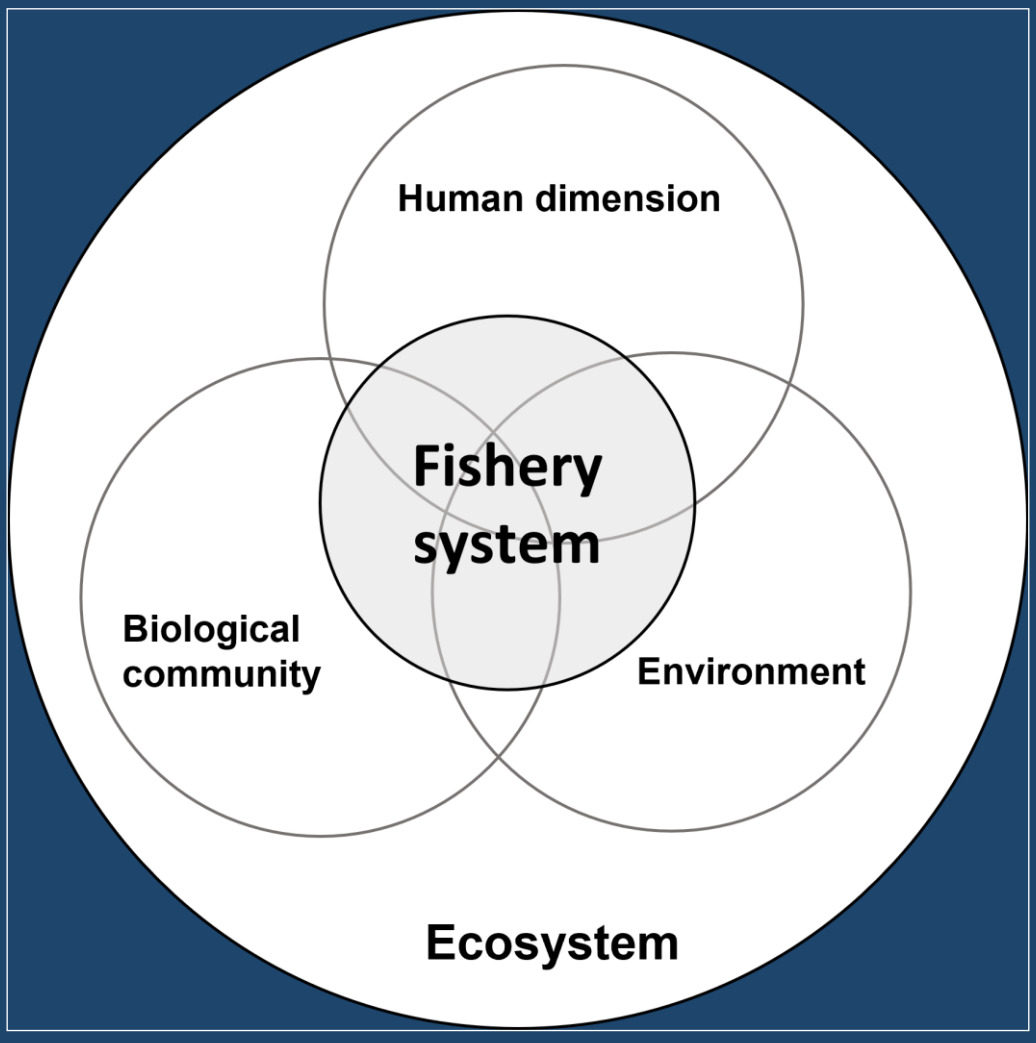
AN INTRODUCTION INTO ECOSYSTEM-BASED FISHERIES MANAGEMENT AND CLIMATE CHANGE ADAPTATION

PREPARED BY JESSE VAN DER GRIENT

12/2/2024 VERSION 1



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For more information, please contact The South Atlantic Environmental Research Institute (SAERI) at: info@saeri.ac.fk or visit www.south-atlantic-research.org

Stanley Cottage North
Ross Road
Stanley
FIQQ 1ZZ
Falkland Islands
+500 27374

Falklands House
14 Broadway
London
SW1H 0BH
United Kingdom
+44 (0)203 745 1731

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1. Project optimised – by operating as a streamlined and efficient organisation through the Focal Areas;

2. Fully funded – Falklands registered limited company is able to fund SAERI overheads, ensuring SAERI ultimately becomes fully financially independent from Falkland Islands Government and by ensuring that all grant applications (where possible) contain cost of seat coverage; and

3. The holder of proprietary environmental knowledge of the South Atlantic – by continuing to provide the research expertise offered to date.

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1. INTRODUCTION

Marine ecosystems provide many significant ecosystem services for the benefit of human wellbeing. These services include provisioning (food production, marine genetic resources, materials, renewable and non-renewable energy), regulating (carbon storage, storm protection, climate regulation, waste breakdown and detoxification), supporting (nutrient and water cycling, biodiversity) and cultural services (physical and mental wellbeing, tourism, knowledge and learning, recreation, sense of place, inspiration, spiritual and religious connections; Figure 1). However, these services can be affected by environmental change via impacts such as climate change, pollution, invasive species, habitat degradation or loss, and overexploitation. Changes to the services will affect human wellbeing and ocean economies (Doney et al., 2012; IPCC, 2022). There are, however, strategies that aid with anticipating changes and aim to minimise negative effects on ecosystems and the services they provide. This often requires a management style that is centred on adaptive co-management that manages the ecosystem as the interconnected system it is.

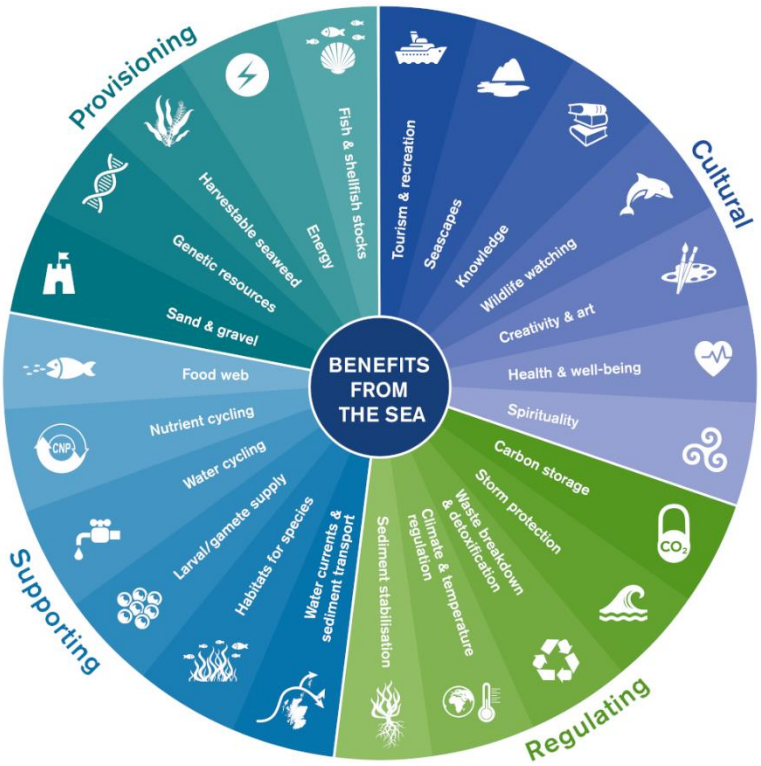

Figure 1: The ocean provides many services for human wellbeing. ©NatureScot

Across the globe, the effects of climate change on marine ecosystems are increasingly noticeable, including via changes in seawater and air temperature, seawater acidity, current strengths, dissolved oxygen levels, primary productivity, nutrient availability, atmospheric patterns including via increased frequency and strength of storms, and increased frequency of marine heatwaves, amongst other effects (IPCC, 2022). Marine organisms will be affected by these changes on individual levels via changes to their growth, reproduction, and survival, which in turn affects population biomass levels, and ultimately this can affect food-web interactions and thereby the ecosystem services provided by the biological community (Dueri et al., 2014; Lan et al., 2013). Several species, including exploited species, are reportedly moving poleward, which can introduce them to new areas where local communities may be restructured in response to their arrival (Cheung et al., 2012; Simpson et al., 2011; Sumaila et al., 2011). Taxon responses to various effects (or stressors) may depend on the stressor duration, frequency, and magnitude and the number of stressors present (Bailey and van der Grient, 2020; Crain et al., 2008). Further, responses may depend on the taxon life stage, and can often be affected by interactions with other species via mediation or exacerbation (Crain et al., 2008; Przeslawski et al., 2015). Detecting and ideally

predicting responses to stressors on species and community levels depend in part on data availability and quality, and the choice of indicators for change (Fredston et al., 2023; Welch et al., 2023), and changes can occur suddenly (Beamish and Noakes, 2002), as the recent collapse in the Bering snow crab demonstrated (Szuwalski et al., 2023). In addition, population responses dependent on other factors, including the state of their natural habitat (e.g., presence of pristine, degraded, or absence of key habitats such as spawning sites), and their exploitation levels (recovering, well-managed, or overexploited) (Bindoff et al., 2019). Healthy populations and communities are more resilient to changes or shocks and can maintain their key characteristics (sometimes called ecological integrity) and services. There are two ways to define resilience: one focuses on how resistant a community is to change after a shock (Holling resilience), and the second focuses on how quickly a community can recover to its original state after a shock (Pimm resilience) (Holling, 1973; Pimm, 1984). These two types of resilience are not mutually exclusive, and both play a role in determining ecosystem health. It underlines the importance of creating and maintaining healthy marine ecosystems given the ongoing and worsening climate crisis, as it influences exposure, sensitivity, and adaptive capacity for the coupled human-environment system (Figure 2).

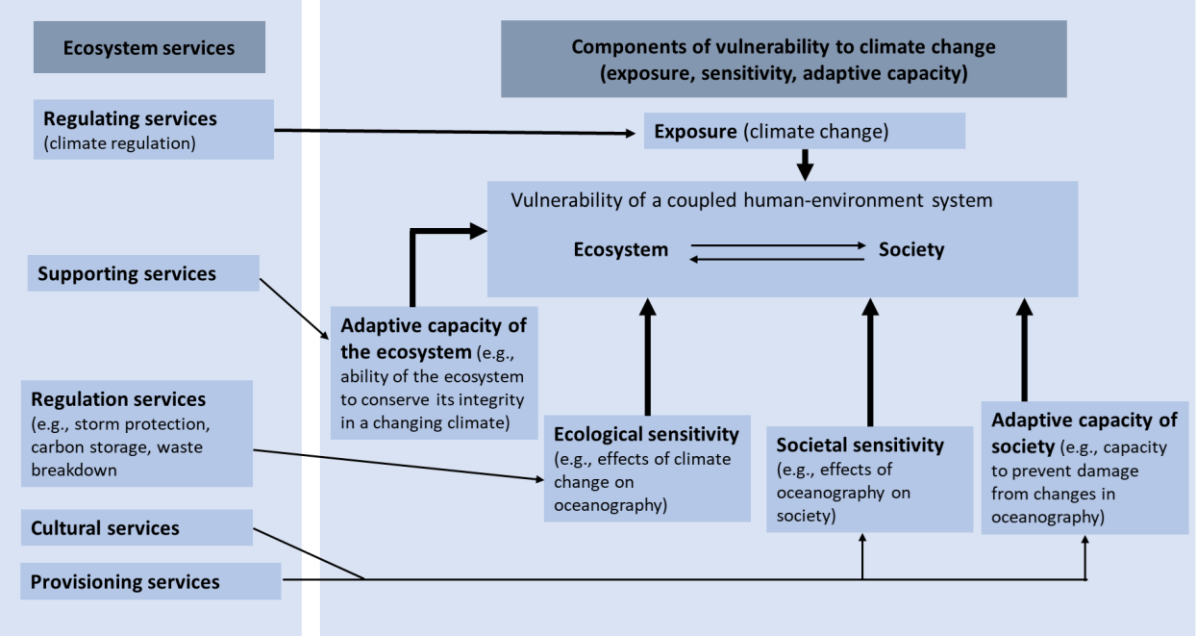

Figure 2: Ecosystem services links highlight the vulnerability of the ecosystem to climate change. Adapted from Locatelli et al. (2008).

Ocean ecosystems are vital for food security and job provisioning. Across the globe, at least a billion of people are directly dependent on the ocean as their primary source of protein. Healthy ocean ecosystems are therefore crucial now and for the future, which requires sustainable exploitation. The challenge in this is that historical fishing practices have often seriously impacted stocks and rebuilding these stocks to sustainable levels is not easy (Morato et al., 2006; Pitcher and Cheung, 2013; Swartz et al., 2010). For example, $^{1}/_{3}$ of the 104 British fish stocks are still overfished (Oceana in the UK, 2023). Globally, 35.4% of fish

stocks are overfished (FAO[1]). However, this can vary regionally; for example, 9-14% of the 175 U.S. fish stocks are overfished (NOAA[2]). Other challenges also are present, including managing the recovery of populations of large mammals (e.g., cetaceans and pinnipeds) and seabirds from past overexploitation, effects from using the ocean as a dumping ground for pollution, and habitat degradation (for example via coastal development), amongst others. Further, the changes in species distribution and community composition in response to climate change will likely have an impact on fisheries (Allison et al., 2009; Bell et al., 2013; Frusher et al., 2014; Metcalf et al., 2015; Sumaila et al., 2011). Therefore, the challenge is to manage the ocean in such a way to allow for recovery of fish stocks and other populations where necessary, maintaining healthy and sustainable populations including stocks, while recognising the multitude of objectives for other ocean users. This requires a holistic approach to ocean management.

Ecosystem-based management styles

A holistic approach in ocean ecosystem management can be seen as a continuum in management approaches, starting from single species approaches to fisheries management (SSFM; also sometimes referred to as SSAFM) and going towards multi-species and multi-sectorial management (Dolan et al., 2016). Three common versions of ecosystem management include ecosystem approach to fisheries management (EAFM or EAF), ecosystem-based fisheries management (EBFM), and ecosystem-based management (EBM). In many cases, these terms are used interchangeably, although they refer to different strategies (Figure 3).

Traditionally, SSFM stock assessments focus solely on the biology of the target stock, which ideally includes information on (age-based) catch history, fishing effort, catchability, and natural mortality to understand the biomass level that can be safely removed from the stock each fishing season (Dolan et al., 2016; Shertzer et al., 2008). The quotas, provided as Total Allowable Catch (TAC) or Total Allowable Effort (TAE), that are derived from this practice are known as biological reference points (BRPs) and play an important role in informing management decisions. Ideally, there are fishery management plans (FMPs) in place to regulate the stock, which would assess success in rebuilding (if necessary) and maintenance of healthy populations (Dolan et al., 2016).

More advanced stock assessments include environmental (e.g., habitat-mediated or physiochemically mediated effects, climate effects) and ecological (e.g., predation) factors that may affect stock recruitment, growth, and population dynamics (Clark et al., 2003; Hobday and Tegner, 2002; Hollowed et al., 2009; Keyl and Wolff, 2008; Link, 2010; Lorenzen, 2008; Mace, 2001; Rossberg et al., 2013; Schirripa et al., 2009; Tyrrell et al., 2011). Such approaches are EAFM as it includes ecosystem considerations for single stocks. EAFM can require a consideration of space, which may be especially important when there are different habitat requirements for different life stages. As such, the inclusion of, for example, marine protected areas to promote fish population growth in a larger area can be considered part of EAFM. This shows the increase in potential objectives a fishery may need to consider in order to manage the stock. Like in SSAFM, BRPs related to quotas are produced in stock assessment models except now they explicitly include ecosystem effects (Dolan et al., 2016). This also means that the management implementation of EAFM and the use of FMPs are operationally similar to that of SSFM (Dolan et al., 2016).

[1] https://www.fao.org/3/cc0461en/online/sofia/2022/status-of-fishery-resources.html
[2] https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates

A step up, whereby multiple, if not all, species in an ecosystem are considered within a management context is EBFM. EBFM takes a community or system-level place-based perspective and aims to optimise overall fishery yield over time, recognising trade-offs between managing different stocks may be required (Dolan et al., 2016; Link, 2010; Patrick and Link, 2015a). Stock assessments are no longer performed on single species, but on an aggregated group of stocks. Environmental, climate and habitat effects are incorporated into these stock assessment models to derive aggregated BRPs (Fogarty et al., 2012; Gaichas et al., 2012a, 2012b; Gamble and Link, 2012; Mueter and Megrey, 2006). Other types of models can be used too, including food-web models and end-to-end models to aid in understanding potential wider ecological effects. Food web models are models that capture all (major) prey-predator interactions of, often aggregated, groups in an ecosystem. End-to-end models are similar to food-web models but explicitly include the effect of the abiotic environment on biological community too (Fulton et al., 2011; Link et al., 2010; Townsend et al., 2008). Decision criteria regarding environmental goals (e.g., conservation, ecosystem resilience, socio-economic considerations) can be included in the management of the fish stocks and provide opportunities to consider various scenarios on trade-offs between reaching different objectives (Dolan et al., 2016; Kellner et al., 2011). At this point, BRPs are included as systemic reference points (SRPs), but SRPs can thus also relate to other environmental objectives. While theoretically it is possible to set SRPs, often in practice this is not done. Instead, BRPs are set that are derived and constrained by what is known about the ecosystem (Stram and Evans, 2009). The use of FMPs per stock should be extended to fishery ecosystem plans (FEPs) to ensure that fisheries are strategically managed based on tactical (short-term) and strategic (long-term) decisions, sector level targets, and (environmental) goals (Dolan et al., 2016). Last, there should be enforceable management decisions in place that have been agreed upon in advance, which are triggered when goals are not met (Dolan et al., 2016). The management of EAFM is adaptive, thus goals should be regularly reviewed, and as more information becomes available on environmental variability and change, and the effect of this on the ecosystem, updated as necessary, along with other necessary changes as needed (Dolan et al., 2016).

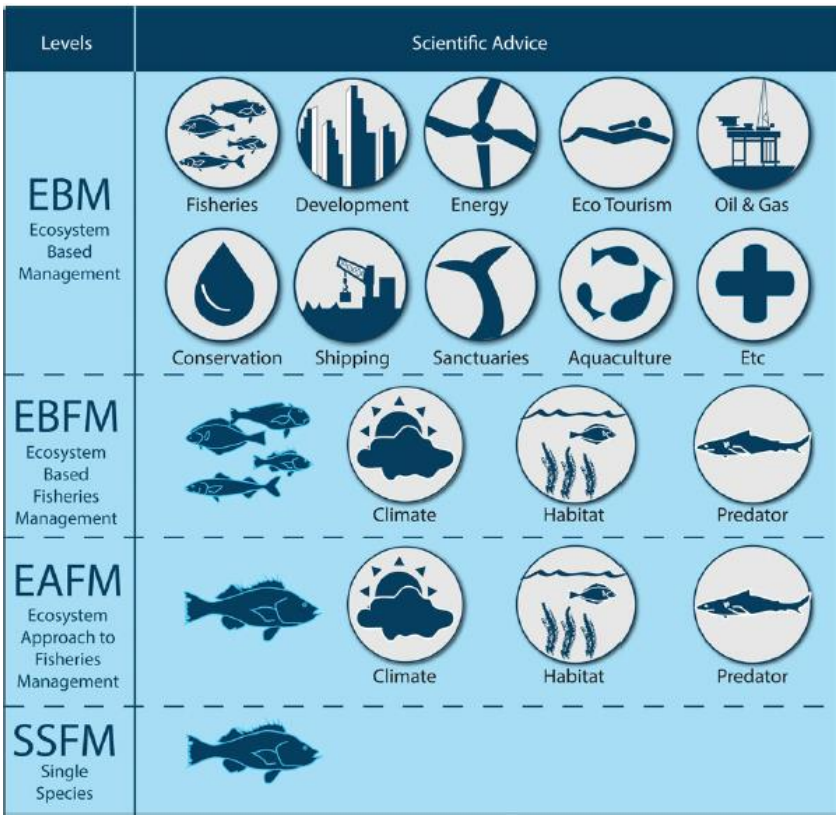

Figure 3: The difference in fisheries management styles. From Dolan et al. (2016).

Considering other sectors in the management plan alongside fisheries represents EBM. An accepted definition of EBM is still not available, and many attempts have been made to define it (Dolan et al., 2016;

FAO, 2003). Generally, however, definitions including explicit focus on sustainability, ecological status (or integrity or resilience), and marine spatial planning. The larger focus on the human dimension sets EBM apart from EBFM (Dolan et al., 2016). This approach considers the multiple stressors that enact on marine environments and aim to determine how best to manage a range of ecosystem services across sectors along with quantifying the risks these ecosystem services are impeded because of environmental change or management decisions. The implementation and monitoring of EBM success requires the use of both BRPS and SRPs in an adaptive management approach.

2. ECOSYSTEM-BASED FISHERIES MANAGEMENT (EBFM)

Conventional fisheries management tends to focus on one stock or one fishing sector (e.g., finfish, groundfish, etc.) within rigid (e.g., exclusive economic zones) boundaries at the time. Advanced stock assessments for target species may consider recruitment success and variability in response to environmental conditions, predation mortality, or habitat suitability, but this approach is not standard across stock assessments (Essington et al., 2016). In addition, these assessments do not consider the effects of food-web interactions, bycatch, habitat needs, or behaviour of people and markets on stocks (Bayley et al., 2021; Elliott et al., 2017; Hall and Mainprize, 2004; Kroetz and Sanchirico, 2015; Parsons, 2005). This can risk estimating target species stock biomass levels or trajectories poorly, setting poor catch quotas, or have wider negative ecological consequences, including on the ecosystem services produced by the ocean. Further, as fishing sectors are often treated individually, this limits the opportunities to consider overarching management goals and trade-offs between fisheries (Levin et al., 2018).

Recognising that fisheries operate in and are part of an interconnected system and need to be managed in such a way is an important step forward towards creating and managing sustainable fisheries, and this is the foundation of EBFM. In EBFM, the system in which fisheries operate is recognised to consist of different ecological components (fish stocks, nontarget species, habitats, etc.) and ideally it includes socio-economic components related to the fishery system (e.g., people employed in the fishing industry). The links between these components (prey-predator interactions, market, or job links, etc.) can cover various regulatory units and jurisdictions. This holistic, place-based management approach can allow for the incorporation of social, economic, and cultural objectives alongside ecological ones, although a strong focus on the human dimension would be considered EBM (Levin et al., 2018; Pinto, 2005). EBFM underpin the needs of humanity for healthy, productive, and resilient ocean ecosystems for the use of the ocean's ecosystem services by current and future generations. In addition, it allows for a better identification and understanding of the full suite of threats fisheries may face, identify elements that promote resilience, and incorporate and consider environmental and ecological information in the setting of catch levels (Levin et al., 2018).

EBFM is a framework that allows for the identification and incorporation of objectives from various perspectives (e.g., industry, government, but also conservation, public). These objectives are ideally ranked for importance by stakeholders together and implemented in a stepwise approach to build towards a sustainable use of our ocean environment. The implementation and execution of this approach requires guiding, overarching, and agreed upon principles (strategic objectives) by all stakeholders. For example, NOAA identifies six guiding principles for their EFBM as follows[3]: (1) implement ecosystem-level planning; (2) advance our understanding of ecosystem processes; (3) prioritise vulnerabilities and risks of ecosystems and their components; (4) explore and address trade-offs within an ecosystem; (5) incorporate ecosystem considerations into management advice; and (6) maintain resilient ecosystems. These principles form the basis for setting (operational) objectives to manage the marine ecosystem sustainably, and in an adaptive way. This approach recognises that setting clear objectives and reviewing success is important in moving towards a sustainable management regime, and this requires stepwise change rather than implementing everything all at once. Such an approach will also become increasingly important as climate change continues

[3] https://www.fisheries.noaa.gov/topic/ecosystems/ecosystem-based-fishery-management

to progress, as the EBFM allows for the identification and incorporation of climate change adaptation (CCA) strategies. In addition, the stepwise iterative approach ensures that EBFM can be adapted for any region and tools and data they have available to make a start with implementing EBFM practices.

EBFM requires, like conventional fisheries, performance measures and reference points to determine success or whether change is required. Performance measures can be incorporated at different levels and components in the framework. Thus, they do not solely have to address biological performance measures, but they can also address economics or even management aspects (Grafton et al., 2007). These measures will be indicators that can used to evaluate the success of the EBFM delivery and implementation (Hall and Mainprize, 2004). Reference points can either relate to targets that are being build towards or maintained, or limits that should not be exceed and if they are trigger certain management decisions (Hall and Mainprize, 2004). Reference points related to limits can be used as an 'early warning' indicator to reduce the probability of harmful effects on a stock. When there is a high probability of harmful effects should the limit be exceeded, or high uncertainty in what the value of the limit should be because of issues with estimation or observation, or when management reactions are known to be slow, it is strongly advised to set a precautionary target level to incorporate a conservative buffer in the stock and to allow time for (necessary) management changes before harm occurs as a risk management tool (Arif, 2018a, 2018b; Hall and Mainprize, 2004; Macdonald, 1995). The assessments should be done periodically and be dependent on what they measure and when this information needs to be available. To facilitate this evaluation, it is important that stakeholders agree on these indicators and have a clear plan for action for when thresholds are reached and exceeded in advance (Hall and Mainprize, 2004). The success of the use of performance measures and reference points are determined by their formulation. Useful measures and points are quantifiable, simple, logical or relevant, tractable, faithful, comparable and cost effective (Hall and Mainprize, 2004).

Performance measures and reference points are not new to the fishing industry; common examples related to the status of a stock compared to its virgin biomass level (the level of biomass that would be present without fishing), or a fraction of the maximum-sustainable-yield biomass, which in turn can be used to set quotas, determine the status of the fishery or be used to create a recovery plan for a stock (Hall and Mainprize, 2004). Reference points related to the status of a fishery or stock are often derived from stock assessment models and/or other fish population dynamic models. It is important to recognise that the choice of model, its assumptions, and information or data it can incorporate can influence the estimate of a reference point (Hall and Mainprize, 2004). For example, some models (e.g., yield-per-recruit analyses) do not incorporate recruitment, but focus on growth via mortality and weight, while other models (e.g., biomass-per-recruit analyses) can incorporate recruitment data (Gabriel and Mace, 1999). Ecosystem models can provide additional information regarding the influence of food-web interactions and environmental variability on specific groups besides stock assessments in EBFM and be used to derive aggregate quotas.

Conventional fisheries tend to focus explicitly and predominately on biological reference points related to target species, although implicitly others may be included (e.g., related to employment or maintaining status quo). Note that any aspect of the management process in the fishery can incorporate performance measures and this can relate to non-stock related biological components, or social and economic components of the system (ICES, 2001). For example, indicators focusing on achieving efficiency, providing employment, minimizing conflicts, etc. focus on the socio-economic part of the fishery system (Figure 4)(Hilborn, 2007). By incorporating explicit performance measures and reference points related to all

these components, the step towards EBFM is taken. Indeed, often the simplest and most tractable step towards the implementation of EBFM is incorporating performance measures and reference points for nontarget species such as for example bycatch species, dependent species (e.g., predators of target species), and species affected by scavengers (Hall and Mainprize, 2004; ICES, 2001).

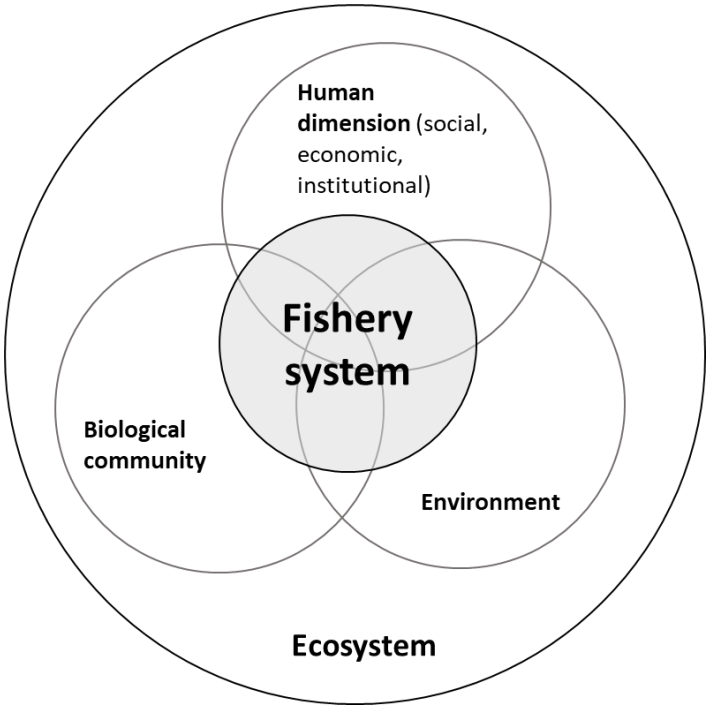

Figure 4: the fishery system centres on three main components that each interact in their own way.

Single-species reference points are for now still the most practical option regarding the biological component in the system. Besides single-species (biomass) metrics, a multivariate approach that represents a summarised, aggregated approach of a suite of metrics has been proposed for EBFM (Link et al., 2002). These metrics can include biotic metrics related to resource dynamics (e.g., total biomass, (relative) abundances, species richness, species evenness) and internal dynamics (e.g., mean animal length or weight, linkage density, cannibalism, consumption, maturity), or abiotic metrics related to physical forcing (e.g., water temperature anomalies, El Niño-Southern Oscillation or North Atlantic Oscillation index), or human metrics (landings, revenues, number of vessels)(Link et al., 2002). Other system reference points based on theory, empirical data or simulations have been proposed (Bundy et al., 2012; Coll et al., 2008; Fay et al., 2011; Large et al., 2013; Libralato et al., 2008; Link, 2005; Murawski, 2000; Samhouri et al., 2010). More importantly, however, is that selected metrics are evaluated over time, as system changes can provide a basis for discussion on ecosystem issues amongst stakeholders in the fishery system (Hall and Mainprize, 2004). Emergent ecosystem-level properties, metrics or indicators are currently not available at a practical level, which is often partly because there is a lack of understanding in the underlying causes or consequences of ecosystem properties (e.g., change in biodiversity), or lack in agreement on what should be measured (Cochrane, 2002; Hall and Mainprize, 2004; ICES, 2001; Link et al., 2002).

EBFM requires a co-management approach, where the fishing sector is involved in decision-making to incorporate user knowledge in the process (Marshall, 2007). The benefit of the co-management approach is a greater understanding of each other's requirements, improving understanding in the rationale behind management decisions, and the inclusion of local knowledge (Okes et al., 2012). Further, a sense of ownership of fisheries can promote maintaining and especially in rebuilding stocks. When fishers have long-term property rights or assurances that they will benefit from practices that promote stock rebuilding in the future, they are often more likely to accept or even take the lead on implementing such measures (Grafton et al., 2007, 2006; Hilborn et al., 2005). Larger involvement of fishers in decisions on the setting of catch limits can promote compliance with the system, including accurate reporting on landings, bycatch, and discards, which in turn are vital data for stock assessments (Grafton et al., 2007; Jentoft, 1989). Co-management

requires a 'bottom-up' approach, wherein those making the decisions have the authority, accountability, and responsibility to make decisions, and these decisions are transparent (Grafton et al., 2007). Transparency in decision-making ensures that decision makers can be held accountable, promote greater acceptance of outcomes across stakeholders, and provide opportunities to learn from past mistakes rather than repeating them (Grafton et al., 2007). Via EBFM, governance aspects such as accountability, authority and responsibility, transparency, incentives, risk and management, and adaptability are clearer established between the different stakeholders, which is important as these factors can play a large role in improve fisheries outcomes (Grafton et al., 2007).

Learning is essential across the board, and especially because of climate change (Berkes et al., 2003; Walker et al., 2006). EBFM provides a framework were learning becomes systematic, which is more likely to result in transformational change rather than learning by trial-and-error or via simple adjustments in a narrow policy space (Ogier et al., 2016). Learning comes in in various forms in EBFM. Monitoring is needed as feedback on generating new knowledge as well as understanding whether management decisions made a difference or not (Armitage et al., 2008; Runge et al., 2010). This new knowledge provides a basis and can indicate the direction for change (Ogier et al., 2016). It further aids in identifying whether resources were used effectively or whether and how this can be improved (Armitage et al., 2008; Runge et al., 2010).

3. EBFM IMPLEMENTATION

The theoretically discussions can often make it seem that implementing EBFM is difficult or impossible, but this is rarely the case. There are now several guidelines and suggested approaches available (Garcia et al., 2003; Levin et al., 2018) to help the process. It is important to recognise is that not everything has to be done at once, but that a stepwise approach should be taken. Levin et al. (2018) provide a clear framework to facilitate the implementation of EBFM via the creation of Fisheries Ecosystem Plans centred around learning and adaptation. There are five main questions or steps related to this framework: (1) Where are we now? (2) where are we going? (3) How will we get there? (4) How will we implement the plan? (5) Did we make it? Between steps 3-5 there are opportunities for learning and adapting (Figure 5).

Figure 5: EBFM framework demonstrating the iterative cycle and opportunities for learning in a fishery system. From Levin et al. (2018).

(1) *Where are we now?*

An understanding of the current situation is necessary as a basis to start from. This requires first the development of a conceptual model that captures the ecological, economic, and social components of the ecosystems, the identification of the institutions involved, and the links or connections between the

components and institutions (Levin et al., 2018). Second, the status or health and trends of key components should be inventoried, alongside with their threats (Levin et al., 2018). Identified threats to the marine ecosystem should be accompanied by information on which component(s) they act, their spatial scales, and the frequency and magnitude of the threats. This will form a basis for calculating the risk of each threat (Hilborn, 2007) in later steps.

The development of the conceptual model and inventory lists is ideally conducted with stakeholders, as it provides a platform to discuss values and goals, foster communication between different parties, and increase the collective understanding of the system (Garcia et al., 2003; Hannesson, 2004; Pauly et al., 2002). In addition, this platform can be used to determine what the proper (and possible) indicators are for tracking status and trends in the key components. That is, identifying what can be used as metrics for reference points or performance measures. Ideally, indicators can be observed, are based on (well-defined) theory, understandable for all parties involved, cost effective, sensitive, and responsive to reflect the properties they intend to measure, and reflected in historical time series (Levin et al., 2018).

(2) *Where are we going?*

To aid the establishment of clear goals for the fishery system, a vision statement should be developed. This vision statement should be durable, set the ambition and goal for the fishery system, be resistant to staff and organisational change, and include the core values and purposes of all parties involved, which means it must be broad (Crowder et al., 2006; Healey and Hennessey, 1998; Pearse and Walters, 1992). Well planned and communicated vision statements can aid the mission by linking all levels of planning and goal setting together, and this can have a positive effect on organisational performance (Food and Agricultural Organization of the United Nations, 1995; Garcia et al., 2003; Hannesson, 2004, 2004; Pauly et al., 2002).

Several strategic objectives (or guiding principles) should be developed based on the vision statement, which allow the vision statement to become actionable and attainable (McEvoy, 1988; Pinkerton, 1994). Strategic objectives are therefore more focused on specific key components. Strategic objectives may be codified in law, but this is not a prerequisite and can reflect matters important to stakeholders (Levin et al., 2018). Strategic objectives can relate to aims of understanding the ecosystem better (often to reduce uncertainty in indicators), communicate the aim of implementing EBFM, and focus on addressing potential threats to the fishery system.

Many strategic objectives can be derived for a system, with multiple strategic objectives for each component of the system. However, it is impossible to implement or address these objectives all at once. Instead, the objectives need to be ranked, with input from all stakeholders. There are a few considerations that can provide a basis to rank strategic objectives. A systematic first approach is conducting risk assessments for meeting/not meeting strategic objectives. Risk assessments provide scores, and these risk values provide a ranking of strategic objectives (Paterson and Petersen, 2010). It requires an understanding of which threats are likely to have an impact on the system, how large this impact may be, where the impacts may occur (which key component), and how this relates to the fishery system as a whole (Holsman et al., 2017; Levin et al., 2018; Paterson and Petersen, 2010). Besides risk assessments, knowledge on status and trends can provide an indication of urgency or prioritisation of certain strategic objectives (Levin et al., 2018). Last, practical issues such as feasibility, logistics, governance and institutional issues, stakeholder support, threat reversibility, and implementation costs (for each objective) should be considered as well. These

considerations need to be documented so that criteria for ranking and selecting priority objectives remain clear and transparent for all parties involved in the future (Grafton et al., 2007; Wilson et al., 2006).

The ranked strategic objectives provide a basis to select strategic objectives for which operational objectives can be developed. Strategic objectives are high-level statements that provide direction and vision, while operational objectives are practicable and actionable (Levin et al., 2018). Operational objectives should follow the SMART principle: specific, measurable, achievable, realistic, and time-bound (Levin et al., 2014; Mace et al., 2009). Operational objectives delineate what FEPs will and will not address, enable progress to the measurable end goal, ensures that EFBM remains feasible (rather than stretching the efforts too thin), and focus on changing the system in such a way that creates the largest amount of benefit to the whole ecological-economic-social system (Levin et al., 2018).

It is important to recognise that not everything can or has to be done immediately. The number of, and which, operational objectives can be developed will, for example, depend on the institutions involved, resource availability (human, time), and tools available. The list of strategic objectives or possible operational objectives will remain available and can be incorporated in later iterations of the process. In this way, the EBFM approach can be adapted to the regional needs and available tools, information, and resources.

(3) *How will we get there?*

The development of the operational objectives provides the starting point to implement the FEP. Performance measures and reference points (BRPs and SRPs) which are related to operational objectives and are responsive to management actions are needed to track the success of operational objectives (Levin et al., 2018, 2015; Samhouri et al., 2017, 2012, 2011). The selection of appropriate indicators may be dependent on available technical experts and data, and can be supported by (large, complex) ecosystem models, but this latter is not always necessary nor is it required to start the EBFM implementation (Craig and Link, 2023; Levin et al., 2018). As review is part of the FEP, indicators and tools can be updated when necessary and possible each iteration.

The performance measures and reference point indicators provide a basis to create alternative management scenarios or actions, including for what to do if thresholds are crossed. For example, this may trigger management actions such as changing catch limits or closing area under some scenarios, while instigate meetings to either scientifically review the information and provide guidance to managers or stakeholder discussions to determine potential solutions in others (Levin et al., 2018). This review of alternatives may also provide input in improving survey designs to increase the accuracy and precision of indicator measures, which in turn can be incorporated in updated risk assessments (Levin et al., 2018; Paterson and Petersen, 2010).

The alternative scenarios need to be analysed to determine the robustness of management strategies, and which scenarios lead to greater system benefits and minimization of negative impacts. Management strategy evaluation (MSE) is a common policy analysis approach that tests the strengths and weaknesses of alternative scenarios based on indicators, and works well to eliminate poorly performing strategies, and identify which strategies promote resilience in the fishery system, but it does not provide an indication of the 'best' approach (Fulton et al., 2015, 2014; Patrick and Link, 2015b; Smith, 1994). This is in part related to the complexity of EBFM, but it is also a benefit to have multiple options of management scenarios as the selection of one scenario over another can influence the EBFM implementation plan. It is

important to note that MSE is useful given the uncertainties in indicators and historical trends. For example, there may be uncertainty in knowing initial overexploitation, fishing or natural mortality rates, fluctuations in and causes thereof in populations, etc (Ludwig et al., 1993). By using planned alternative scenarios in computer models, simulations can be run to assess the likely effectiveness, but eliminate poor strategies for at least some unforeseen effects (Link et al., 2002; Thurstan et al., 2015). The results of the MSE, and criteria for selecting the final management strategy should therefore be well documented and be transparent, so it will remain useful as a resource over the years (Grafton et al., 2007; Levin et al., 2018).

(4) *How to implement the plan?*

With the information and prioritised objectives from steps 1-3, projects can be developed to facilitate EBFM implementation. The design of the projects needs to consider time allocation, funding, and human resources. Thus, here it becomes obvious what the benefit is of the MSE as this process will likely provides various strong management options, which may require the support of different projects. Each project can be costed to determine the best management option for this round. Besides determining cost and resource need for each project, they should also be clearly defined in their scope. This means that the specific work done is outlined, why it is necessary to do this work and how it relates to the vision, and strategic and operational objectives, what tools are required to conduct the work, what the project outputs are, and how this project relates to other projects (Levin et al., 2018).

Projects in this step can be similar to projects for SSFM or EAFM, like for example fisheries survey projects. However, given the holistic approach of EBFM, focus on other ecosystem components is needed, and therefore there can be projects focusing on non-target, and biophysical and socioeconomic indicators (Samhouri et al., 2017). For example, projects can focus on reducing bycatch strategies, improving habitat quality, establishing marine protected areas or other conservation practices, assessing prey dynamics, dispersal dynamics, assessing influence of fisheries on local jobs or markets or perception, health and safety at sea, compliance at sea, etc. It is possible to create incentives via these projects to promote certain behaviours (Carwardine et al., 2009; Samhouri et al., 2012).

(5) *Did we make it?*

Regular reviews of performance are vital for monitoring the success of the EBFM implementation. These reviews provide the opportunity to determine if the management strategies chosen and implemented in the previous steps improve or maintained ecosystem health, status, and provisioning of ecosystem services, or whether there may be unexpected and unintended effects (Levin et al., 2018). The periodicity of review may vary depending on the indicators. For example, it is likely that most can be reviewed at least annually, but some, and especially those related to catch limits or success may need to be reviewed at a higher temporal resolution that is more sensible for the fishery. Upon review, it is possible that changes need to be made on previous plans developed in steps 3 and/or 4, or that with the new information available other strategic or operational objectives can be addressed. Larger changes are likely required in the first few rounds of the process as critical unknowns or unexpected consequences are identified. It further provides the ability to customise the EBM implementation further to the needs and constraints of the region (Levin et al., 2018). Last, the EBFM approach prepares the fishery system and its management for future challenges under climate change.

The iterative and adaptability of the process described above underlines that it is currently possible to implement EBFM in most if not any fishery. This approach does not require drastic changes to fishery governance (Patrick and Link, 2015b). While a mandate to implement EBFM can aid the process as it signals clear intention, this top-down signal is not necessary for implementation, nor has it stopped EBFM implementation before (Tromble et al., 2008). Extensive data and complex models, although helpful, are not necessary to make a start on implementation, as these can be incorporated into the process and improved upon during later iterations when larger understanding is created because of the learning process. Further, it is important to recognise that model complexity depends on the factors included in the model and how uncertainty is incorporated (Link et al., 2012, 2010). The key thing is to recognise which processes in the system are important and require more detail, and which part of the ecosystem does not, and what type of model (qualitative, semiquantitative, quantitative) is needed; these decisions are part of the EBFM process (Patrick and Link, 2015b). There may be a worry that allowable catches may be reduced under EBFM because of precautionary limits based on uncertainty or protection measures for nontarget species, but these assumptions are often based on predicted single-species yields rather than the aggregated yield, with the latter often not changing in analyses (Lucey et al., 2012; Patrick and Link, 2015b). Further, the economic value of the landings may stay constant and may even increase over time when groups are recovering (Patrick and Link, 2015b). Further, improved resilience in the ecological component of the system will benefit the stability of the socioeconomic components in the system (Patrick and Link, 2015b).

4. WHAT CAN SUPPORT THE SUCCESS OF EBFM?

The success of the FEP and thus implementation of EBFM can depend on effective stakeholder participation, and adequate representation of each stakeholder group, both which may require trust (Levin et al., 2018; Porobic et al., 2018). It is therefore worth investing in well-trained facilitators, especially in the beginning, when contentious issues may be discussed (Levin et al., 2018). Stakeholder participation and transparent documentation of decisions made can also aid in building trust and understanding among groups (Grafton et al., 2007; Levin et al., 2018).

To facilitate EBFM and promote its success, training in EBFM is required that is accessible and useful to all stakeholders involved (e.g., fisher people, compliance officers, observers, managers, etc.)(Okes et al., 2012). It is recommended that such a course is made available alongside stakeholder meetings to discuss other matters related to decision making (Okes et al., 2012).

The success of EBFM can also depend on the selection of indicators. If poor indicators are chosen, then progress is not evaluated properly, and issues may not be recognised or solved (Porobic et al., 2018). Management structure and scientific councils play a role in this via data collection, analyses, and evaluation. Their work may traditionally be more focused on single species, but efforts are needed to shift the mindset to ecosystem perspectives (Porobic et al., 2018).

Implementing EBFM can make the decision-making process more complex, because of the use of probabilities and uncertainty which can be difficult to understand, and the increased number of components which will bring together (potentially) competing ecosystem objectives (Garcia and Cochrane, 2005; McEvoy, 1988). However, via EBFM governance aspects such as accountability, authority and responsibility, transparency, incentives, risk assessments and management, and adaptability are clearer established between the different stakeholders, and these factors often improve fisheries outcomes (Grafton et al., 2007).

Part of the success in EBFM lies in its adaptability. Given that the ocean is an uncertain system because many processes are still not well understood, or have data covering long periods of time, being able to adapt is useful. It provides the opportunity to be flexible and responsive to change and especially unexpected change, allows for the systematic consideration of alternative options and states and linking this to trade-offs, allow for experimentation (when appropriate) to promote learning, improve decision making via available simulations of different policies, and as a result provide quicker and better-informed responses to unexpected situations. The success does depend on the flexibility of institutes or institutional structures to adjust, but it also highlights the nested structure in management that makes it clear how this flexibility in management structures can be promoted (Grafton et al., 2007).

5. EBFM AND CLIMATE CHANGE ADAPTATION

EBFM lends itself to consider and incorporate alternative climate change adaptation (CCA) strategies in management plans to minimise climate change impacts on fisheries. Indeed, similar strategies and requirements (e.g., stakeholder participation, implementation across levels of governance, experimentation, and learning, recognising connections) have been proposed for CCA. The impacts of climate change on fisheries will vary between regions and possibly fishing sectors in the same area (Daw et al., 2009; Madin et al., 2012). As stated before, EBFM lends itself to be adapted to specific regional needs, and thus it is a useful framework to incorporate CCA strategies (Ogier et al., 2016). Success of incorporating CCA into this framework depends in part on the way public policy is enacted; ideally CCA strategies are incorporated into all areas of public policy making, implemented at all levels of governance (local, national, or international level), and focus on both mitigation and adaptation strategies (Ogier et al., 2016). Other obstacles towards improving adaptation capacity can be identified by asking 'who should adapt' (i.e., individuals, communities, governments), 'what should be adapted' (i.e., what is the scale of adaptation - local, regional, national) and 'how to adapt' (i.e., what resources or capital are available for adaptation, will it be reached via a bottom-up or top-down approach)(Grafton, 2010). These considerations can be discussed alongside the standard considerations for EBFM in the framework. Long-term benefits are more likely to occur when strategies focus on building and maintaining resilience and adaptive capacity in the fishery system, while successes can be hampered by a strong focus on short-term fixes or when implementation is slow (Madin et al., 2012; McIlgorm et al., 2010; Ogier et al., 2016). Implementing long-term, anticipatory strategies can contribute to reducing economic costs in the future, reduce vulnerability, and allow systems at risk to build up a buffer. These strategies may need to be accompanied by certain precautionary conservation strategies (e.g., marine protected areas) and placements of such place-based strategies need to be considered in the whole framework (Serrao-Neumann et al., 2016).

The management style of the fishery system influences the potential for CCA possibilities. Management should be co-management, as this style provides a platform between stakeholders to discuss and resolve issues, share knowledge, build understanding of various needs, allows for discussion and transparency in trade-offs necessary in decision-making, improves acceptance in decisions, underlines the shared responsibility, empowers stakeholders and build capacity, provides opportunities in shared and systematic learning and innovation, improves long-term planning, and provides the flexibility to cope with changes caused by climate change (McIlgorm et al., 2010; Ogier et al., 2016). Adopting EBFM means the management style becomes adaptive co-management, allowing for the incorporation of fishery system complexity and uncertainty which is especially useful in the face of climate change, and the iterative approach of EBFM towards ecosystem management allows for managing for short- and long-term impacts (Allen et al., 2011; Arvai et al., 2006; Berkes, 2012; Lester et al., 2010). Learning is essential across the board, and especially because of its role in reducing uncertainty associated with climate change effects (Ogier et al., 2016; Walker et al., 2006). Adaptive co-management further implies that barriers to adaptation strategies are reviewed across a wider range of options than traditional management styles can – there are more opportunities to address issues across the ecological-economic-social context of an ecosystem than, for example, what is possible in the context of SSAFM. This raises the likelihood and capacity to confront and address complex issues (Ogier et al., 2016).

Incorporating CCA in EBFM can aid the fishing industry in anticipating uncertainty and/or changes to their practices. Traditionally, fishing can be restrictive to certain areas and/or seasons through legislation. As climate change continues, resilience in the fishing industry may require more flexibility in, for example but not limited to, the timing of the fishing seasons and/or fishing areas. These strategies (or checks) can be incorporated as strategic and operational objectives in the EBFM framework, allowing the fishing sector to be more reactive and adaptable to climate change, but only as long as this is accompanied by appropriate changes in policy. This is an example of where slow response in legislative change can hamper the success of EBFM. Legislation needs to be changed such that it allows for strategic planning for variability, uncertainty, and flexibility in the fishing sector (McIlgorm et al., 2010). The benefit of preparing for these situations means that fishing efforts can be spread over time and/or space to reduce the vulnerability of the target species and wider ecosystem (McIlgorm et al., 2010). Further, it can set the flexibility too for developing new fisheries for species that are moving polewards and possible replace or supplement traditional target species catches (McIlgorm et al., 2010). The adaptability can also result in planning resources more efficiently in a changing environment, and as a last resort can aid for planning for potential resource declines (McIlgorm et al., 2010). Of course, these options need to be explored in conjunction with other objectives for the fishery system.

The inclusion of monitoring programmes in EBFM is even more important for the consideration of climate change effects. Changes may occur over a long period so that they are difficult to detect, risking a 'shifting baseline syndrome' situation. The shifting baseline syndrome is a situation when environments are degraded, and these changed environments are accepted as the norm, which has implications for protection and conservation, recognising population declines, building resilience in the system, and recognising thresholds (Soga and Gaston, 2018). This situation is especially likely to happen when information about the past is not available (Soga and Gaston, 2018). In addition, monitoring can aid in determining the trajectory of change. Changes may seem linear, but more likely there are nonlinear, which can result in sudden large-scale changes which are more difficult to manage (Brander, 2009). Changes may also be scale- or context-specific, and thus the choice of indicators to aid in detecting climate change effects is critical (Serrao-Neumann et al., 2016). Monitoring allows for the early detection of trends and approaching tipping points and therefore provide guidance on what needs to be done and when. Monitoring also provides a basis for building up our knowledge on the ecosystem and its complexity which improves the conceptual model of the area and allows us to improve on the development of objectives and indicators, and ultimately decision making. Last, monitoring can provide another avenue for stronger collaboration between different institutes and organisations, thereby reinforcing that EBFM success is built upon collaboration and stakeholder participation.

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SOUTH ATLANTIC ENVIRONMENTAL RESEARCH INSTITUTE

www.south-atlantic-research.org
@SAERI_FI

FALKLAND ISLANDS OFFICE
Stanley Cottage North, Stanley, Falkland Islands. FIQQ 1ZZ
Tel: +500 27374 Email: info@saeri.ac.fk

UK REGISTERED OFFICE
Falkland House, 14 Broadway, Westminster, London, United Kingdom, SW1H 0BH
Tel. +44 (0)203 745 1731