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Ecosystem processes are rarely included in tactical fisheries management

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Abstract

Fish stock productivity, and thereby sensitivity to harvesting, depends on physical (e.g. ocean climate) and biological (e.g. prey availability, competition and predation) processes in the ecosystem. The combined impacts of such ecosystem processes and fisheries have lead to stock collapses across the world. While traditional fisheries management focuses on harvest rates and stock biomass, incorporating the impacts of such ecosystem processes are one of the main pillars of the ecosystem approach to fisheries management (EAFM). Although EAFM has been formally adopted widely since the 1990s, little is currently known to what extent ecosystem drivers of fish stock productivity are actually implemented in fisheries management. Based on worldwide review of more than 1200 marine fish stocks, we found that such ecosystem drivers were implemented in the tactical management of only 24 stocks. Most of these cases were in the North Atlantic and north-east Pacific, where the scientific support is strong. However, the diversity of ecosystem drivers implemented, and in the approaches taken, suggests that implementation is largely a bottom-up process driven by a few dedicated experts. Our results demonstrate that tactical fisheries management is still predominantly single-species oriented taking little account of ecosystem processes, implicitly ignoring that fish stock production is dependent on the physical and biological conditions of the ecosystem. Thus, while the ecosystem approach is highlighted in policy, key aspects of it tend yet not to be implemented in actual fisheries management.

Keywords Ecosystem drivers, ecosystem-based management, fisheries management, management strategy evaluation, stock production

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Introduction

The structure and functioning of marine ecosystems change through time, thus altering the foundations of fish stock productivity (Alheit and Niquen 2004; Frank *et al.* 2007; Lilly *et al.* 2013; Vert-pre *et al.* 2013). Climate variability and change impact stock recruitment (Ottersen *et al.* 2013) and food availability through bottom-up regulated processes (Frank *et al.* 2007; Stige *et al.* 2010; Dalpadado *et al.* 2014). Where interacting predators and prey or competing species are involved, changes in the one may impact the other (Myers and Worm 2003; Frank *et al.* 2007; Bundy *et al.* 2009). Such ecosystem interactions typically affect the productivity of fish stocks (Finney *et al.* 2010; Vert-pre *et al.* 2013) and may influence their sensitivity to harvesting rate. Several stock collapses have been attributed to the combined impacts of changing ecosystems and intensive fisheries, including the Peruvian anchoveta (*Engraulis ringens*, Engraulidae), the Alaskan Pollock (*Theragra chalcogramma*, Gadidae) and the 'northern' cod (*Gadus morhua*, Gadidae) off eastern Canada (Alheit and Niquen 2004; Bailey 2011; Lilly *et al.* 2013).

It could therefore be argued that management systems should adapt to changing ecosystems to enhance responsiveness and precision relative to changes in stock production (Polovina 2005; King and McFarlane 2006, Brown *et al.* 2012). Including the impacts of ecosystem processes on fish stock production is one of the main pillars of the ecosystem approach to fisheries management (EAFM), a management framework that has been formally adopted by many governments and international organizations and agreements since the 1990s (House of Lords 1996; U.S. National Marine Fisheries Service 1999; Pikitch *et al.* 2004; Bianchi *et al.* 2008). Nevertheless, Pitcher *et al.* (2009) found that few countries are actually moving towards EAFM. Despite the optimistic views that fish stock responses to environmental variability could be readily incorporated in management advice (Quinn and Deriso 1999), fisheries management is still predominantly based on a 'single-species equilibrium' paradigm (Vert-pre *et al.* 2013). This assumes that fluctuations in vital rates (growth, mortality and recruitment) and the resulting stock productivity are centred on a stationary mean at a given harvest rate, and that stock production is predominantly linked to stock abundance *per se*, which may be controlled through regulating the harvest rate. Thus, if management targets, such as maximum sustainable yield, are based on a high-productivity regime, a shift to a low-productivity regime will result in increased risk of overfishing. Conversely, management targets based on a low-productivity regime will result in overly cautious harvest during high-productivity regimes (Vert-pre *et al.* 2013).

Policy documents welcome EAFM, and a large number of studies have emphasized the deficiencies of single-species management (Pikitch *et al.* 2004; Hilborn 2011). However, to date no one has performed an over-arching evaluation of the extent to which ecosystem information has in fact been included in tactical fisheries management practice. Here, we report on an analysis of fish stocks that are managed by 22 international and two national fishery management bodies, with regards to inclusion of ecosystem drivers of stock productivity in tactical fisheries management, which we define as advice for short-term decisions on total allowable catch (quotas). We furthermore assess how such implementation is associated with regional science support. We expected that both identification of such ecosystem drivers, and their inclusion in management, are associated with strong scientific support.

Materials and methods

Reports of assessment and management advice for marine stocks across the world were reviewed to identify stocks where ecosystem drivers of stock productivity were included in the tactical management decisions. These drivers could be included either in the stock assessment models or in the harvest control rules (HCRs). We included stocks assessed and managed by (i) international regional fishery bodies (RFBs); and (ii) the national management bodies of the USA and Australia (Tables S1 and S2). These two countries were chosen as they both manage a high number of fish stocks and are at the forefront of EAFM development and implementation (Pitcher *et al.* 2009).

Most RFBs have been established in association with the Food and Agricultural Organization of the United Nations to manage populations of fish, marine mammals and seabirds. Currently, 44 RFBs exist (http://www.fao.org/fishery/rfb/en), 31 of which provide information on marine fish stocks written in English. We found stock assessment reports and management advice on the web from 22 RFBs (Tables S1 and S2). Including the US and Australian national bodies, we reviewed reports from around 1250 stocks (Tables S1 and S2).

While comprehensive, our review is not a complete coverage of all stocks managed by these management bodies as (i) we primarily included the most recent assessments reports that were publicly available from the different management bodies; (ii) we may have missed reports when searching the web; and (iii) reports may be unavailable on the web. There is also a geographic bias in the reviewed material (Fig. 1). Reports in English were found on few stocks from the south-east Pacific, and on no stocks from the south-west Atlantic. Several reports from Asian waters provided aggregated information across groups of stocks which may have concealed relevant cases. Apart from the geographic bias, none of the above remarks are likely to change the general results and conclusions presented in this study.

The volume of published papers from searches on the ISI Web of Knowledge was used to assess the scientific support in the different regions of the world. The different regions consist of several Large Marine Ecosystems (LMEs, http://www.lme.-noaa.gov/index.php). In the search, we used two terms: 'LME (e.g. North Sea) and fish' and 'LME and (ecosystem approach or ecosystem based) and fish' to assess scientific support within fish and fisheries research and within research related to ecosystem approach to management. The LMEs included in the search are listed in Table S3 in the Supporting Information.

Results

The 24 cases in which ecosystem drivers of stock productivity were included in tactical management advice made up 2% of the more than 1250 stocks reviewed (Tables 1–3, Tables S1 and S2). Ecosystem drivers were incorporated into the management frameworks of both small pelagic (n = 9), large pelagic (n = 4) and demersal fish stocks (n = 8), as well as shrimps (n = 1), rockfish (n = 1) and coral reef fish (n = 1, Tables 1–3), thus including both short-lived and long-lived species. The ecosystem drivers cover a range of physical factors such as temperature, upwelling and sea ice coverage and biological factors including primary production, prey and predator abundance, all of which influence a wide range of population-dynamic processes such as recruitment, individual growth, natural mortality, population intrinsic growth rate and system carrying capacity (Tables 1–3). Several methodological approaches, both quantitative and qualitative, were also employed (Tables 1–3). For example, when predicting the biomass of the Icelandic cod stock 1 year ahead, low individual weights were assumed due to low abundance of the prime prey, capelin (*Mallotus villotus*, Osmeridae, Table 3). These short-term predictions are simulated stock

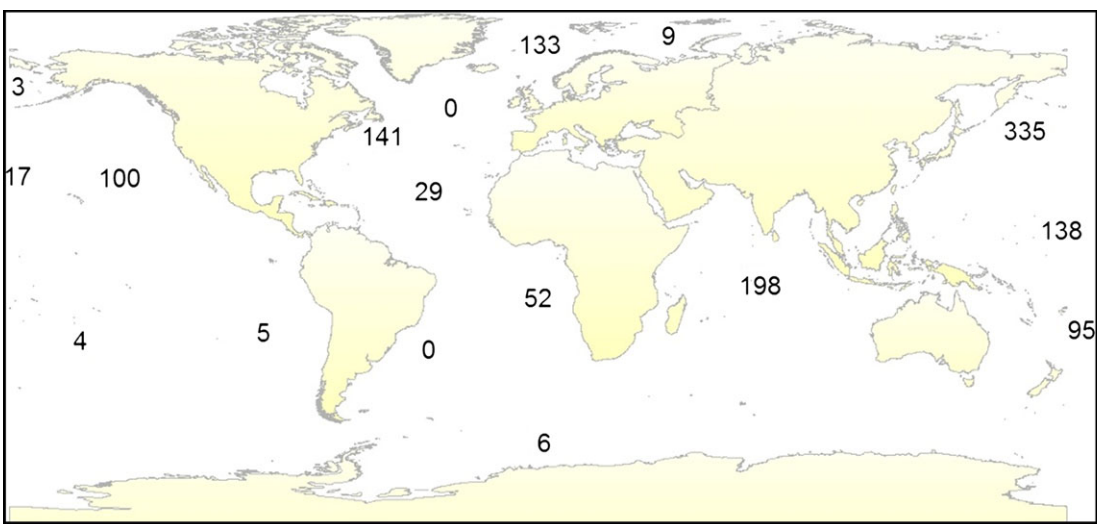

Figure 1 Number and geographic distribution of stocks reviewed in the current study. The numbers are summarized from information provided in Tables S1 and S2.

responses to different fishing mortalities and used for setting quotas. For the Barents Sea cod, recruitment is simulated *post hoc* using multiple regression models with capelin biomass, ice coverage, water and air temperature, and oxygen saturation as ecosystem drivers (Table 3). Furthermore, before setting the Barents Sea fishing quotas for capelin, the estimated food requirement by cod is set aside to ensure a healthy cod stock (Table 1). For sardines (*Sardina pilchardus*, Clupeidae) and anchovy (*Engraulis encrasicolus*, Engraulidae) in the Mediterranean Sea, simple surplus production models were fit to relative abundance indices, and system carrying capacity *K* and intrinsic growth rate *r* set to depend on the chlorophyll concentrations in the sea, respectively (Table 1). Finally, the survival and hence the return of pink salmon (*Oncorhynchus gorbuscha*, Salmonidae) to rivers is predicted using regression models with ocean temperature and prey availability among the drivers (Table 2).

The identified cases included both typically data-rich stocks with high scientific support that enabled estimates of population structure, vital rates and total abundance to be incorporated in quantitative stock assessments, and data-poor stocks managed by relative abundance indices such as catch per unit effort and simpler production models, assuming rather than estimating the population-dynamic processes involved (Tables 1–3). The 24 cases were identified in the north and south-east Pacific and the Atlantic, in regions with low (e.g. south-east Atlantic) to high (e.g. north-east Atlantic) scientific support (Fig. 2). Due to the geographic bias in the number of stocks reviewed (Fig. S1), geographic trends should be interpreted with care. However, most cases (17) were found in the North Atlantic and north-east Pacific. These stocks are predominantly managed by the US, and by EU and the Joint Norwegian–Russian Fisheries Commission on advice from the International Council for the Exploration of the Sea (ICES).

Table 1 Small pelagic fish stocks with ecosystem drivers of stock production included in the tactical management framework. The table lists stocks as identified through review of fisheries management reports across the world. 'Ref' refers to reference list provided in Supporting Information.

Species	Ecosystem driver and implementation in management framework	Geographic region	Ref
Sardine *Sardina pilchardus*	Chlorophyll *a* index impacts K carrying capacity in the surplus production model BioDyn	NEA (Mediterranean)	39
Sardines *Sardina pilchardus*	An unspecified environmental index included in Schaefer production model to account for sudden drop in biomass	SEA (West Africa)	49
Sardine *Sardinops sagax*	The harvestable fraction of the stock depended on ocean temperatures	NEP	68
Anchovy *Engraulis Encrasicholus*	Chlorophyll *a* index impacts the *r* intrinsic growth rate in the surplus production model PopDyn	NEA (Mediterranean)	39
Anchovy *Engraulis encrasicholus*	An upwelling index included in recruitment model	NEA (Bay of Biscay)	69
Capelin *Mallotus villosus*	Predation by cod implemented in mortality in short-term predictions	BAR (Barents Sea)	34
Sprat *Sprattus sprattus,* Clupeidae	Cod predation implemented in estimates of natural mortality	NEA (Baltic Sea)	34
Herring *Clupea harengus membras*	Cod predation implemented in estimates of natural mortality. Biomass of prey and temperature used in predictions of year-class strength	NEA (Baltic Sea)	34
Atlantic menhaden *Brevoortia tyrannus*	Natural mortality estimated in multispecies virtual population analyses modelling menhaden – predator interactions in a Beaufort forward-projection model	NWA	70

NEA and SEA, north-east and south-east Atlantic; BER, Bering Sea; NEP, north-east Pacific; NWA, north-west Atlantic; BAR, Barents Sea.

Table 2 Large pelagic fish stocks with ecosystem drivers of stock production included in the tactical management framework. The table lists stocks as identified through review of fisheries management reports across the world. 'Ref' refers to reference list provided in Supporting Information.

Species	Ecosystem driver and implementation in management framework	Geographic region	Ref
Pink salmon *Oncorhynchus gorbuscha*	Return rates to rivers, and commercial catches, forecasted by regression models using prey availability and ocean temperatures as drivers of fish mortality	NP	20–21
Skipjack tuna *Katsuwonus pelamis, Scombridae*	Spatial distributions estimated as responses to sea surface temperature, oceanic currents and primary production in the spatially resolved assessment model SeaPoDyn	EP	71
Swordfish *Xiphias gladius, Xiphiidae*	Abundance indices modelled as lagged responses to ocean climate, hydrographic and primary production drivers, assumed to influence recruitment, and used as input in the assessment model Stock Synthesis	SEP	71
Striped marlin *Kajikia audax, Istiophoridae*	Abundance indices modelled as lagged responses to ocean climate, hydrographic and primary production drivers, assumed to influence recruitment, and used as input in the assessment model Stock Synthesis	NEP	71

NP, North Pacific; NEP, SEP and EP, north-east, south-east and eastern Pacific.

Discussion

Ecosystem drivers of stock production were included in the tactical management advice of 24 cases, about 2% of the 1250 stocks reviewed. Seen in the light of the overall conclusion of Vert-pre *et al.* (2013), which ecosystem processes significantly affected the productivity of 70% of the 230 fish stocks they examined, our findings are rather alarming.

There are several reasons for the slow inclusion of ecosystem processes in tactical fisheries management. Including drivers may only be successful if there is a good understanding of how ecosystem processes stock production. If not reflecting the underlying processes, simple correlations between ecosystem metrics and stock responses often change over time (Myers 1998). Furthermore, adding ecosystem drivers to fish stock assessment models may increase the estimation and measurement uncertainty. For a useful implementation, these sources of uncertainty need to be counteracted by decreasing the process uncertainty (Link *et al.* 2011).

Non-stationary relationships, level of process understanding and precision have indeed challenged the management of stocks where ecosystem drivers have been included. The recruitment of Pacific sardines was positively associated with sea surface temperature (SST) measured at the Scripps Institution of Oceanography pier, and in 1998, the SST was included in the HCR to determine the harvestable fraction of the stock (Zwolinski and Demer 2014 and references therein). However, from 2006 to 2012 there were successive recruitment failures, despite high SST values. Fishing continued, the stock biomass dropped to low levels and the HCR with SST was abandoned in 2012 (Zwolinski and Demer 2014). Re-evaluations demonstrated a disconnection between SST at the Scripps pier and at the spawning grounds (McClatchie *et al.* 2010). Furthermore, Deyle *et al.* (2013) found that sardine responses to SST depend on the state of the anchovy population; changes in temperature seem to have little or opposite effect in periods with low abundance than in periods with very high abundances. They argue that any temperature-sensitive control rule for sardine should be different at low, intermediate and high sardine abundances. Similarly, the annual recruitment of Bay of Biscay anchovy was significantly correlated with an upwelling index and used as a basis for predicting recruitment (Borja *et al.* 1998). In 2000, the spawning stock biomass based on this prediction fell below precautionary thresholds, and the total allowable catch was halved. However, subsequent information indicated that the recruitment prediction was a substantial underestimate, and the use of the upwelling index in predictions was abandoned (ICES 2000, 2001). In the Barents Sea, cod consumption of capelin has been implemented in short-term predictions of capelin stock

Table 3 Demersal fish stocks, and rockfish, snapper and shrimp stocks, with ecosystem drivers of stock production included in the tactical management framework. The table lists stocks identified through review of fisheries management reports across the world. 'Ref' refers to reference list provided in Supporting Information.

Species	Description of ecosystem driver and implementation in management framework	Geographic region	Ref
White hake *Merluccius merluccius*	North Atlantic Oscillation index set to influence stock abundance in a Schaefer surplus production model	SEA (West Africa)	47
Cod *Gadus morhua*	A suite of physical environment and prey indices implemented in the recruitment function in an XSA assessment model	BAR	34
Cod *Gadus morhua*	Low weights assumed in short-term predictions due to low capelin abundance in the ecosystem, in a forward-based statistical catch-at-age model	NWA (Iceland)	34
Cod *Gadus morhua*	Biophysical drivers included in adjusting longline CPUE indices before entered in a XSA assessment model	NEA (Faroe plateau)	34
Cod *Gadus morhua*	Natural mortality due to predation estimated in multispecies model	NEA (North Sea)	35
Haddock *Melanogrammus aeglefinus*	Biophysical drivers included in adjusting longline CPUE indices before entered in a XSA assessment model	NEA (Faroe plateau)	34
Haddock *Melanogrammus aeglefinus*	Natural mortality due to predation by cod implemented in mortality in an XSA assessment model	BAR	34
Whiting *Merlangius merlangus*	Estimates of natural mortality due to predation from multispecies model	NEA (North Sea)	34
Shortbelly rockfish *Sebastes jordani, Sebastidae*	Numbers of age 0 fish in seabird and seal diet used as abundance indices in a Stock Synthesis II (SS2) assessment model	NWP (California Current)	72
Mutton snapper *Lutjanus analis, Lutjanidae*	Physical drivers included in adjusting abundance indices before entered into an ASAP assessment model	SWA (South Atlantic/Gulf of Mexico)	74
Shrimps *Pandalus borealis, Pandalidae*	Predation by cod set to affect natural mortality in a Schaefer Surplus Production model	NWA (West Greenland)	73

NEA and SEA, north-east and south-east Atlantic; BAR, Barents Sea; NWP, north-west Pacific; NWA and SWA, north-west and south-west Atlantic.

biomass since the 1990s (Gjøsæter *et al.* 2014). Retrospective analyses performed by Gjøsæter *et al.* (2014) demonstrated that the cod stock predictions used for estimating consumption were consistently too small. This bias has resulted in predictions of too large capelin stocks and therefore the setting of larger quotas than prescribed by the agreed HCR. Nevertheless, the capelin management has been successful in securing a sustainable stock over the last 20 years, either because fewer spawners are needed to secure good recruitment than expected when defining the biomass reference points or because the capelin stock is also underestimated. Furthermore, the current capelin management regime with cod consumption implemented is more cautious than the earlier management regimes (Gjøsæter *et al.* 2014). Finally, regression models used to predict pink salmon survival and returns have been run since 2004, and the models are rerun every year with a set of competing drivers reflecting the biophysical environment (Table 2 and references therein). While the predicted harvest rates generally lie within 0–17% of the actual harvest rates, the prediction in 2006 was 209% higher than the catch, clearly indicating that the available drivers included in the models do not capture all major processes influencing salmon survival (Table 2 and references therein).

Lack of familiarity and comfort with new management frameworks probably slows down the process of implementation (Hilborn 2012). It has been argued that large international management bodies in particular may be reluctant to adopt new approaches as methodological consistency is important for reaching agreements (Hilborn

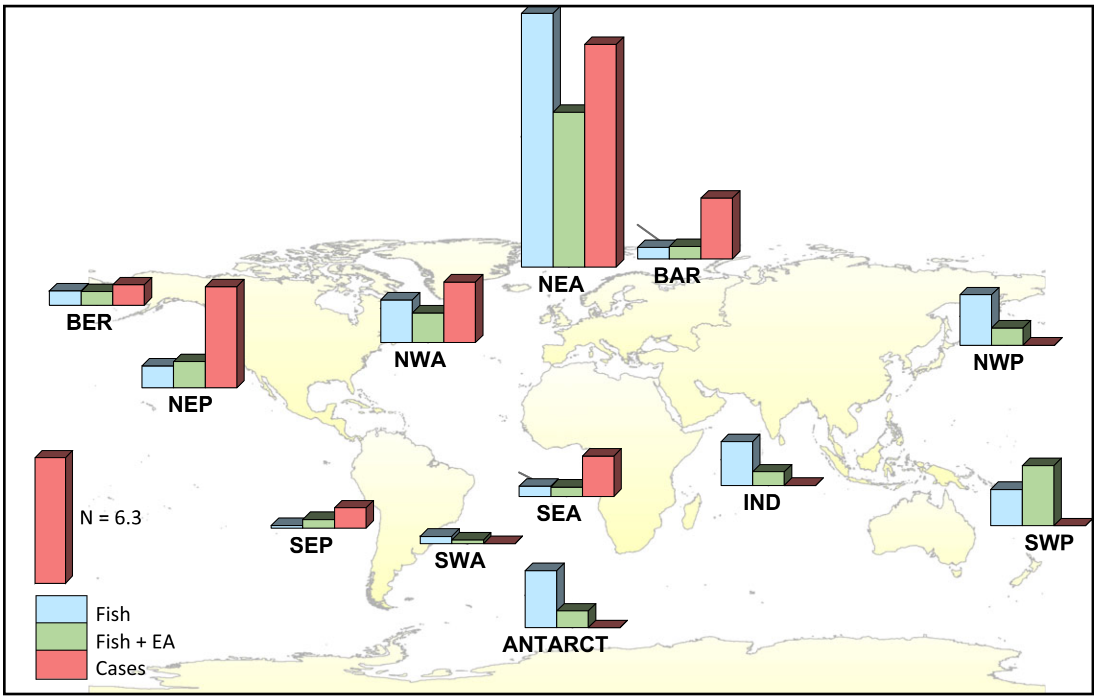

Figure 2 Geographic distribution of tactical fisheries management frameworks incorporating ecosystem drivers of stock production, and regional scientific support. The extent of the scientific support was assessed through using the number of publications found in the ISI Web of Knowledge using the terms 'fish' (blue bars, numbers in 1000s) and 'ecosystem approach or ecosystem based and fish' (green bars, numbers in 100s) for different geographic regions (details on web search results are provided Materials and methods and in Table S4). Red bars indicate the number of stocks with ecosystem drivers implemented in stock assessment and management advice that have been identified in this review.

2012). Yet, our results demonstrate that most cases were found within ICES, a large management advisory body (20 member states). Finally, while ecosystem effects on fish stock population dynamics and production are scientifically interesting, not all impacts are equally useful for fisheries management. A number of simulation studies demonstrate that the gain of including ecosystem drivers of stock production into management decisions is not clear-cut, and may depend on the dynamics and predictability of the environmental changes, the strength of the stock responses to ecosystem drivers and the life history of the stock (e.g. Basson 1999; De Oliveira and Butterworth 2005; Polovina 2005; King and McFarlane 2006; A'mar *et al.* 2009; Brunel *et al.* 2010). In short-lived stocks as illustrated by small pelagic fish, the performance of a management regime may depend on relatively rapid responses to ecosystem changes affecting recruitment, determining the near-immediate appearance of new year-classes in the fishery (Freon *et al.* 2005; King and McFarlane 2006; Lehodey *et al.* 2006; Rice 2011). This may not be the case in long-lived stocks as represented by large demersal fish, as annually updated assessments consist largely of cohorts monitored for several years. The management of long-lived stocks may be more sensitive to, for example, predation affecting natural mortality (Bax 1998; Rice 2011). Nevertheless, in the identified cases, ecosystem drivers of recruitment were included for both short-lived pelagic fish and long-lived demersal fish (Tables 1 and 3). Drivers of natural mortality were, however, included for demersal fish, and for shrimps (Table 3). Finally, the ecosystem must be monitored on an operational basis, and the pertinent information made available in sufficient time to be incorporated into annual or multiannual management advice, at an affordable cost.

The diversity of ecosystem drivers and approaches taken, even between stocks of the same species (Tables 1–3), suggests that inclusion of ecosystem drivers in tactical fisheries management is a bottom-up driven process by individual or groups of scientists, adapting their approaches to local conditions of data availability and their understanding of the processes involved. Yet, most cases were identified among US and ICES stocks. Both US and northern ICES countries have long traditions in monitoring the marine environment and fish stocks, which has supported a large number of studies on ecosystem drivers of fish stock productivity (e.g. Hallowed *et al.* 2011; Link *et al.* 2011; Ottersen *et al.* 2013; Fig. 2). With such scientific support, scientists have put the inclusion of ecosystem effects on the agenda in fisheries management bodies, and positioned these regions at the forefront of EAFM implementation (Pitcher *et al.* 2009; Hallowed *et al.* 2011; Link *et al.* 2011). Although Australia is also a leading proponent of EAFM implementation (Pitcher *et al.* 2009), we were unable to locate any direct use of ecosystem drivers in Australian tactical fisheries management frameworks. That country's main focus is on the effects of fisheries on ecosystems (Fletcher 2008), another important pillar of EAFM (Bianchi *et al.* 2008). Our results thus suggest that regional scientific support and policies are more important than the size of the management body in supporting bottom-up initiatives on implementation of new management frameworks.

While direct inclusion of ecosystem drivers was rare, general descriptions of ecosystem impact on stock productivity were offered far more frequently, and used as 'contextual' assessments. This suggests that for many stocks, the causal mechanisms and the proof of concepts have already been established and available for model testing and implementation (e.g. Link *et al.* 2011). The importance of actually doing so was highlighted in many assessment reports. Some contextual assessments may also have influenced the tactical decisions through informal processes not stated in the assessment reports. However, it is our impression that these contextual assessments were predominantly provided as guidelines or auxiliary information, while the actual management decisions were based on the more traditional stock monitoring data.

Our results demonstrate that there is a long way to go before more than a small percentage of the world's marine stocks are actually managed in accordance with EAFM principles. They also indicate that management frameworks including ecosystem processes in tactical fisheries management are still in their infancy. Ecosystem drivers have been abandoned in some cases due to erroneous stock predictions (e.g. Bay of Biscay anchovy, Pacific sardines) based on non-stationary relationships with ecosystem drivers, while others are still in use

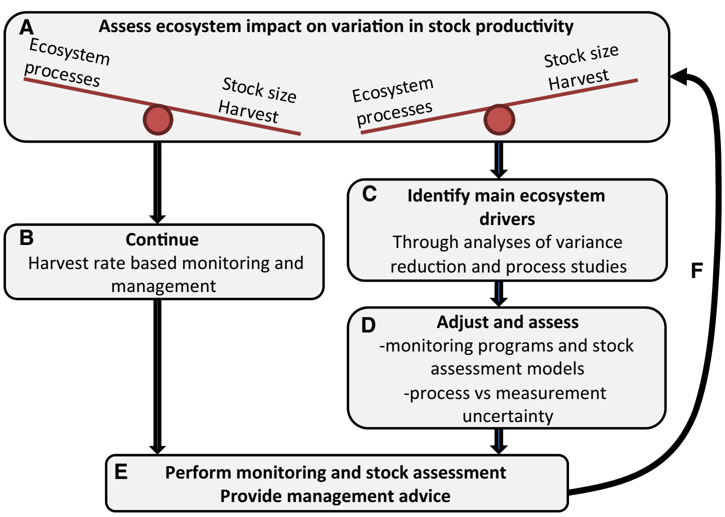

Figure 3 A suggested framework for including ecosystem drivers of stock production into an adaptive fisheries management framework. (A) First, estimate variance in stock productivity caused by stock abundance and harvest rates vs. ecosystem processes. (B) If harvest rate is the main driver of stock productivity, control of harvest rate remains the main tool. (C) If (also) ecosystem processes significantly impact stock productivity, identify the relevant ecosystem drivers through analyses of variance reduction and focused process studies. (D) Modify monitoring programmes and stock assessment models to incorporate relevant processes and drivers. (E) Provide advice and (F) reassess the management strategy on a regular basis.

after decades of implementation (e.g. Barents Sea capelin, cod and haddock (*Melanogrammus aeglefinus*, Gadidae), Baltic sprat (*Sprattus sprattus*, Clupeidae), herring (*Clupea harengus*, Clupeidae) and cod, Atlantic menhaden (*Brevoortia tyrannus*, Clupeidae) and Pacific pink salmon, references in Tables 1–3). Our advice is that when a stock is known or expected to respond to changes in the ecosystem, alternative management strategies should be contrasted in formal Management Strategy Evaluations (MSE, Butterworth and Punt 1999). In MSE, simulations of each step in the management cycle are run, including the responses of fish stocks to ecosystem change scenarios, to test the robustness and precision of different management frameworks. A roadmap for such an MSE process is outlined in Fig. 3. The crucial steps include minimizing the *ad hoc* variance by implementing ecosystem drivers of stock production. A key factor here is the cost of adjusting monitoring programmes to adequately cover the influential ecosystem processes. This approach may differ from current practice, whereby single-species abundance surveys, fisheries monitoring programmes and models developed for single-species management are often used as a basis for implementing the key ecological process information. After deciding on the strategy, the appropriate monitoring and fish stock assessment models are applied. As ecosystems are dynamic, different states may require emphasis on different ecosystem drivers; we therefore suggest an adaptive approach with re-evaluation after each management cycle (Walters 1986). Alternatively, when variance reduction through the inclusion of ecosystem drivers remains difficult, management frameworks that are robust to, rather than adapting to, changing ecosystems should be evaluated, even at the cost of reduced harvesting rates (Froese *et al.* 2011; Punt *et al.* 2013).

The increasing flexibility of assessment software and simulation tools already provides several options for testing assumptions in fish stock assessments and for adding (potential) ecosystem drivers of stock productivity in MSE (Skagen *et al.* 2013; Wayte 2013). Using such structured MSE approaches (Fig. 3) across stocks within management bodies will aid the development of well-defined and realistic goals for EAFM implementation, identify the scientific and monitoring support required, and possibly speed up the implementation of EAFM principles in tactical fisheries management.

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Supporting Information

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

Table S1. Summary of review of Regional Fisheries Body (RFB) reports, Pacific and Indian Ocean.

Table S2. Summary of reviewed Atlantic, Antarctic, Trans-ocean, Australian and US fisheries bodies.

Table S3. Scientific support by geographical region.

Table S4. Reference list.