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# Adaptations to maintain the contributions of small-scale fisheries to food security in the Pacific Islands

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## ABSTRACT

In several Pacific Island countries and territories (PICTs), rapid population growth and inadequate management of coastal fish habitats and stocks is causing a gap to emerge between the amount of fish recommended for good nutrition and sustainable harvests from coastal fisheries. The effects of ocean warming and acidification on coral reefs, and the effects of climate change on mangrove and seagrass habitats, are expected to widen this gap. To optimise the contributions of small-scale fisheries to food security in PICTs, adaptations are needed to minimise and fill the gap. Key measures to minimise the gap include community-based approaches to: manage catchment vegetation to reduce sedimentation; maintain the structural complexity of fish habitats; allow landward migration of mangroves as sea level rises; sustain recruitment and production of demersal fish by managing 'source' populations; and diversify fishing methods to increase catches of species favoured by climate change. The main adaptions to help fill the gap in fish supply include: transferring some fishing effort from coral reefs to tuna and other large pelagic fish by scaling-up the use of nearshore fish aggregating devices; developing fisheries for small pelagic species; and extending the shelf life of catches by improving post-harvest methods. Modelling the effects of climate change on the distribution of yellowfin tuna, skipjack tuna, wahoo and mahi mahi, indicates that these species are likely to remain abundant enough to implement these adaptations in most PICTs until 2050. We conclude by outlining the policies needed to support the recommended adaptations.

## 1. Introduction

Fish[1] is widely recognized as a cornerstone of food security in the Pacific Island region [10,42,43,99], where it provides 50–90% of animal protein for coastal communities in many Pacific Island countries and territories (PICTs). Most of this fish has traditionally come from small-scale coastal fisheries, which have contributed to food security both directly through subsistence fishing and indirectly through incomes earned from artisanal fishing. These activities include bottom fishing (hook and line) in lagoons and reef slopes; spearfishing on reef flats and shallow coral habitats (including at night with torches); gillnetting in intertidal and shallow subtidal habitats; trolling and drop-line fishing for tuna and other large pelagic fish in nearshore waters; and gleaning on intertidal and shallow subtidal reefs and sand flats, as well as in mangrove and seagrass habitats [31,84]. The collection of sea cucumbers has also contributed significantly to the income of communities across the region [87]. However, poor management and limited monitoring of sea cucumber fisheries has led to overharvesting, with concomitant severe declines in stocks [78,86,88]. The aquarium trade also provides livelihoods in a number of PICTs

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[1] Fish is used here in the broad sense to include finfish and invertebrates.

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(e.g., Fiji, French Polynesia, Kiribati, Marshall Islands, Solomon Islands and Vanuatu). In this trade, small, colourful, fish species are typically supplied by artisanal fishers, whereas giant clams and corals are usually produced by small-scale aquaculture operations [100,105,106,107].

Most of these small-scale activities have focused on demersal fish and invertebrates associated with coral reef ecosystems, and to a lesser extent on those associated with mangrove, seagrass and intertidal flat habitats [84]. More recently, there has been increased diversification of small-scale fisheries into targeting large pelagic fish, including tuna, in nearshore waters of several PICTs across Melanesia, Micronesia and Polynesia (Fig. 1). Despite this diversification, a gap is emerging in several PICTs between the amount of fish recommended for good nutrition – 35 kg per person per year [99] – and coastal fish catches [10,11]. This gap is being driven largely by rapid population growth, which is expected to double for the region as a whole by 2050,[2] and also by reductions in fisheries production due to over-exploitation and/or degradation of coastal ecosystems at some locations [84].

An assessment of the vulnerability of tropical Pacific fisheries and aquaculture to climate change co-ordinated by the Pacific Community [8,13] has demonstrated that shortfalls in coastal fisheries production are likely to be exacerbated further by continued greenhouse gas (GHG) emissions. In particular, the productivity of coral reef fisheries is expected to decrease by 20% by 2050 under a 'business as usual' (high) GHG emissions scenario, due to the effects of ocean warming and acidification on the biological and physical structure of coral reefs [54,84], and the distribution, fitness, availability and catchability of demersal fish [85]. In addition, the areas of mangroves in PICTs are expected to decrease by 50–70% by 2050 under a high GHG emissions scenario, due mainly to sea-level rise and more intense storms. Increased runoff from higher rainfall, more intense storms, and increasing sea surface temperatures associated with global warming are also likely to reduce the areas of seagrass habitats in PICTs by 5–35% by 2050 [111].

Here, we describe practical adaptations that should assist small-scale coastal fishers to help supply the fish needed for good nutrition of Pacific Island populations in the face of rapid population growth and the effects of climate change on coastal fish stocks and habitats. These adaptations were selected using a framework that addresses the main short-term drivers of fish availability (population growth, fishing pressure and habitat degradation) and longer-term climate change. They were also selected to: 1) minimise the gap by supporting the sustained production of fish from coral reefs, mangroves and seagrasses; and 2) fill the gap, mainly by making it easier for small-scale fishers to access the region's rich tuna and other nearshore pelagic fish resources. We conclude by describing the policies needed to support the implementation of these adaptations.

We do not discuss the complementary adaptations to climate change and supporting policies recommended for industrial tuna fisheries, aquaculture or freshwater fisheries to maintain or increase the contributions of these operations to local food security because they have been documented elsewhere [12,14,41,58,60,79].

## 2. Adaptation framework

We used the framework shown in Fig. 2 to identify two types of practical, planned adaptations.

1. 'Win-win' adaptations, where investments help address, for example, the effects of rapid population growth on the availability of fish

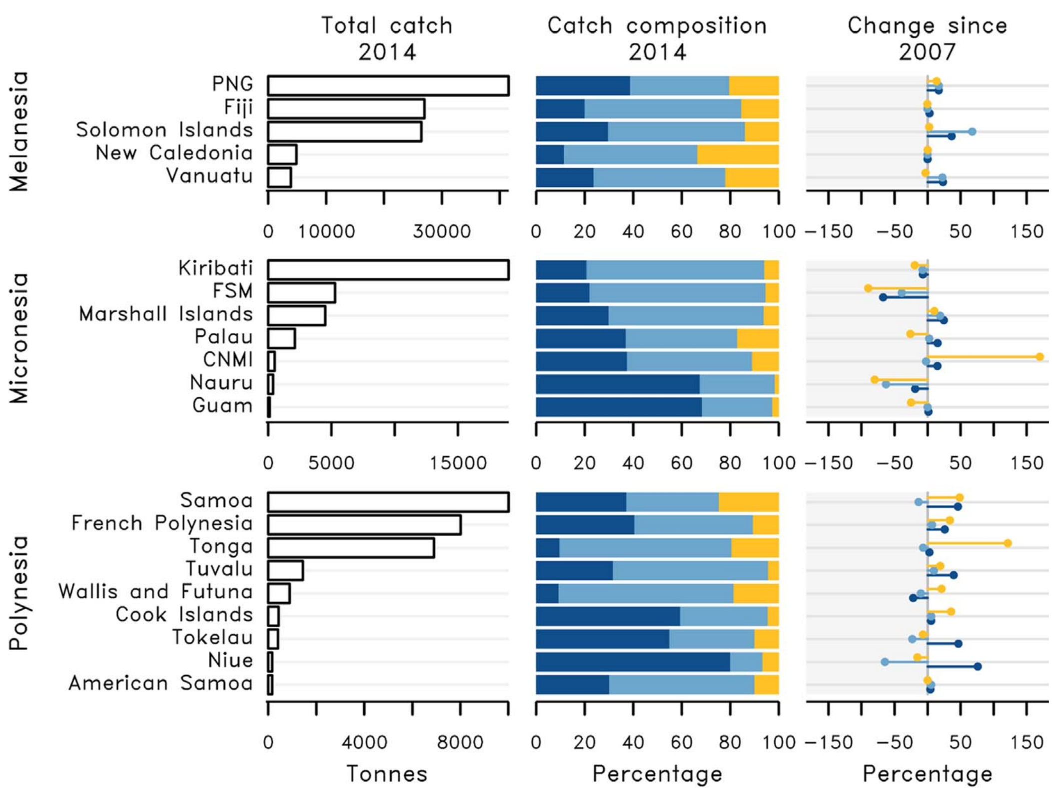


**Fig. 1.** Total coastal fisheries catch (tonnes) for Pacific Island countries and territories (PICTs) in 2014 (left), together with the estimated percentage of demersal fish (■), nearshore pelagic fish (■) and all invertebrates (■) comprising the total catch in 2014 (centre) and the percentage change in each catch component since 2007 (right). Based on information in Gillett (2009) [42], Gillett (2016) [43], Pratchett et al. (2011) [84] and the Supplementary Material. Note differences in scale for total catch between PICTs in Melanesia, Micronesia and Polynesia. See Supplementary Tables 1 and 2 for details of estimated catches in each PICT in 2007 and 2014, respectively. PNG = Papua New Guinea; FSM = Federated States of Micronesia; CNMI = Commonwealth of the Northern Mariana Islands.

[2] http://prism.spc.int/regional-data-and-tools/population-statistics

in the near term, and the effects of climate change in the longer term. 'Win-win' adaptations are not to be understood as having no costs, particularly social and economic costs. However, they should deliver immediate gains (a 'win' now) and help insulate resources/communities from the effects of continued GHG emissions (a 'win' in the future).

2. 'Lose-win' adaptations, where the economic and social costs exceed the benefits in the near term, but where investments should build the resilience of PICTs to climate change in the longer term.

In general, some lose-win adaptations are needed to help ensure that the gap in fish supply is not unduly exacerbated by climate change, whereas win-win adaptations help to fill the gap. Lose-win adaptations involve foregoing some fish harvest, or alternative uses of coastal habitats, in the short term to enable these natural resources to take full advantage of their natural (autonomous) capacity to adapt to higher sea surface temperatures, ocean acidification and other stresses caused by increased GHG emissions.

The recommended investments in win-win and lose-win adaptations are not based simply on the availability of technology and projected future responses of the resources underpinning coastal fisheries production. Potential social and financial barriers to the uptake of adaptations, e.g., cultural norms and gender issues that could limit broad-based community participation, have also been considered. We specifically excluded 'win-lose' investments (such as support to increase coastal, demersal fishing effort or capacity through construction of larger vessels or more effective gear types) because they represent maladaptation to climate change for small-scale coastal fisheries.

Ultimately, the economic benefits and costs from the recommended adaptations should be fully considered using, for example, formal cost: benefit analysis to compare the proposed investment to a range of alternatives based on the best available information and economic modelling. In addition to analysis of the economic costs and benefits of recommended adaptations, social and cultural aspects should also be considered, including the distribution of the expected benefits from the investment.

## 3. Adaptations to minimise the gap

The key adaptations for sustaining the production of demersal fish and invertebrates associated with coral reefs, mangroves and seagrasses, in the face of the changing climate [39,59,68] and the impacts

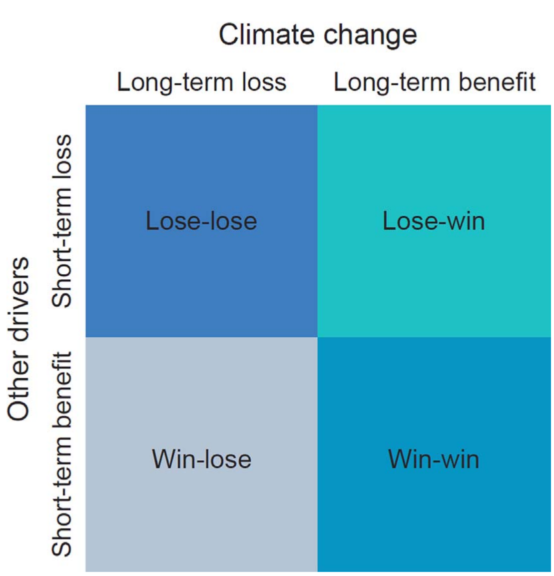


**Fig. 2.** Decision framework to identify adaptations to address the effects of climate change in the long term and other drivers, like population growth, in the near term. Source: Grafton (2010) [47] and Bell et al. (2011) [8].

of increasing human coastal populations [92], will depend on minimising degradation of coastal fish habitats (and reversing degradation where practical), and monitoring and managing harvest levels. Many of these interventions are not new – they have been proposed for many years as an integral part of effective coastal zone management [3,32,44]. Climate-informed, ecosystem-based approaches to fisheries management, which integrate community awareness of the effects of the changing climate on coastal fish stocks and habitats with customary marine tenure and other social capital, local governance, traditional knowledge, self-interest and self-enforcement capacity, provide the most effective way forward [52]. Several practical adaptations for the coastal fisheries sector have already been described in detail in the regional vulnerability assessment [8]. These adaptations are summarised below, and augmented with other interventions that we also consider to be important.

### 3.1. *Manage and restore vegetation in catchments (win-win)*

Sustaining coastal fish production around islands depends on good land-management practices to maintain the quality of coastal waters and habitats [34,38,63,113]. A good coverage of vegetation on slopes and wide riparian buffer zones are needed to reduce the transfer of sediments and nutrients to coastal habitats after heavy rainfall [40,113]. Low vegetation cover due to deforestation and poor farming and land-use practices results in accelerated runoff and erosion, which directly damages coral reef, mangrove and seagrass habitats through increased turbidity, sedimentation and nutrient loads [5,54,70,104,111] (Fig. 3). Maintaining and restoring catchment vegetation is not only required to protect these important fish habitats in the near term, it should also help reduce future damage from the effects of projected increases in extreme rainfall events [68].

### 3.2. *Minimise other degradation of coastal habitats (win-win)*

The key measures needed to safeguard coastal habitats from other present-day stresses are: 1) maintaining water quality by controlling pollution from sewage, chemicals (including fertiliser and pesticides) and waste; 2) eliminating activities that damage the three-dimensional structure of coral habitats, such as destructive fishing practices, extraction of coral for building materials, careless anchoring of boats and poorly-designed coastal infrastructure and tourist facilities; and 3) prohibiting activities that threaten the health and extent of mangrove and seagrass habitats (e.g., timber harvesting, damaging fishing practices, dredging). These measures should help maintain coastal fish habitats in the near term. They are also expected to help make coral reefs, mangroves and seagrasses more resilient to the various stressors associated with climate change in the future [54,111].

### 3.3. *Provide for landward migration of mangrove habitats (lose-win)*

Allowing the inundation of low-lying land adjacent to mangrove forests will provide opportunities for these fish habitats and their associated biota to migrate landward [111]. Where existing road infrastructure blocks the inundation of low-lying land suitable for colonisation by mangroves, channels and bridges should be constructed to allow for inundation (Supplementary Fig. 1). Planting young trees in such places can also help fast-track establishment of new mangrove habitat if necessary. The near-term costs of this adaptation – loss of some uses of undeveloped, low-lying land and expenses associated with raising and planting seedlings – are expected to be balanced by the benefits of maintaining fish habitats in the longer term and the protection that mangroves provide to coastal areas [21].

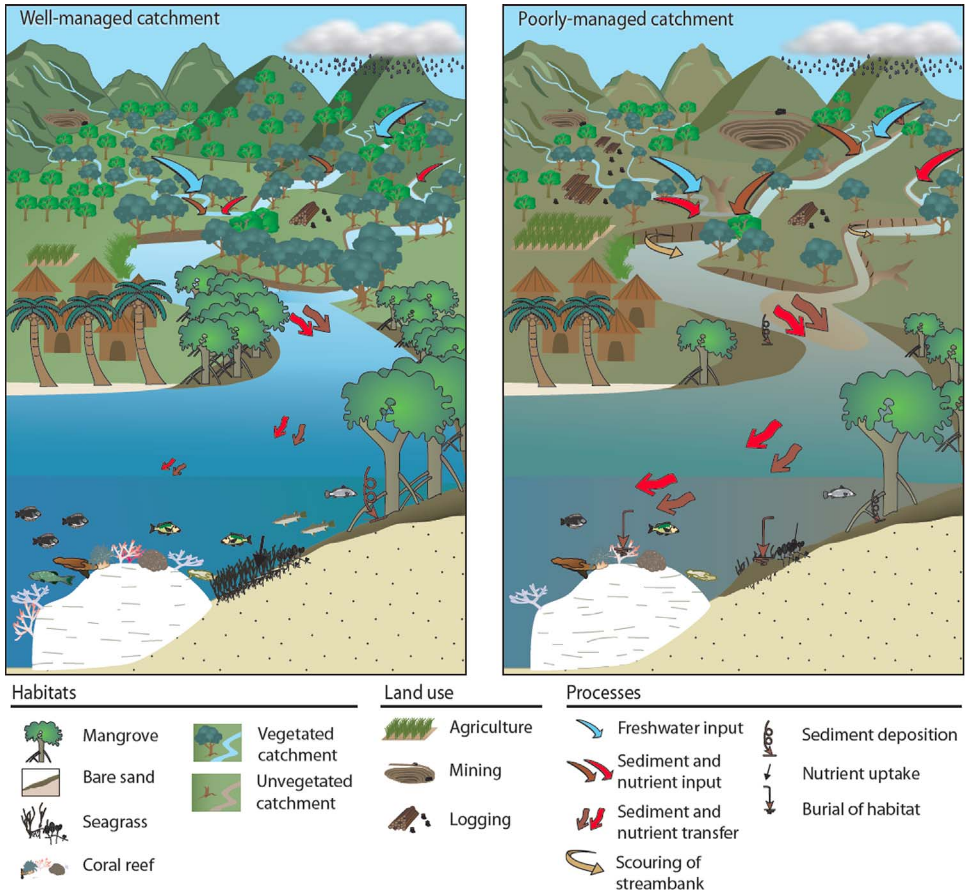


**Fig. 3.** The effects of poorly-managed catchments on coastal fish habitats. Source: Bell et al. (2011) [12].

### 3.4. *Sustain production of coastal demersal fish and invertebrates (lose-win)*

Strengthening community-based ecosystem approaches founded on 'primary' fisheries management will help keep production of demersal fish and invertebrates within sustainable bounds where governments and communities lack resources for regular monitoring of catches and analysis of stock status [29,52,71,82]. Primary fisheries management recognises the need to use simple harvest controls, such as size limits, closed seasons and areas, gear restrictions and protection of spawning aggregations. Although this precautionary approach places limits on the harvest of demersal fish and invertebrates in the near term [29], and will have to be applied even more conservatively due to the uncertainty of climate change (Supplementary Fig. 2), it is still expected to help minimise the gap between the fish needed by rapidly growing populations and coastal fisheries production. Over the longer term, it should also help to explicitly address the impacts of climate change [53,69,85] by building the resilience and replenishment potential of stocks. Where resources are available for monitoring and in-depth data analysis, consideration can be given to investments that would permit less conservative catch levels that nonetheless maintain a resilient spawning biomass [20,29].

### 3.5. *Maximise the efficiency of spatial management (win-win)*

Ensuring that areas dedicated to help protect sufficient spawning biomass for regular replenishment of coastal fish stocks and conserve biodiversity [89] are designed to take account of the ecology of target fish species, e.g., sequential use of different habitats with ontogeny [77,95], the dependence of these fish species on structurally complex habitats [91], and spatial variation in vulnerability of fish stocks to sustained and ongoing climate change [85]. It is particularly important to identify mosaics of coral reef, mangrove and seagrass habitats likely to persist as the climate changes so that the connectivity among habitats needed for successful recruitment of juvenile fish and invertebrates is maintained, and to provide migration corridors and diverse feeding areas for adult demersal fish. Well-designed networks of protected areas have the potential to help increase the resistance of coral reefs to coral bleaching, disease and *Acanthaster planci* starfish predation, as well as recovery from these disturbances [73].

### 3.6. *Diversify catches of coastal demersal fish (lose-win)*

Shifts in the local structure of fish assemblages are expected to occur due to changes in species' distributions [24], and in response to changes in the structure of coral reefs and other coastal habitats [54,83,84]. Transferring effort away from those species projected to be first and worst affected by climate impacts to species expected to increase in abundance (or to be more resilient to environmental change), and targeting species with greater rates of production, should help reduce the decline in the overall catch of demersal fish [85]. However, caution will be needed to limit harvests of fish species with important ecological functions [6,18], or species that have an inherent vulnerability to overfishing [48]. Herbivorous fish are a case in point. These species are fundamental to the resilience of coral reef ecosystems because they remove algae, thereby facilitating recovery of corals in the aftermath of major disturbances [22,56,74]. Foregoing some of the catch of herbivorous fish reduces potential harvests but will help maximise resilience of reef ecosystems [17,23,55], and other coral reef fish.

## 4. Adaptations to fill the gap

### 4.1. Transfer coastal fishing effort from demersal fish to nearshore pelagic fish (win-win)

The rich tuna resources, and stocks of other large pelagic fish (e.g., wahoo, mahi mahi), of the Western and Central Pacific Ocean (WCPO) provide PICTs with the opportunity to fill the gap between the fish needed for good nutrition and sustainable harvests of demersal fish [11,14]. There are few if any concerns for human health associated with this adaptation; yellowfin and skipjack tuna from the Pacific Island region can be consumed up to 12 and 16 times per month, respectively, without exceeding the limits on methylmercury intake recommended by the US Environmental Protection Agency [14].

The most practical way of empowering small-scale fishers to catch more tuna and other large pelagic fish in nearshore waters is to increase the number of fish aggregating devices (FADs) anchored within a few kilometres of the coast [15], and improve the safety and success of small-scale fishing operations around FADs [9]. This is a prime win-win adaptation for small-scale fisheries in the Pacific Islands region because it will increase access to fish in the near term, and set the stage for communities to continue to fill the gap as it gets progressively larger due to population growth and continued degradation of coral reefs caused by more frequent bleaching and ocean acidification [54,72,102].

Nevertheless, some key questions are 'will climate change and any future increases in the level of industrial fishing affect the distribution and abundance of tuna, and investments in nearshore FADs programs for small-scale fishers? Recent modelling [66,75,76,93] using SEAPODYM [65] (Supplementary Material) allows assessment of the projected effects of climate change and fishing effort 1.5 times greater than recent levels on the biomass of tuna across the tropical Pacific. This modelling indicates that ocean warming is likely to change the locations preferred by the two tuna species caught most commonly by small-scale fishers, yellowfin and skipjack tuna, in different ways. Due to the effects of climate change alone, average abundances of yellowfin tuna are expected to decline in the area west of 160°W and south of ~10°N, and increase east of 160°W (Fig. 4) by 2035 and 2050, relative to 2005. For skipjack tuna, projected decreases in abundance by 2035 due to climate change alone are limited mainly to equatorial areas west of ~160°E, changing to west of 170°E by 2050, with increases in abundance expected elsewhere, particularly in equatorial areas and around 10–20°N in the western WCPO (Fig. 4).

When the effects of increased fishing pressure are combined with those of climate change, the patterns are generally the same. However, the increases in abundance are more modest and the decreases in abundance are greater (Supplementary Table 4). Based on this modelling, most PICTs are expected to fall into one of two general categories with respect to future changes in tuna biomass within their exclusive economic zones (EEZs). In Federated States of Micronesia (FSM), Marshall Islands, Palau, Papua New Guinea (PNG), Solomon Islands, Nauru and Tuvalu, the biomass of yellowfin and/or skipjack tuna is expected to decline by > 15% in 2035 or 2050 (Supplementary Table 4). In Fiji, French Polynesia, New Caledonia, Niue, Northern Mariana Islands, Pitcairn Islands and Tonga, the biomass of skipjack tuna is projected to increase by > 15% by 2035 (Supplementary Table 4). PICTs in this second category are located mainly in the eastern part of the WCPO or in subtropical waters.

The substantial projected declines in biomass of yellowfin and skipjack tuna for PICTs in the western WCPO are not expected to have unduly negative implications for the use of anchored, nearshore FADs for food security. The large present-day industrial catches of tuna in PNG, FSM and Solomon Islands (Supplementary Table 5) suggest that yellowfin and skipjack tuna should still be plentiful enough to justify investments in nearshore FADs as an efficient adaptation response to declining demersal fisheries and increasing human populations. However, over time, a greater proportion of the tuna catch will need to be allocated to small-scale fishers [14], underscoring the need to improve the monitoring of artisanal and subsistence tuna fisheries and to include these catches in stock assessments.

Modelling the effects of climate change on the preferred habitats of two other large pelagic fish commonly caught by small-scale fishers around nearshore FADs in PICTs, wahoo and mahi mahi, using a multi-species distribution approach (Supplementary Material), indicates that climate change is likely to have a negative effect on future occurrence of both species in the EEZs of PICTs due to poleward migration. The warming of the WCPO is expected to reduce the suitability of the habitat for mahi mahi to a greater extent than for wahoo (Fig. 5). Conditions for mahi mahi are projected to deteriorate in the EEZs of all PICTs by 2035 relative to the suitability of present-day habitat, whereas conditions for wahoo are not expected to worsen in most PICTs until 2050s (Supplementary Table 6).

### 4.2. Expand fisheries for small pelagic species (win-win?)

The relatively high resilience to fishing of small pelagic fish (mackerel, anchovies, pilchards, sardines, scads and fusiliers), which to date have been exploited only lightly in the region, provides another potential way to increase the catch of small-scale fishers in the near term [84,90]. This is particularly true in Melanesia, where coastal waters are relatively nutrient-rich due to runoff from high islands and seasonal coastal upwelling (especially in PNG), and often support a higher biomass of these species than locations in the central and eastern WCPO. The 'bagan' method used for catching small pelagic fish throughout southeast Asia is well suited to the lagoons in Melanesia, and preliminary trials elsewhere in the Pacific Islands have yielded positive results [94,96]. Regardless of the relatively high resilience of small pelagic fish to harvesting, development of any new fisheries based on such species should implement primary fisheries management to maintain production within sustainable bounds, particularly given the role of such species in ecosystem function and energy transfer [80].

The outlook for harvesting small pelagic fish in the longer term is less certain and likely to be site specific. Projected decreases in primary productivity due to increased stratification associated with higher sea surface temperature [64], or the effects of changes in the velocity of ocean currents on formation of eddies that bring nutrient-rich waters into the photic zone [39], may cause abundance of small pelagic fish to decline in some areas. Conversely, greater projected rainfall in tropical Melanesia [68] may further increase runoff and production of small pelagic fish in some coastal waters.

### 4.3. Extend the shelf life of fish catches (win-win)

Training communities, particularly women, in how to improve traditional methods for smoke curing, salting and drying large catches of both large and small pelagic fish will enable households to store fish for those times when conditions are not suitable for fishing. In large island nations, such as PNG, it could also create better opportunities to trade seafood products with inland communities without access to fish. Improved post-harvest methods will increase the amount of fish product available for food and reduce wastage in the near term due to better efficiency. It should also assist communities in locations where climate change is projected to increase variability in fish supply.

Development of successful methods for improving the shelf life of tuna caught around FADs will also involve raising awareness of the conditions that cause histamine poisoning in tuna, also known as scombrotoxin.[3] Where there is no access to ice, the duration of trips made by small-scale fishers intending to sell tuna fresh will need to be limited.

[3] http://www.foodsafetywatch.org/factsheets/scombrotoxin-histamine/

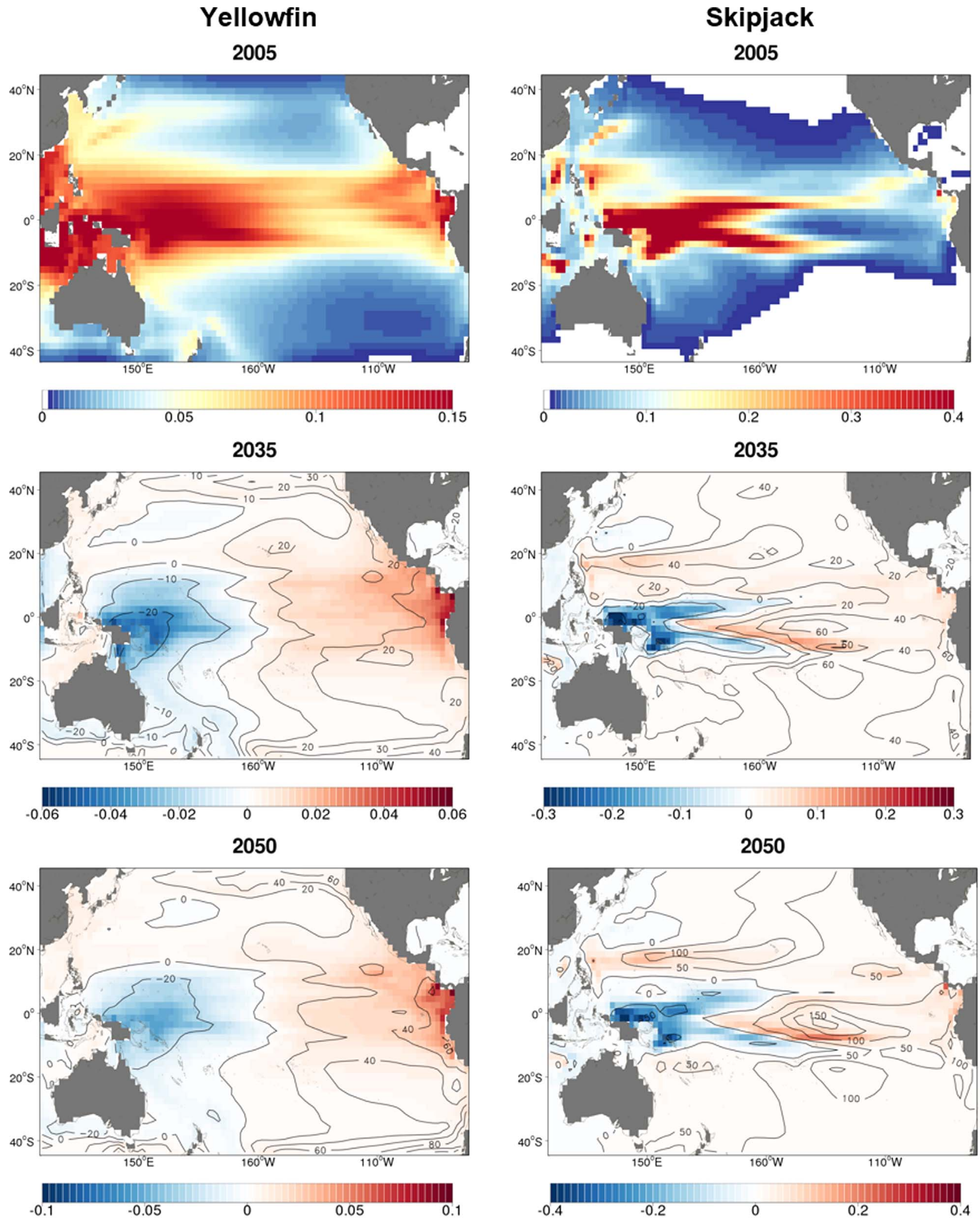


**Fig. 4.** Maps of average distribution of unfished yellowfin (top-left) and skipjack (top-right) biomass (in tonnes/sq.km) predicted by SEAPODYM in 2005. The maps for 2035 and 2050 show the biomass change for each species since 2005 (in tonnes/sq.km) projected to occur under a high emissions scenario (see Supplementary Material). The isopleths show the projected locations of relative percentage changes in biomass with respect to 2005, i.e. $100*(B_{year} - B_{2005})/B_{2005}$.

## 5. Supporting policies

Policies are needed to support the implementation of the adaptations to reduce the risks posed by climate change and to maximise the opportunities described above. Several suggested supporting policies were identified during the regional vulnerability assessment [12]. Others have also been included in the Noumea Strategy [2,98], which prioritises coastal fisheries and provides a pathway towards sustainable,

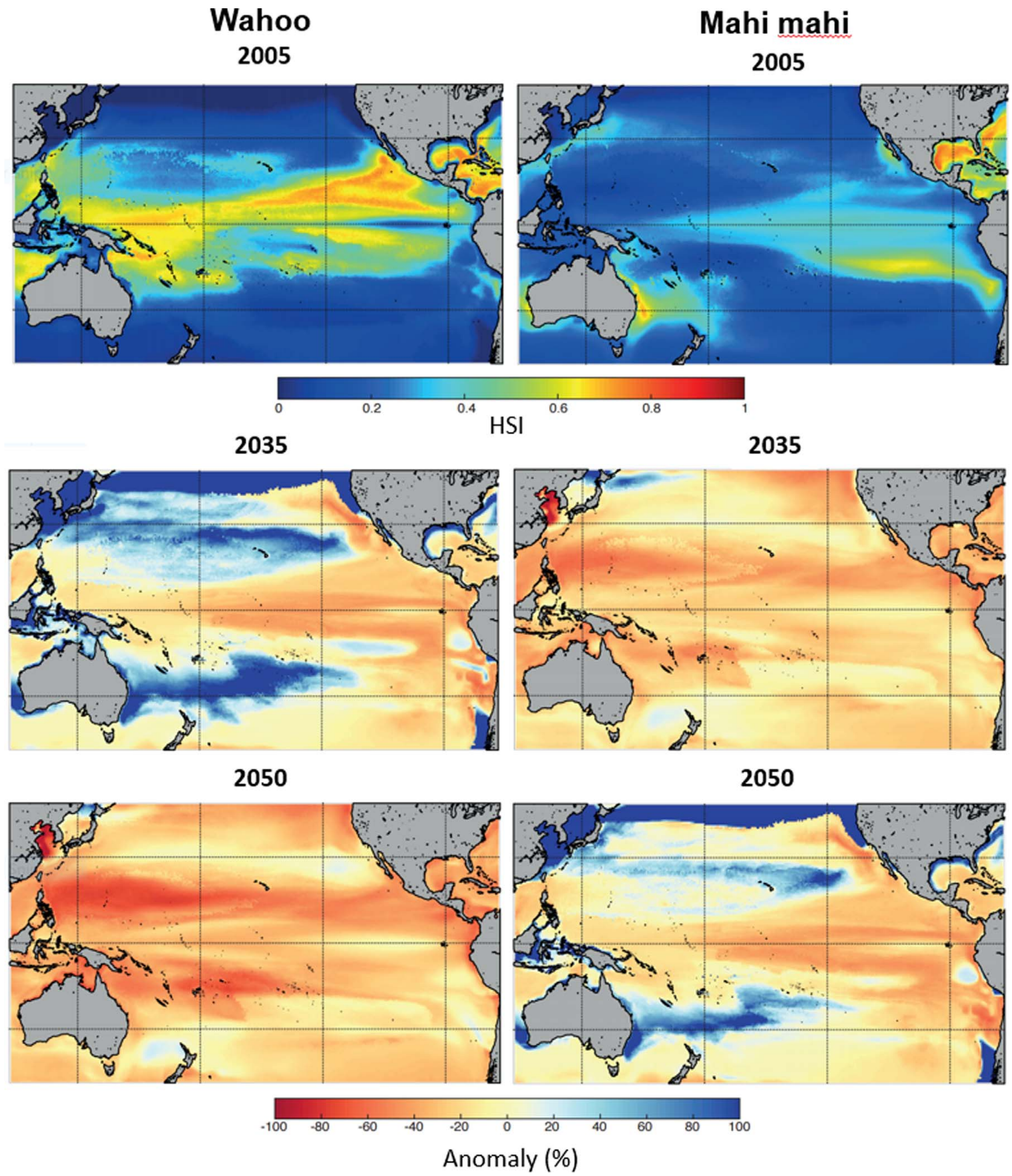


**Fig. 5.** Maps of average habitat suitability indices (HSI) for wahoo and mahi mahi for the Western and Central Pacific Ocean for the period 1970–2000 (top panels), and HSI anomalies for both species for 2035 and 2050 under a high emissions scenario (see Supplementary Materials) relative to 1970–2000.

well-managed fisheries underpinned by community-based approaches to fisheries management. These various policies are outlined below and summarised in Table 1.

### 5.1. Polices to support adaptations to minimise the gap

#### 5.1.1. Improve governance for sustainable use and protection of coastal habitats

This involves 1) building the capacity of management agencies to understand and implement adaptive measures to respond to the threats posed by climate change; 2) strengthening land-use practices and regulations, licence conditions and enforcement for forestry and mining operations to reinforce protection of catchment vegetation and downstream coastal fish habitats; 3) amending existing legislation to empower communities and recognise traditional customs for managing fish habitats; 4) establishing exchange networks to transfer knowledge on habitat management to coastal communities [7,30]; and 5) assisting communities to monitor changes in habitats to strengthen understanding of the vulnerability of coastal fisheries to climate change, and to comply with management decisions and regulations.

#### 5.1.2. Strengthen fisheries legislation to apply community-based management, founded on an ecosystem approach and primary fisheries management

PICTs have a long tradition of community-based approaches to fishery management [57]. Strengthening this tradition by equipping

**Table 1**
Summary of adaptations and companion supporting policies to maintain or improve the benefits of small-scale fisheries for food security in Pacific Island countries and territories.

| Adaptation | Type | Supporting policies |
|---|---|---|
| ***Adaptations to minimise the gap*** | | |
| • Manage and restore vegetation in catchments | Win-win | Improved governance for sustainable use and protection of coastal fish habitats, including better land-use practices for agriculture, forestry and mining |
| • Minimise (and reverse) degradation of coastal fish habitats | Win-win | |
| • Provide for landward migration of coastal fish habitats | Lose-win | |
| • Sustain production of coastal demersal fish and invertebrates | Lose-win | Strengthened fisheries legislation to apply community-based management, founded on an ecosystem approach and primary fisheries management; enhance national regulation of small-scale, commercial fishing; promote access to fish expected to increase in abundance; limit export of demersal fish; promote the health benefits of fish; develop ecotourism to relieve fishing pressure on demersal fish stocks |
| • Maximise the efficiency of spatial management | Win-win | |
| • Diversify catches of coastal demersal fish | Lose-win | |
| ***Adaptations to fill the gap*** | | |
| • Transfer coastal fishing effort from demersal fish to nearshore pelagic fish | Win-win | Include nearshore FADs as part of the national infrastructure for food security; transfer some access rights and revenues from industrial tuna fisheries to small-scale fisheries; evaluate whether industrial fishing exclusion zones provide adequate access to tuna for small-scale fishers; apply targeted subsidy programs to support key adaptations |
| • Expand fisheries for small pelagic species | Win-win | |
| • Extend the shelf life of nearshore pelagic fish catches | Win-win | |

communities with knowledge about climate change and the tools to regulate harvests is broadly seen as offering the best hope of securing optimal production of coastal fisheries resources for the future [29,46,52,97,98].

*5.1.3. Enhance national regulation of small-scale, commercial fishing (where necessary)*

In PICTs where 1) a significant proportion of the coastal, demersal fish catch is taken by small-scale, commercial fishers, and 2) there is scope for conflict with subsistence fishers over resource use in jurisdictions managed by communities due to human population growth, consideration should be given to complementing community-based management approaches with national regulation of fishing. Any such controls on effort should be developed in dialogue with fishers and communities and be consistent with the international guidance provided by the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication [35]. Possible models for sharing coastal, demersal fish resources between subsistence and small-scale commercial fishers include zoning and licencing, for example, reserving inshore waters for subsistence fishing and restricting licenced, commercial fishing to waters outside such boundaries (see Supplementary Materials for an example of present-day management of small-scale, coastal fishing in Fiji based on both zoning and licencing). The extent of customary marine tenure areas will also need to be taken into account in several Melanesia countries. Where requests for commercial fishing licences to target coastal, demersal fish increase it may be necessary to transition from primary fisheries management to investments in secondary fisheries management (Supplementary Fig. 2) to determine how many commercial fishers can be supported over and above subsistence use of these resources. Given the extent of tuna resources in the WCPO [14], there should be no need to limit the number of licences issued to small-scale, commercial fishers to target large pelagic fish species.

*5.1.4. Promote access to demersal fish species expected to increase in productivity due to climate change*

Assisting small-scale fishers to make the transition to fishing and marketing alternative species, or fishing in new areas to target these species, will help offset production losses from demersal fish species that decline in abundance due to ocean warming and acidification. Targeting demersal fish species that are increasing in abundance in ways that optimise sustainable production should also help reduce pressure on declining species.

*5.1.5. Limit export of demersal fish*

Given the high levels of subsistence fishing in most PICTs [10] and the emerging gap between the fish required for good nutrition and sustainable harvests from coastal habitats, demersal fish should be reserved primarily for local consumption. This should be relatively simple to implement through local licencing schemes and the export permitting process, and is not expected to be affected by trade agreements or expose local governments to litigation. Nevertheless, export restrictions can have unexpected outcomes and should be carefully designed and considered [16]. Some PICTs already have regulations that prevent the export of demersal fish, but enforcement requires strengthening. One practice that needs to be re-examined is the quantity of fish that nationals living overseas carry with them when departing on international flights after visiting their homeland – limits on the quantity of fish per person need to be considered and implemented.

Exports of small demersal fish and invertebrates harvested or cultured in PICTs for the aquarium trade [108,109] are an exception. These small-scale activities contribute to food security indirectly by creating livelihoods in places where there are often few options to earn income [107]. However, measures such as limits to the numbers of fishers or specimens exported need to be implemented and monitored to ensure sustainability.

#### 5.1.6. Promote the health benefits of fish

Education campaigns are needed to raise awareness of coastal communities about the need to balance the consumption and sale of fish. These campaigns should emphasise that the health benefits for households of eating fish are likely to be much greater than using revenue from the sale of fish to purchase manufactured foods. This is particularly true for low-value fish. Highlighting the relative benefits of using fish directly for consumption rather than selling them for prices that are unlikely to allow purchase of food of comparable nutritional value should help improve food security and public health. An important proviso is that sale of sustainably-caught fish, surplus to the nutritional needs of coastal households, to urban populations with poor access to fish is entirely appropriate.

#### 5.1.7. Develop sustainable ecotourism to relieve fishing pressure on demersal fish stocks

Ecotourism can help maintain demersal fish stocks and minimise the gap to be filled by providing alternative livelihoods for coastal communities [25,26,103]. However, to be ecologically and socio-economically sustainable, ecotourism will require explicit support and regulatory frameworks to ensure that the quality of habitats is maintained and that benefits accrue to local communities [33,36,62]. It will also be important to promote consumption of tuna and other large pelagic fish by tourists to help reserve the use of demersal fish mainly for local communities [110]. The concern that climate change impacts may reduce the appeal of marine ecosystems to tourists can be dispelled in many situations by increasing the suite of tourist activities offered, for example, those related to above-water activities and the cultural components of Pacific Island communities [19,28,61].

### 5.2. Polices to support adaptations to fill the gap

#### 5.2.1. Include nearshore FADs as part of the national infrastructure for food security

Allocating sufficient funds and human capacity to install, maintain and replace FADs at the end of their working life or when lost will provide small-scale fishers with a permanent, additional option for catching tuna and other large pelagic fish [15]. In many cases, these costs cannot be passed on to communities; this is the domain of governments [15]. Even though communities can and should help maintain FADs, national and provincial governments should carry the main responsibility for the replacement of FADs lost or damaged under circumstances beyond the control of communities because communities are unlikely to have the resources to replace FADs quickly. Furthermore, lost FADs should be replaced quickly, otherwise small-scale fishers are likely to revert to fishing more heavily on reefs, and may fail to fish around re-installed FADs as frequently as they might have done previously due to uncertainty about long-term presence of a FAD.

Policies will also be required in some PICTs to reserve specific FADs for the exclusive use of subsistence fishers using paddling canoes. Such FADs will generally be placed closer to the coast than FADs deployed for the use of artisanal fishers operating with a motorized boat.

#### 5.2.2. Transfer some access rights and revenues from industrial tuna fisheries to small-scale fisheries

The tuna fishing catch and effort limits established under the 'vessel day scheme' operated by the Parties to the Nauru Agreement (PNA) [1,51], and the broader regional conservation and management framework established by the Western and Central Pacific Fisheries Commission (WCPFC) [50,112], set the stage for Pacific Island States to increase the use of tuna for domestic food security by transferring a percentage of national allocations of agreed tuna fishing effort (or catch) directly to small-scale tuna fishers.

These transfers do not necessarily have to come at the expense of the host small island developing State and can arguably be made through reductions in other non-developing State allocations [49]. For example, the United Nations Fish Stocks Agreement requires regional fisheries management organisations, such as the WCPFC, to 'consider the interests of artisanal and subsistence fishers and avoid adverse impacts on, and ensure access to fisheries by, subsistence, small-scale and artisanal fishers and fish workers, as well as indigenous people in developing States parties, particularly small island developing States parties, and territories and possessions' [101].[4] Pacific Island States could also use a percentage of their tuna licence revenue to build and maintain a national infrastructure of nearshore FADs. Such policies would support the decision of Pacific Island leaders to increase access to tuna for local food security under the Regional Roadmap for Sustainable Pacific Fisheries [37]. They may also require revisions to the dimensions of industrial fishing exclusion zones (see below).

Alternatively, a percentage of access fees could be used to establish 'social funds' [81,114] for communities to make other investments to facilitate small-scale fishing for tuna. Development of any policies related to use of access fees to establish social funds would depend on cohesive consultation with recipient communities, together with significant extension [4], education and support for climate-informed, ecosystem- and community-based fisheries management. In some countries, successful implementation of social funds for this purpose would also require increasing the capacity of national fisheries administrations, given the complex array of responsibilities for managing tuna access already being borne by these agencies with limited resources [45]. The Government of Tuvalu has begun to pilot social funds for each of the islands in the country, based on a set portion of access fees [114].

#### 5.2.3. Evaluate whether industrial fishing exclusion zones provide adequate access to tuna for small-scale fishers

A recent analysis of tagging data indicates that the proximity of industrial purse-seine fishing to the locations where small-scale tuna fishing occurs is likely to have an effect on local catch rates [67]. The effectiveness of exclusion zones for industrial fishing cannot, therefore, be taken for granted. Rather, the effectiveness of these zones should be evaluated with dedicated tagging programs to determine what proportions of tuna tagged within an exclusion zone are recaptured by industrial fleets and by small-scale fisheries [15].

#### 5.2.4. Apply targeted subsidy programs to support key adaptations

Depending on the national context, several of the adaptations in Section 2. (e.g., building a national infrastructure of nearshore FADs, training in safe and effective FAD-fishing methods, development of fisheries for small pelagic species, improvements in community-based fish processing) may benefit from subsidies, including the allocation of some access fees paid by industrial fisheries as proposed above. Similarly, subsidies for marketing and processing may help incentivize 1) increased consumption of fish species favoured by climate change that were not consumed commonly in the past; and 2) sale of tuna and other large pelagic fish in restaurants catering mainly to tourists so that demersal fish species can be reserved largely for local food security [110]. Where subsidies are deemed necessary, they should involve very clear goals, context-appropriate design, transparent implementation and regular monitoring to prevent maladaptive behaviour and over-exploitation [27,52].

[4] Article 24.2(b). UNFSA. Article 5. UNFSA. – Paragraph 7.7.2(c). Code of Conduct.

## 6. Conclusions

Small-scale fisheries have a vital role to play in continuing to supply nutritious food for rapidly-growing populations in the Pacific Island region. Although the coastal habitats that have traditionally provided most of the fish caught by small-scale fishers are expected to be progressively degraded by global warming and ocean acidification, a range of practical adaptations can help to sustain the important contribution of coastal fisheries to food security. These adaptations promise to maintain substantial, albeit reduced, production of coastal fish stocks in the face of climate change and equip small-scale fishers to take greater quantities of nearshore pelagic fish, particularly tuna. The key adaptations focus on assisting communities to 1) implement climate-informed, ecosystem approaches to the management of coastal habitats and fish stocks; 2) expand the use of nearshore FADs to transfer some fishing effort from coastal demersal fish to tuna and other large pelagic fish, and 3) develop fisheries for small pelagic species. In parallel with adaptations by industrial tuna fleets to land more tuna and bycatch at regional ports to increase availability of fish for urban populations, and expansion of small pond aquaculture to increase access to fish for inland communities, the recommended adaptions for small-scale coastal fisheries should help maintain the traditionally high levels of fish consumption by Pacific Island populations.

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## Appendix A. Supplementary Material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2017.05.019.

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