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A climate-informed, ecosystem approach to fisheries management

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ABSTRACT

This paper outlines the benefits of using the framework for an ecosystem approach to fisheries management (EAFM) for dealing with the inevitable yet unclear impacts of climate change and ocean acidification on coastal fisheries. With a focus on the Asia-Pacific region, it summarizes the projected biological and socio-economic effects of increased emissions of carbon dioxide (CO_2) for coastal fisheries and illustrates how all the important dimensions of climate change and ocean acidification can be integrated into the steps involved in the EAFM planning process. The activities required to harness the full potential of an EAFM as an adaptation to climate change and ocean acidification are also described, including: provision of the necessary expertise to inform all stakeholders about the risks to fish habitats, fish stocks and catches due to climate change; promotion of trans-disciplinary collaboration; facilitating the participation of all key stakeholders; monitoring the wider fisheries system for climate impacts; and enhancing resources and capacity to implement an EAFM. By channeling some of the resources available to the Asia-Pacific region to adapt to climate change into an EAFM, developing countries will not only build resilience to the ecological and fisheries effects of climate change, they will also help address the habitat degradation and overfishing presently reducing the productivity of coastal fisheries.

1. Introduction

The coastal communities of developing countries in the Asia-Pacific region are characterized by heavy dependence on fisheries resources [1] and high exposure to climate impacts [2]. The intense use of coastal resources for food security and livelihoods [3,4], driven by high human population densities in the coastal zone, is causing widespread habitat degradation [5,6] and over-exploitation of fish stocks [7]. Increasing demand for fish by the region's rapidly growing human populations [8] will only exacerbate these problems and increase the scope for conflict [9]. Small-scale fishers already feel the impacts of large-scale operators on their catches and equipment, the inequitable benefits gained by wealthier fishers who can afford more efficient gear, and differential access to fishing grounds [10].

Part of the widely accepted solution to this dilemma is to integrate fisheries management into an 'ecosystem approach', which aims to balance conservation, sustainable use and the fair allocation of benefits

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derived from natural resources [11]. The application of the ecosystem approach to fisheries has been endorsed internationally through the United Nations Food and Agriculture Organization Code of Conduct for Responsible Fisheries [12], and in the Asia-Pacific region through the intergovernmental Regional Plan of Action agreement among the six member states of the Coral Triangle Initiative for Coral Reefs, Fisheries, and Food Security (CTI-CFF) and in their respective National Plans of Action [13].

The ecosystem approach to fisheries management (EAFM) considers interactions between: (1) the core elements of the fishery (fish and fishers), (2) habitats and environmental conditions that interact with the fishery and, (3) the socio-cultural, economic and governance systems that surround the fishery [11]. This places non-trivial demands for more and varied types of information, financing options, jurisdictional and institutional cooperation and societal consensus on the future of the fishery in question [14]. Guidance on overcoming these challenges is growing, based on enabling policy and legislative environments, good governance and institutions, stakeholder participation and adequate resources [11,15–18]. However, there has been little systematic guidance on how adaptation to climate change and ocean acidification should be incorporated into planning for an EAFM, despite the fact that climate impacts are a major driver for coastal ecosystems [19–21] and can have negative effects on the socio-economic benefits derived from fisheries [2,22–24].

This paper is structured as follows. First, the projected biological and socio-economic effects of climate change and ocean acidification on coastal fisheries in the Asia-Pacific region are summarized. Second an EAFM framework is outlined, before the reasons as to why it presents a good vehicle for assisting coastal fishing communities in adapting to climate change and ocean acidification are described. Additional activities are presented that could integrate considerations of climate change and ocean acidification into such an EAFM framework. Finally, national and regional activities required to provide a supportive environment to implement an EAFM in a climate-sensitive manner are outlined. This paper concludes that the need to address the projected effects of climate change and ocean acidification on coastal fisheries, and the expected availability of resources to assist developing countries in doing so, offer an opportunity to overcome some of the challenges that have so far impeded widespread implementation of an EAFM.

2. Projected effects of climate change and ocean acidification on coastal fisheries in the Asia-Pacific region

2.1. Projected changes to the ocean

The multi-model data from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) provide the most robust projections for the state of coastal and marine waters under various CO_2 emissions scenarios. These IPCC projections are based on atmosphere-ocean general circulation models (AOGCMs) [25,26], which are numerical representations of the physical climate system, and on Earth System Models (ESMs) that include biogeochemical cycling [27,28].

Over the next century, the Asia-Pacific region is likely to experience the following changes:

1. Warming and increases in precipitation, with projected increases in sea surface temperature (SST) ranging from 1.0 to 3.4 °C in Southeast Asia, and increased and more variable precipitation throughout the equatorial Pacific (Fig. 1) [28];

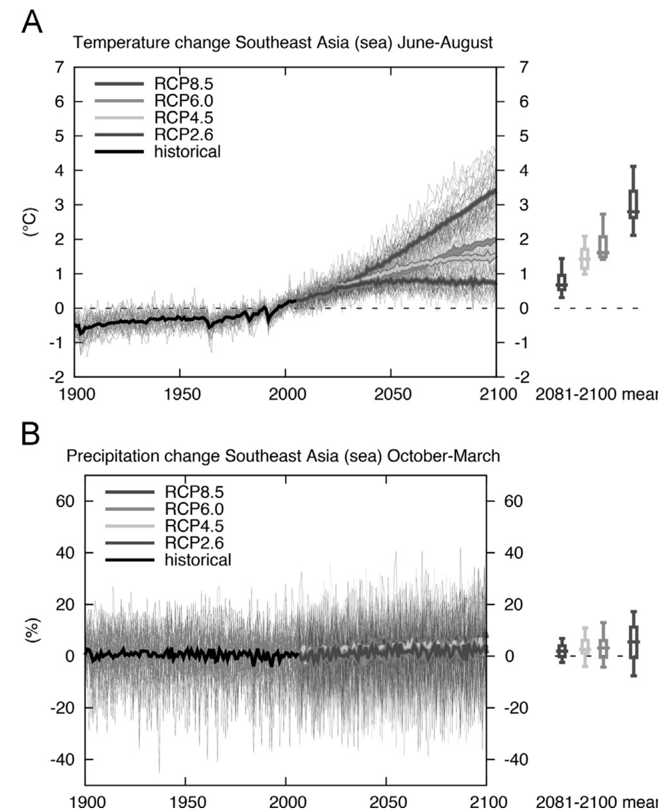

Fig. 1. A. Time series of temperature change relative to 1986–2005 averaged for sea grid points in Southeast Asia (10°S to 20°N, 95°E to 155°E) in June to August. B. Time series of precipitation change, relative to 1986–2005, averaged for sea grid points in Southeast Asia (10°S to 20°N, 95°E to 155°E) from October to March. Thin lines denote one ensemble member per model, thick lines the CMIP5 multi-model mean. On the right-hand side the 5th, 25th, 50th (median), 75th and 95th percentiles of the distribution of 20-year mean changes are given for 2081–2100 in the four RCP scenarios. Adapted from Figs. AI.65–66 (top right panels) (IPCC, 2013).

2. Slowdown in the trade winds and currents in the high-precipitation region north of Papua New Guinea (PNG) and an increase in winds over Indonesia [25,26].
3. Tropical cyclones of greater intensity, however, there is little consensus about where these more intense events will be located [28];
4. Mean rise in sea-level of 0.4 to 0.6 m, although even greater increases may occur according to some models [28].
5. Increases in ocean acidification of up to 0.3 pH units [28].

These projected changes are expected to (1) increase stratification of the water column in the western Pacific, reducing the amount of nutrient-rich water reaching the photic zone from the deeper ocean and decreasing primary production; (2) reduce stratification in the Indian Ocean west of Indonesia and increase primary production; and (3) decrease aragonite super-saturation by 50% across much of the Asia-Pacific region due to increased uptake of CO_2 at the ocean surface [25,26,29].

Strong year-to-year variability in precipitation and SST in the region associated with El Niño-Southern Oscillation (ENSO) is expected to continue. However, AR5 models differ concerning the amplitude and frequency of future ENSO events.

2.2. Projected impacts of changes to the ocean on coastal biota

The changes to the atmosphere and ocean are expected to have a variety of knock-on effects for coastal fish habitats and fish stocks (Fig. 2). Increases in SST of just a few degrees Celsius (°C)

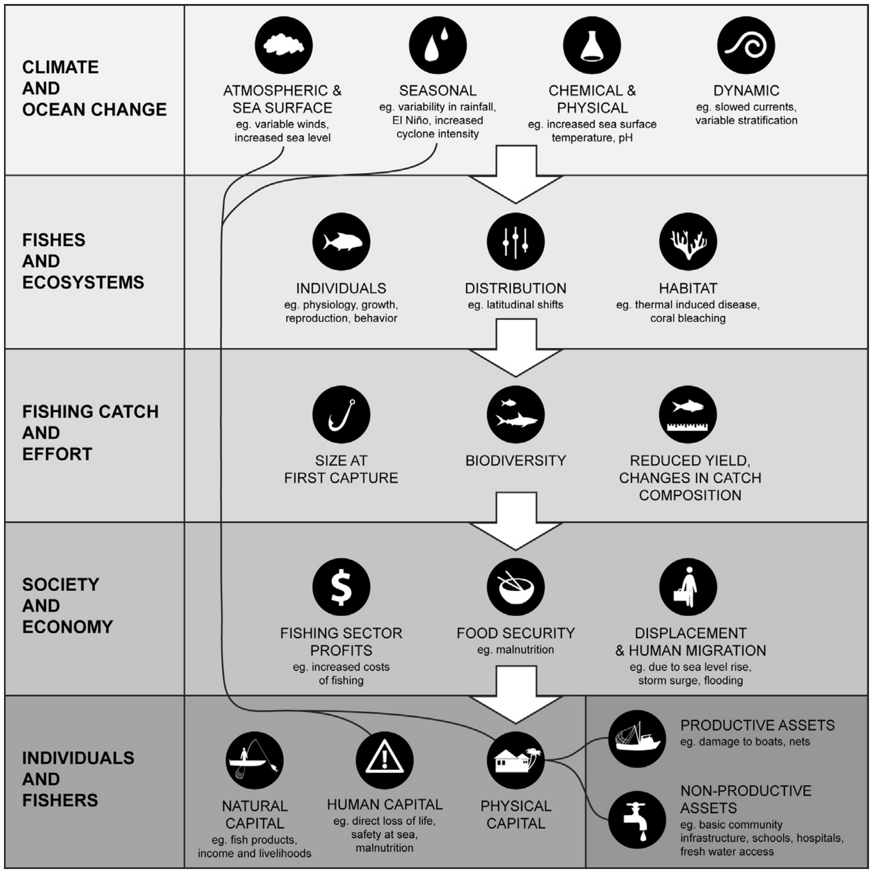

Fig. 2. Potential pathways for climate driven impacts on fisheries systems. Projected changes in climate and ocean properties (top tier) in response to increased CO_2 emissions will directly affect human and natural capital (bottom tier). Changes in these aspects of the ocean will affect fishes and their related ecosystems (second tier) which will amplify through the fishery system, affecting aspects of fishing catch and effort (third tier). This will in turn have national level societal and economic repercussions (forth tier), in addition to influencing the natural and physical capital of individuals and fishing related communities (bottom tier).

influence the physiological condition, developmental growth rate, reproductive performance and behaviour of fishes [30–32]. There is also significant variation in the sensitivity of species to elevated SST—the physiological performance of some species decreases dramatically with an increase in temperature of 2–3 °C, whereas other species appear much more tolerant [33,34]. However, because most fishes reproduce within a narrow temperature range, declines in reproductive output are likely to occur under warmer conditions [35–37].

As the more thermally sensitive species decline in abundance and shift their distributions towards higher latitudes, where temperature conditions are more favorable, the composition of reef fish communities is expected to change. In general, the effects of increasing water temperatures are expected to have a greater impact on equatorial and low latitude populations, which appear to be living close to their thermal maximum and have less capacity to cope with future temperature increases compared with populations from higher latitudes [38]. Although developmental and trans-generational acclimation to elevated temperatures has been demonstrated in one reef fish species [35,39], the capacity of entire existing fish assemblages to acclimate and adapt to higher SST is unknown [40].

Ocean acidification also significantly impacts the physiological processes of marine organisms, with the greatest effects occurring for invertebrates with calcified shells and skeletons [41]. Reduced calcification leading to slower shell growth, reduced shell strength and decreased development and survival of juveniles has been documented in a number of temperate bivalves, particularly sessile species [42–44]. Cephalopods, crustaceans and echinoderms appear to be less directly affected by ocean acidification [45]. The extent to which tropical invertebrate species will be affected by ocean acidification, or the combined effects of warming and acidification, is poorly understood.

Fishes are generally more tolerant to elevated levels of CO_2 than calcified invertebrates [21,46,47]. However, larval, juvenile and adult fishes exposed to elevated CO_2 have impaired sensory function and exhibit a range of behavioral changes affecting habitat selection, homing ability and predator avoidance [39,48,49]. The most notable of these effects is diminished predator avoidance, which is expected to lead to higher mortality rates of juveniles, with potential consequences for population replenishment [50,51].

Less understood is the how these individual responses of fish and invertebrates to climate and ocean change could amplify into impacts on fisheries yields. This is because of our limited ability to scale from the reported experimental effects through to population and ecosystem processes [52]. There is, however, more certainty about the indirect effects of climate change on fisheries due to the projected alteration of habitats [53,54] and reductions in primary productivity. Several studies indicate that degradation of coral reefs is likely to be the most significant and immediate effect of climate change and ocean acidification for coastal fisheries in the Asia-Pacific region [32,35,51]. This is because (1) coral reefs are highly susceptible to degradation from thermally-induced coral bleaching, physical damage from stronger storms and reduced calcification due to ocean acidification [20,30,32,53,55–57]; and (2) reduced coral cover and loss of reef structural complexity lead to significant declines in coral and non-coral dependent fish species [58–62]. Changes in primary production due to climate change [63,64] are expected to affect the food webs underpinning fisheries production [65].

Model simulations of the direct and indirect effects of climate change and ocean acidification indicate that future fisheries yields will be reduced [66–68]. Some of the main projections are that increased metabolic demand due to ocean warming is expected to reduce the maximum body size of fish [69], and that high rates of local extinction are likely to occur in low latitude regions by 2100 [70] due to warming, exacerbated by ocean acidification [71,72]. These projections are supported by the changes in catch composition of fish due to warming temperatures observed in Asia over the last 40 years [69].

Present-day ENSO events also indicate the types of effects that climate change is expected to have on tropical fisheries. A striking regional example comes from the mackerel purse-seine fishery in Taiwan. Following the 1997–1998 El Niño episode, reduced catch-per-unit effort resulted in a loss of USD 6.2 million across the fishery [73]. The bottom-up effects of the projected changes to the ocean are likely to interact with the top-down effects of fishing, increasing overall impacts on coastal fisheries production [66,74]. To manage fisheries on a sustainable basis, fish harvest strategies would need to be adapted in response to changes in productivity caused by ENSO and other climate forces.

2.3. Socio-economic impacts

The changes in fisheries production due to climate change and ocean acidification are expected to alter the socio-economic benefits derived from the fisheries sector (Fig. 2). The sustainable livelihoods approach, which considers assets in terms of natural, physical, human, financial and social capital, provides a useful way of examining how small-scale fishers, and coastal communities in general, are likely to be affected by the projected changes to fish stocks, and ecosystems [75,76].

Shifts in the distribution of fish and changes in fish abundance, will alter the natural capital of fishing communities [76]. Possible consequences include: (1) changes in net income of fishers due to the increased costs of traveling to more distant fishing grounds [76]; and (2) the need to alter harvesting strategies and invest in new gear types to capture species more tolerant to local, altered conditions.

Increased prevalence of diseases in response to ocean warming also poses a threat to fisheries production [77]. At present, the relative effects of warming and other environmental stresses, e.g., pollution, on the spread of diseases is poorly understood [78,79]. However, because pathogen development, disease transmission and host susceptibility increase with temperature [80], and the severity of disease outbreaks is greater in the tropics than at higher latitudes [81,82], warming is expected to result in greater disease impacts. The significant increase in the prevalence of coral disease as a result of higher SST associated with the 1997–1998 El Niño event [79] supports this contention. Marine pathogens are already a major obstacle to sustainable aquaculture, e.g., in Bangladesh shrimp farms [83], and increased disease risks are a concern to food production and livelihood strategies.

Sea-level rise and the attendant increased risks of storm surge and flooding threaten the physical capital (boats, fishing gear, wharfs, etc.) of fishing communities, and the supporting infrastructure that they rely on for their livelihoods (e.g. schools, hospitals, roads) [84,85]. Depending on the gradient of coastal land, sea-level rise also threatens to displace people living in low-lying coastal regions [86], resulting in increased settlement in inland areas and strain on the physical capital of other sectors [76,87].

In general, human capital is relatively vulnerable to the projected effects of climate change due to the exposure of coastal fishing communities to natural and health-related disasters [88,89]. Climate change is projected to render these communities more vulnerable. The risks to human capital from tropical cyclones—loss of life from reduced safety at sea, flooding and the spread of water-borne disease—are well known [84,90]. Global warming is expected to place human capital at increased risk because many climate models indicate that cyclones will become more intense [28]. ENSO events are known to increase the incidence of malaria and cholera epidemics [91], and any future changes in the frequency and amplitude of ENSO events, and increases in rainfall, are expected to increase the health burden on coastal communities [92].

Malnutrition caused by reduced fisheries production is also expected to affect the productivity of human populations. Coastal communities in many countries in the Asia-Pacific region depend on fish for 50–90% of dietary animal protein [4] and, although human population growth is expected to have the greatest effect on availability of fish per capita, climate change is projected to reduce fish availability further [23].

In brief, both ecological and human systems are vulnerable to the changing climate [24,93–95]. The risks posed by climate change and ocean acidification need to be addressed concurrently with efforts to address the other threats influencing tropical fisheries— overfishing, habitat degradation, pollution, eutrophication and invasive species. There is an urgent need for 'no regrets' and 'win-win' management strategies that can deal with the existing stresses and reduce the impacts of longer-term climate impacts [24,93]. The challenges involved are particularly demanding in the Asia-Pacific Pacific, where coastal fisheries are characterized by a lack of data, limited human capacity in fisheries management, and weak governance [96,97].

3. EAFM, climate change and ocean acidification

An EAFM is the application of ecosystem-based management to the fisheries sector. That is, an EAFM is an extension of the conventional principles for sustainable development in general, and sustainable fisheries development in particular, to cover the ecosystem as a whole. An EAFM aims to ensure that the capacity of ecosystems to produce fish and shellfish for food, employment and livelihoods, and to provide other essential services, is maintained for the benefit of the present and future generations in the face of variability, uncertainty and natural changes to coastal environments [12]. The key features of an EAFM include: consideration of the ecological, social, and governance processes over broad spatial and temporal scales; a focus on resilience; adaptive management, co-management, institutional cooperation and coordination, and a precautionary approach. Because the risks of climate change and ocean acidification are just part of a wider set of drivers affecting fisheries systems [98], the features of an EAFM listed above, and those given in Table 1, lend themselves to managing coastal fisheries under the uncertainty associated with these additional impacts.

Indeed, many features of an EAFM predispose the framework to be an effective adaptation to climate change. The need to manage fisheries over large spatial scales under an EAFM, and to include life history stages associated with different habitats within the distributions of self-replenishing populations, enables changes in the distributions of target species due to climate change to be detected. Similar to other management efforts centered on the principles of sustainable development, building resilience is integral to an EAFM. Resilience is the capacity of elements of integrated socio-ecological systems to withstand disturbance and adapt to change while maintaining their core attributes [100]. Building resilience aims to develop capacity and is a buffer to deal with future stresses and shocks to the systems [10]. Resilience applies to fish populations and habitats, ecosystems, people's livelihoods within fishing communities, economic structures, and policy and management institutions [101–103]. The focus of an

Table 1
A selection of the principles of the 'ecosystem approach' [99] relevant to climate impacts, the corresponding principles of an 'ecosystem approach to fisheries' (EAF) [12] and their practical implications on fisheries management.

CBD EA principles	FAO EAF principles	Practical implications to fisheries management
Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems *Principle 7:* The ecosystem approach should be undertaken at the appropriate spatial and temporal scales	Management measures should be compatible across the entire distribution of the resource	Fisheries management goals need to be holistic and long term, and management objectives compatible across ecological, social and governance domains
Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach	Ecological relationships between species should be maintained Fisheries should be managed to limit their impact on the ecosystem to an acceptable level	Ecological resilience is recognized as integral to sustainability, is achieved through institutional and social resilience and the trade-offs between ecological and social resilience are made in a transparent manner.
Principle 9: Management must recognize that change is inevitable	Precaution in decision-making and action is needed because the knowledge on ecosystems is incomplete	The planning process is based on adaptive management and the precautionary approach is applied to decision-making
Principle 12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines	Governance should ensure both human and ecosystem well-being and equitability	Decision-making is participatory, this requires good governance, co-operation and coordination across institutions and co-management

EAFM on resilience assists communities to cope with the alterations in species composition of catches and with changes to fishing methods and costs through, for example, livelihood diversification, adopting alternative fishing strategies and occupational pluralism [18,75]. In an integrated management framework, like EAFM, resilience has limitations when specified as a fishery management objective in itself because it is not a value-neutral term. Resilience-orientated management actions will raise practical questions, namely resilience to what and for whose benefit [104]. Maintaining or increasing resilience will require cross-system dynamics and trade-offs to be made explicit, for example, the long-term gains of marine protected areas versus the immediate impacts on food and livelihood security [105]. As a participatory process, in which conflict management mechanisms are employed, an EAFM provides a process in which climate resilience can be considered in a transparent manner.

The precautionary approach embodied within an EAFM reduces local stressors on coral reefs and other coastal habitats, enabling these ecosystems to retain more of their natural capacity to adapt to changing environmental conditions. It also ensures that excessive harvests are not made in the face of the considerable uncertainty associated with environmental variation and recruitment success. An EAFM sets the stage for the greater levels of caution needed to allow for increased uncertainty associated with: (1) future CO_2 emission scenarios; (2) our ability to forecast the effects of climate change and ocean acidification on coastal fisheries due to biases remaining in global circulation models; and (3) the responses of ecosystems and societies to future conditions [106].

The co-management component of an EAFM shares the burden of responding to climate change and ocean acidification by facilitating information exchange between stakeholders to empower decision-making [107]. Such institutional cooperation and coordination help develop the coherent and complementary policy arrangements needed to reconcile adaptations to address the effects of climate change and ocean acidification on food security and marine biodiversity [108]. Adaptive management helps mitigate uncertainty [109,110] through 'learning by doing' [111,112], something that is facilitated by assisting communities to share management experiences, e.g., through locally managed marine area networks [113].

In summary, an EAFM is appropriate for dealing with the uncertainty of climate and ocean change because the risk assessment approach can be extended to qualitatively and transparently evaluate how best to prioritize and address the associated issues and threats.

4. EAFM planning framework and climate change

The various models of the EAFM planning process (e.g., [16–18,114], are based on the same management strategy framework contained in the International Standards Organization (ISO) standards for environmental management [115] and are therefore broadly similar. The underlying framework for this system is based on management strategy evaluation, and in an EAFM this is merged with structured decision-making that is participatory throughout.

Adjustments are needed to all five steps of the EAFM planning process (Fig. 3) to enable communities to maximize the benefits of the EAFM framework for adapting to climate change and ocean acidification. Below, important pre-requisites, or 'start-up' activities are listed, for the EAFM planning framework and for adjusting the framework to integrate responses to climate change. Each of the five steps of the EAFM planning process is then briefly described along with the modifications needed to each step.

Two working assumptions are applied to this section of the paper. Firstly, it is assumed that an EAFM promoting organization, such as the government institution or community-based organization mandated to administer and manage the fisheries in question, has identified the EAFM team that is responsible for implementing the EAFM process. Secondly, it is assumed that stakeholder involvement will be active throughout the EAFM planning and implementation process and that communication of information between the implementing EAFM team and stakeholders will be two-way [116]. It is noted, however, that the level of stakeholder participation that is appropriate for any particular EAFM plan will largely depend on the existing governance arrangements.

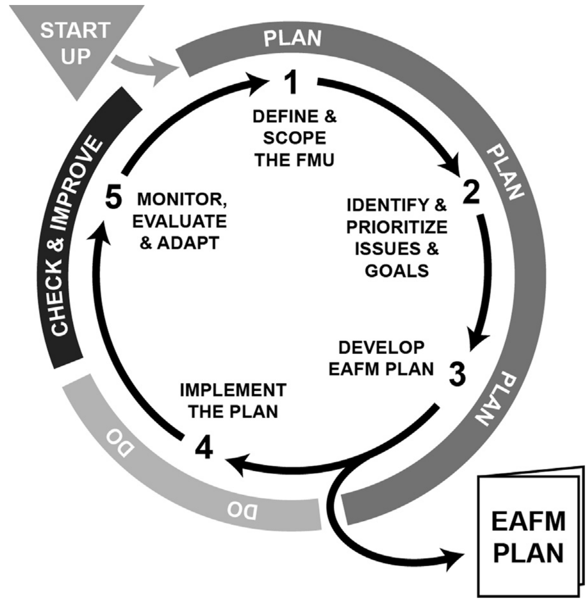

Fig. 3. The EAFM planning framework.

The promoting organization will initiate the start-up activities to ensure that the pre-requisites for an EAFM are properly addressed, including: engagement of all relevant stakeholders; establishing the customary and legal basis for implementing an EAFM through co-management; selecting team leaders and members; and agreeing on the decision-making processes [117–121]. To help ensure that an EAFM assists communities in adapting to climate and ocean changes effectively, two of these pre-requisites need special attention. It is essential for the EAFM promoting organization to evaluate the ability of the EAFM team to convey the complexity of climate change and ocean acidification impacts to stakeholders and incorporate them into the EAFM planning process. If the EAFM team does not have adequate knowledge of the effects of increased CO_2 emissions on fish habitats and fish stocks, expert partners will be required to communicate existing and future climate impact risks.

Care should also be taken to consider which stakeholders are most likely to be affected by the implications of climate change and ocean acidification. Engagement of stakeholders should be as inclusive as possible, but guided by the expected degree of participation through co-management [122]. Coordination across government agencies to avoid maladaptations is particularly important, i.e., situations where actions by one sector to cope with climate change have adverse effects on another sector, or where short-term solutions increase vulnerability in the longer term [123]. A particularly relevant example of maladaptation is protecting coastal infrastructure from rising sea levels in ways that that prevent landward migration of mangroves [54].

Care is also needed to avoid maladaptation within the coastal fisheries sector. Developing eco-tourism based on diving on coral reefs may, in some instances, be a maladaptive in locations where reefs are highly vulnerable to damage from increased run-off from higher rainfall, more frequent bleaching caused by increases in SST, and decreased reef accretion and increased bio-erosion due to ocean acidification. Such investments are unlikely to provide ongoing long-term benefits to communities.

4.1. Step 1: define and scope the fisheries management unit

Establishing clear geographic boundaries for the area to be managed [117,124], commonly referred to as the Fisheries Management Unit (FMU), is essential for effective co-management within an EAFM. The FMU should balance ecological relevance with the feasibility of governance [97,125,126]. The surrounding 'large marine ecosystem' may be the appropriate FMU in some cases, provided sufficient external funding is available for the necessary intergovernmental collaboration [97]. More commonly, the FMU will be a jurisdiction or group of jurisdictions at a smaller scale. For instance, the management boundaries may mirror existing jurisdictional units, however, in such situations, it will be important to identify the external factors influencing the FMU.

Regardless of the geographic size of the FMU, the EAFM team should examine whether the impacts of climate change and ocean acidification are likely to involve alterations to the distribution and abundance of fish species, and to human-use patterns of these natural resources, at a scale larger than the FMU. If so, expansion of the boundaries of the FMU should be considered to address the projected climate-induced impacts more effectively. Where this is not feasible, cross-boundary collaboration and coordination with other communities harvesting the shared stocks will be required.

Stakeholders should also be requested to assist in developing a joint vision for the desired future state of the FMU [127], based on the status of habitats and stocks, patterns of resource use, and the relevant regulations and management institutions [18,114,128]. Creating this vision allows communities to ask the important question 'How could climate and ocean changes affect our plans to optimize the socio-economic benefits from our fisheries resources?' Communities can then be assisted to identify the priority adaptations by evaluating the strengths, weaknesses, overlap, and duplication in policy and management actions using a gap analysis [129,130]. This process promotes learning about the trade-offs likely to be needed within the socio-ecological system, builds trust among stakeholders [131,132], and should help streamline existing management actions and develop adaptations to climate change and ocean acidification for local coastal fisheries.

4.2. Step 2: identify and prioritize issues and goals

During this step, stakeholders undertake an initial evaluation of the threats and issues associated with the fisheries and their supporting ecosystems within the FMU. The precautionary approach guides decision-making by dealing with uncertainty by assessing and then managing risk [133,134].

External and internal 'drivers' influencing the FMU are identified using participatory rural appraisal techniques [135,136], including component tree approaches, causal chain analysis, risk mapping, and transect walks [114,137,138].

Risk assessment is used to prioritize the management of the various drivers. For highest prioritized issues, goals are defined [114], usually expressed as formal statements of the long-term outcomes that management is trying to achieve in addressing these issues [139]. This participatory and inclusive approach to the planning process helps ensure that management decisions are relevant and owned by those carrying and managing the risks [98,140].

Little adjustment is involved in adding the risk of climate change and ocean acidification impacts to this step. However, evaluation of these risks will be improved greatly by the use of vulnerability assessments. Vulnerability assessments integrate exposure of the resources and communities within the FMU to projected changes, the sensitivity of the FMU to the exposure, and the capacity of the FMU to adapt to the impacts [141]. For many countries in the Asia-Pacific region, assessments of the vulnerability of coastal fisheries to climate change are available at the national level [24,142]. Such national vulnerability assessments can be localized, or local assessments can be performed using established guidelines [143].

Vulnerability assessments allow stakeholders to learn about local and regional impacts of global increases in atmospheric CO_2, uncertainty, and strategies to deal with climate change and ocean acidification. Climate change vulnerability assessments can also lead to a more transparent process for evaluating the trade-offs between short-term priorities and longer-term adaptation plans [144].

A practical way of raising the awareness of coastal communities about the effects of climate change on their fisheries resources is to assist them in writing a 'local climate story' about how past climatic events have affected fish habitats, fish stocks, and catches. Such exercises provide valuable insights into the likely risks associated with future climate change [132,136]. A participatory climate adaptation planning exercise involving two communities in the Solomon Islands provides a pertinent example. The exercise revealed how: (1) increased wave exposure during the cyclone season caused variation in target species; (2) cyclones and short-term sea-level rise damaged coastal infrastructure; and (3) fishers switched to other ways of earning income when target invertebrate populations decreased during heat waves [145].

4.3. Step 3: develop the EAFM plan

Four key actions are needed to develop and evaluate an EAFM plan. The first involves setting clear management objectives for achieving agreed goals [109]. The second is based on developing appropriate targets for demonstrating that the goals have been achieved, and specifying the indicators to be used to evaluate the extent to which the targets relating to sustainability, biodiversity, habitat and socio-economic conditions have been met [146]. The third is aimed at identifying the most practical measures for achieving the management objectives, and the fourth monitors the management system to assess performance so that management measures can be adapted if needed [115]. Stakeholder input during the selection of indicators, and more widely through participatory monitoring and evaluation of performance, will ensure that the EAFM plan is grounded in reality, and result in broad ownership [147].

In situations where communities have already developed an EAFM plan but have not included goals or objectives relating to addressing the impacts of climate change and ocean acidification, it will be important to determine whether these external drivers are likely to prevent the objectives of the EAFM plan from being realized. The time required to make this assessment is not expected to cause any real problems because EAFM is an iterative process and by its very nature builds resilience to a variety of drivers, including those related to climate and ocean change, by helping to safeguard the natural adaptive capacity of coastal habitats and fisheries resources.

4.4. Steps 4 and 5: implementation, monitoring, evaluation and adaptation of the plan

Evaluating and documenting whether the plan is being implemented effectively and whether the objectives are being met is the crux of evaluating the success of an EAFM plan and adapting future management strategies and actions to address outstanding issues [148]. Clear communication about performance of the plan to all stakeholders is essential—miscommunication undermines the confidence of stakeholders in the EAFM team and damages their credibility. Social marketing can also be used to bring about the behavioral changes needed to effectively implement an EAFM plan.

The uncertainty associated with climate change and ocean acidification places added emphasis on the need for stakeholders to be prepared to adapt the EAFM plan by applying more precautionary approaches. In the data-poor situations typical of many coral reef fisheries in the Asia-Pacific region, this will involve an even more conservative application of 'primary' fisheries management [149]. Primary fisheries management recognizes the need to use simple harvest controls, such as size limits, closed seasons and areas, gear restrictions and protection of spawning aggregations. Such management measures are needed for most coral reef fisheries due to the large numbers of species involved, and the relatively low values of any given species. Secondary and tertiary fisheries management may be needed in some situations but require greater investments (e.g., stock or ecosystem assessments) to reduce uncertainty about the economic benefits that can be gained from more accurate and precise estimates of sustainable harvests.

More flexible approaches to adaptation will also be needed to handle the conflicts that are common between fishers using different gear types, or between those fishing for the same species at different stages of its life cycle. Climate change and other drivers, e.g., population growth, are likely to exacerbate such conflicts. In particular, areas that are more resilient to climate and ocean change impacts may experience an influx of people from less resilient or more heavily impacted regions.

5. Discussion

Fisheries in the Asia-Pacific region are considered to be highly sensitive to increased CO_2 emissions, and have only low to moderate adaptive capacity [2]. An EAFM provides a process to reduce the vulnerability of people in the fisheries sector to climate change and ocean acidification. In particular, the EAFM planning process can be considered to be both a 'no-regrets' and 'soft' climate adaptation strategy *sensu* [150], that will yield the wider benefit of improved fisheries management and institutionalize longer planning horizons even in the absence of climate impacts.

The participatory framework outlined here is flexible and designed to be implemented within the prevailing governance context. It also has potential to trigger fundamental change incrementally [151], provided there is an enabling environment. However, the following national and regional activities are required to implement an EAFM in a climate-sensitive manner.

5.1. Facilitating a better understanding of climate change and ocean acidification amongst planners

Availability of technical support and skilled facilitators will help communities to apply information from regional and national climate change vulnerability assessments to better forecast impacts on local fisheries resources. The understanding of key issues by local decision-makers at all levels can be enhanced through the use of regional learning networks, e.g. the Asia Pacific Adaptation Network 〈http://www.apan-gan.net/〉, and by information available from the Association of Southeast Asian Nations (ASEAN) and the United Nations Food and Agriculture Organization (FAO) [152–155]. Learning networks can also be used to identify and build links across complementary and overlapping agendas of regional initiatives (e.g. the Pacific Islands Framework for Action on Climate Change, Asian Development Bank knowledge management theme for fisheries and economic analysis, and the Secretariat for the Pacific Community's research on food security).

Agencies promoting the use of EAFM for adapting to the effects of climate change on coastal fisheries will also benefit from a fuller understanding of the end-to-end 'climate-to-fish-to-fisheries' processes that affect fisheries production and the associated socio-economic benefits [23]. Knowledge from institutions engaged in assessing the projected changes to the atmosphere (e.g., World Meteorological Organisation) and ocean (e.g., NOAA), is crucial to projecting the consequences of climate change and ocean acidification for coastal fish habitats and fisheries production [94]. Promoting such collaborations will equip planners with a sound understanding of how to manage to minimize the threats and capitalize on the opportunities.

5.2. Promote trans-disciplinary collaboration

Institutional inertia often presents a significant barrier to cooperation across sectors, and can lead to maladaptation. This can be addressed by establishing and incentivizing national and local committees tasked with facilitating inter-ministerial coordination and cooperation. As an example for addressing the mismatch between jurisdictional boundaries and the distribution of target fish stocks in decentralized management scenarios, new legislation in the Philippines has enabled more flexible local fisheries management responses to climate change by establishing an Integrated Fisheries Management Unit (IFMU) scheme. Clusters of municipalities were joined together, coordinated at the provincial level, and provided with technical support. The approach used in the Philippines provides a model for scaling-up the coordination and management of shared resources across jurisdictional boundaries to ecological scales. Such collaboration has been difficult to achieve in the past but the common challenge of addressing climate change and ocean acidification will hopefully act as a catalyst for effective trans-boundary management of fisheries across political jurisdictions.

5.3. Facilitate stakeholder participation and empowerment in decision-making through outreach for increased awareness

There is a risk that addressing climate and ocean change will be perceived entirely as the responsibility of higher levels of government [156]. Nationally coordinated education and outreach programmes will help to reverse such misconceptions and empower local communities to identify and implement effective adaptations. The education of the next generation of decision-makers is likely to be best achieved by including climate change and ocean acidification in national curricula. Innovative communication methods, such as community radio and simple interactive games, can be used to raise awareness of older members of communities. ReefGame, a board game coupled with a computer simulation model, has been used in the Philippines to stimulate discussion by connecting current management decisions to future habitat status and associated fish landings [157]. Use of information hubs can give stakeholders without computer skills access to this growing pool of transformative technology [158].

5.4. Support monitoring of the wider fisheries system for climate impacts

Considerable effort is needed to separate the effects of climate change and ocean acidification on fish habitats and fish stocks from effects due to local stressors. Building the necessary capacity in the well-designed monitoring programmes needed to distinguish the effects of natural fluctuations in coastal fisheries systems from climate and ocean changes will be facilitated by monitoring networks and regional cooperative programs [159]. Standardized climate impact indicators and trans-boundary data management infrastructure will be required [160,161]. Timely reporting of climate impacts and projections in user-friendly ways, e.g. the Australia Marine Climate Change Impacts and Report Card System 〈http://www.oceanclimatechange.org.au/〉, will also be useful to ensure that climate and ocean change impacts are integrated into fisheries management decisions.

5.5. Enhance resources and capacity to implement EAFM

An EAFM offers long-term opportunities to unlock financial resources through more efficient and integrated planning but in the short-term the application of this approach and the consideration of climate change may increase the costs of management and the resources required by implementing agencies. It will be important to establish which national and regional financial and infrastructure resources are available to support provincial, district, and community-based activities. To ensure that EAFM initiatives receive the best scientific advice, efforts should be made to enlist the services of experts by forming regional scientific advisory groups, e.g., the advisory committee that guided the assessment of the vulnerability of tropical Pacific fisheries and aquaculture to climate change [24].

6. Conclusions

An EAFM provides a practical framework for the management of fisheries worldwide, but promises to be particularly potent for data-poor coastal fisheries in developing countries. By definition, an EAFM embraces and integrates all drivers affecting coastal fisheries production. Significant changes have already occurred to the physical and chemical attributes of coastal waters, with direct and indirect knock-on effects on fish habitats and stocks. Such changes are projected to accelerate and eventually dominate impacts on coastal fisheries production from local stressors. Integrated coastal zone management, which is a central tenant of an EAFM for coastal fisheries and one of the most effective adaptations to climate change [23], has been promoted for years but lacked adequate financial support. By using some of the considerable funding expected to be available to developing countries in the Asia-Pacific region for adaptation to climate change, and through the Global Environment Facility to implement an EAFM, countries will not only build resilience to a range of CO_2 emissions scenarios, they will also address the range of local impacts affecting coastal fisheries production.

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