-species based and also tended to focus on immediate problems such as the need to rebuild the Irish Sea cod stock (Kelly *et al.* 2006). ICES is beginning to develop ecosystem-based assessments for Irish Sea stocks and will eventually develop an overall EBFM plan, but this work has only recently commenced (ICES 2016c). This ecosystem is also transboundary and comes under multiple jurisdictions (England, Northern Ireland, Ireland, Wales and the Isle of Man), and this may be one reason why its governance has been relatively weak despite it being located in a high HDI area with the political systems being reasonably well aligned.

The African and Mediterranean Sea ecosystems grouped together in both PCAs, due to their poor scores on most Survey questions, and their relatively poor ecological status. Guinea, for example, has a low HDI, no fisheries policy and other regulatory mechanisms are inadequate, which has led to the development of IUU fishing (MRAG-DFID 2005; Boto *et al.* 2009). Furthermore, scientific assessments, which were frequent and rigorous from 1985 to 1995, in collaboration with IRD (Institut de Recherche pour le Développement) have since become very irregular (Domain *et al.* 1999). The translation of scientific advice into sustainable fisheries management policy is limited (Fontana 2015). Recent studies on the state of the Guinean continental shelf show that this ecosystem is degraded (Camara *et al.* 2016). Abundance indices are down, and trade sizes have decreased. These factors threaten the sustainability of Guinean fishing (Domain *et al.* 1999). Similarly, Senegal has a low HDI with a relatively small size and poor ecological status. Despite the economic and social importance of the fisheries sector in Senegal, it has faced considerable challenges for several years, mainly due to the lack of effective management and governance approach (Thiao and Laloë 2012). Historically, the public policies to improve the management and governance of the fisheries sector and to rebuild major fish stocks are ineffective because of many socioeconomic and managerial constraints that undermine any attempt to reduce the fishing pressure, restore and conserve the coastal ecosystem and regulate economic incentives (Thiao and Laloë 2012).

Low HDI, however, does not explain the poor results for the north-central Adriatic or the southern Catalan Sea, both of which are part of the EU, with HDI values comparable to those for the rest of Europe (http://hdr.undp.org/en, accessed February 2016). In the Mediterranean, fisheries have a relatively low economic importance, with relatively low catches (Eurostat 2013). They are also multispecies, multigear, and operated by an extremely large number of mostly small-scale fishing vessels along an extended coastline, with a large number of landing points. In such systems, the direct and indirect interactions among multigear fisheries should be taken into account when implementing fisheries plans (Moutopoulos *et al.* 2013) to reinforce the positive trade-offs (Link 2010). All these qualities may render their management (and surveillance) quite costly and difficult to control (Colloca *et al.* 2013). Therefore, the poor scores for Management Effectiveness and Governance Quality, and the poor ecological status of the north-central Adriatic or the southern Catalan Sea may be due to the low priority given to fisheries, their complexity, and the lack of investment in them. It is noteworthy that even though fishing activities in the Mediterranean extend back centuries, (i) fishery science is underfunded and has developed more recently, (ii) international collaborations and governance through the RFMO (General Fisheries Commission for the Mediterranean) is weak and there is a large proportion of IUU (Pauly *et al.* 2014), while (iii) priority has been given by the EU to its Atlantic fisheries (Smith and Garcia 2014). Note that the five Mediterranean systems are grouped together in the PCA, indicating that these issues are resulting in poor Management Effectiveness and Governance Quality throughout the Mediterranean, and possible poor ecological status, as shown with ecological indicators (Coll *et al.* 2016).

Finally, the PCA results for the eastern Scotian Shelf using the Survey data and the ecological indicators were different. The latter associated the eastern Scotian Shelf with ecosystems that had lower scores for ecosystem status. This is because the ecological status of the eastern Scotian Shelf is a reflection of past management and governance and not the current practice. In the early 1990s, the cod (*Gadus morhua*, Gadidae) fishery collapsed, other groundfish fisheries were reduced to low levels and a groundfish moratorium was introduced (Bundy *et al.* 2009). The moratorium continues to the present day, but cod and many other groundfish are still at low biomass levels. The low values for SS, NDES, and ES largely reflect these changes in the fish community. However, there have been several changes to management and governance as reflected by DFO's adoption of the precautionary principle and the Sustainable Fisheries Framework (http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/overview-cadre-eng.htm, accessed 23 Dec 2015). Now, invertebrate species such as lobster, snow crab and shrimp form the basis of well-managed fisheries on the eastern Scotian Shelf.

Conclusions

Despite misunderstandings and myths (Patrick and Link 2015), and an array of definitions and principles (Arkema *et al.* 2006; Long *et al.* 2015), EBFM is beginning to happen (FAO 2014a). We conclude that systems with higher scores for Management Effectiveness and Quality of Governance have higher scores for ecosystem and stock status. This supports the assertion that strong and effective ecosystem-based fisheries management combined with a strategic vision are likely to promote good ecosystem status. Key factors that point to success in this analysis are the use of reference points, reasonably frequent review of assessments, addressing IUU and importantly, inclusion of stakeholders to ensure adequate debate of issues and exploration of possible solutions in decision-making process. At the same time, there should be long-term management plans, which need to include the economic and social dimensions of exploited ecosystems and also take into account the multispecies and wider ecosystem interactions of fisheries (Skern-Mauritzen *et al.* 2016). By definition, it is very difficult to implement EBFM in ecosystems where there is no EBFM plan. Increasingly, EBFM also needs to be implemented as one component of a wider process of marine planning in order to ensure that developments across all sectors do not lead to further environmental degradation (Long *et al.* 2015).

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1 Management Effectiveness and Governance Quality Survey Template, including instructions to experts and a glossary of terms.

Table S2 Weighting factors for estimation of average ecosystem compliance scores for multi-jurisdictional ecosystems.

Table S3 Additional social, economic, governing and ecological indicators used in BEST analysis.

Table S4 Spearman correlations between social and economic indicators for the 27 IndiSeas ecosystems. Acronyms are provided in Table S3. Indicators in bold were used in the BEST Analysis[1].

Table S5 Average Scores for each of the 11 questions from the Management Effectiveness and Governance Quality Survey.

Figure S1 Cluster analysis of the 11 Management Effectiveness and Governance Quality Survey results.

Figure S2 Standardised average Management Effectiveness and Governance Quality Survey scores plotted against ecosystem size (squareroot transformed and standardised).