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Incorporating climate-readiness into fisheries management strategies

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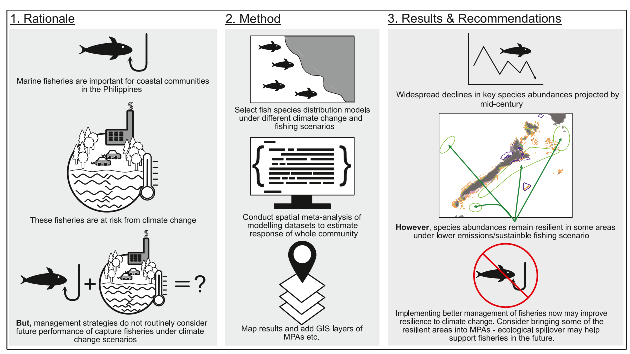
HIGHLIGHTS

- Marine capture fisheries in the Philippines are at risk from climate change.
- SS-DBEMs were used to assess key species responses to climate change scenarios.
- Abundance declines were projected across much of the case study area by mid-century.
- Improving sustainability now may increase fisheries resilience to climate change.
- MPAs in climate resilient areas may support fisheries in the future via overspill.

GRAPHICAL ABSTRACT



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ABSTRACT

Tropical oceans are among the first places to exhibit climate change signals, affecting the habitat distribution and abundance of marine fish. These changes to stocks, and subsequent impacts on fisheries production, may have considerable implications for coastal communities dependent on fisheries for food security and livelihoods. Understanding the impacts of climate change on tropical marine fisheries is therefore an important step towards developing sustainable, climate-ready fisheries management measures. We apply an established method of spatial meta-analysis to assess species distribution modelling datasets for key species targeted by the Philippines capture fisheries. We analysed datasets under two global emissions scenarios (RCP4.5 and RCP8.5) and varying degrees of fishing pressure to quantify potential climate vulnerability of the target community. We found widespread responses to climate change in pelagic species in particular, with abundances projected to decline across much of the case study area, highlighting the challenges of maintaining food security in the face of a rapidly changing climate. We argue that sustainable fisheries management in the Philippines in the face of climate change can only be achieved through management strategies that allow for the mitigation of, and adaptation to, pressures already locked into the climate system for the near term. Our analysis may support this, providing fisheries managers with the means to identify potential climate change hotspots, bright spots and refugia, thereby supporting the development of climate-ready management plans.

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1. Introduction

Marine fisheries substantially contribute to societal well-being, particularly in coastal communities dependent on fisheries for food security, livelihoods, economic development and culture (Dyck and Sumaila, 2010; Golden et al., 2016; Teh and Pauly, 2018). Globally, fish account for ~17 % of total animal protein, and 7 % of all proteins consumed (FAO, 2020). Communities in the tropics however, rely on fish for at least 20 % of their mean daily animal protein intake, and in some regions of the Indo-Pacific and West Africa this figure is upwards of 50 % (FAO, 2020). Additionally, fish provide essential amino acids, vitamins and minerals, all of which can prevent the risks of perinatal and maternal mortality, growth retardation, child mortality, cognitive deficits and reduced immune function associated with micronutrient malnutrition (Black et al., 2013; Golden et al., 2016).

Capture fisheries in the tropics are increasingly vulnerable to a number of direct and indirect climate change impacts, including ocean warming, acidification and deoxygenation (Bell et al., 2018; Fernandes, 2018; Lam et al., 2020). As ectotherms, fish growth, reproduction and survival is dependent on specific temperature ranges, as determined by their physiology and ecology (Pörtner et al., 2001). Thermal tolerances in tropical marine species are more limited than in temperate species (Pörtner and Farrell, 2008), and as such, they are particularly sensitive to ocean warming (Pauly and Cheung, 2018). Consequently, species distributions have shifted polewards, to deeper waters or to follow ocean isotherms (Lenoir et al., 2020; Pinsky et al., 2013; Poloczanska et al., 2013) where environmental conditions (particularly temperature) are more favourable (Pinsky et al., 2013; Poloczanska et al., 2013). Ocean deoxygenation can limit the growth and reproduction of fishes via an impairment of metabolic function (Roman et al., 2019), and in conjunction with warming it can reduce body size (Cheung et al., 2013; Pauly and Cheung, 2018). Deoxygenation can also reduce species temperature tolerances and so geographic ranges (Pörtner et al., 2017). Direct effects of ocean acidification on fishes can be variable (Cattano et al., 2018; Esbaugh, 2018), but coral reefs, which provide feeding grounds and habitat for some or all of fish lifespans are known to be vulnerable to acidification (Hill and Hoogenboom, 2022). The effects of climate change on the ocean environment will likely continue to increase until mid-century even if greenhouse gas emissions are curbed (Barange et al., 2018; IPCC, 2021; Santos et al., 2020), affecting natural population dynamics (Queirós et al., 2018), and the habitat distribution and abundance of tropical marine fish (Oremus et al., 2020). These changes to fish stocks, and subsequent impacts on capture fisheries production, may have considerable implications for the UN Sustainable Development Goals concerning the elimination of poverty (SDG1), food security (SDG2) and sustainable economic development (SDG8).

In addition to climate change pressures, overexploitation of resources is a key challenge facing tropical fisheries (Krueck et al., 2017; Link and Watson, 2019). While distant-water industrial fishing fleets are often singled out for unsustainable practices, (Swartz et al., 2010; Tickler et al., 2018), small scale and artisanal fisheries can also reduce the richness and abundance of target species (Exton et al., 2019; Lavides et al., 2016; Lavides et al., 2009; Muallil et al., 2014; Purcell et al., 2016; Verba et al., 2020). Further exacerbating this problem is the issue of illegal, unreported and unregulated (IUU) fishing. By definition, the scale of IUU fishing is difficult to estimate, but a recent study suggested that globally, between 8 and 14 million metric tonnes of unreported catches could be traded illicitly each year, amounting to gross revenues of US$9 to US$17 billion (Sumaila et al., 2020). The effects of overfishing can be devastating, as populations, habitats and trophic structures are disrupted through intensive and selective fishing, thereby weaking the overall health of marine ecosystems and fish stocks (Halpern et al., 2015; Sumaila and Tai, 2020). In combination, climate and fisheries impacts can produce changes in physical and biological properties of the oceans, which in turn may have significant consequences for marine species, food webs, and, ultimately, provisioning services and human wellbeing (du Pontavice et al., 2020; McClanahan et al., 2015; Ramírez et al., 2022).

Clearly, the goal of fisheries sustainability in the face of a changing climate is likely to be impeded without the timely implementation of effective, adaptive and proactive management frameworks (Lomonico et al., 2021). Reducing fishing pressure in areas where climate forcing is especially high may allow for greater resilience to climate change by supporting maintenance of genetic diversity and potentially maximising adaptation potential (Chevin et al., 2013; Kovach-Orr and Fussmann, 2013; Morgan et al., 2020). However, despite the existence of a number of tools to do so (e.g. climate risk assessments, ecosystem models) most management strategies do not routinely assess the possible future performance of fisheries resources under climate change scenarios (Holsman et al., 2020), perhaps due in part to the fact that individual management policies and climate research studies are often mismatched in terms of their spatial and temporal scales (Holsman et al., 2019). We therefore suggest that, in order to enhance the climate-readiness of fisheries management plans and build sustainability into the sector in response to changing ocean conditions, assessing fisheries resources vulnerability to climate change on a spatial scale and within a time frame of relevance to managers is critical. To help address this challenge, we present here a climate change assessment of fisheries resources from a case study site in in Palawan, Philippines (Fig. 1), which can be used to inform climate-smart fisheries management policies. We used a recently published method of spatial meta-analysis (Queirós et al., 2021), explicitly designed to support the spatial management of maritime activities and conservation efforts, and employed here to identify where potential changes in the abundances of species underpinning fishing activity in Palawan may be driven by climate change. We hoped to inform the development of climate-smart management strategies that could be prioritized within the new fisheries management plan for Palawan, in order to deliver on the stated goal of sustainable fisheries and food security (BFAR, 2019), even in the face of climate change driven pressures.

2. Methods

2.1. Case study site and local fisheries management

In 2021, total production from capture fisheries in the Philippines was approximately 2 million metric tonnes, with a value of US$2.3 million, and more than 1 million people were directly employed by the sector (BFAR, 2022). Palawan, the westernmost province of the Philippines, is an archipelago composed of more than 1700 islands (Fig. 1). It is a marine biodiversity hotspot (Fabinyi, 2010; Fabinyi and Dalabajan, 2011; Tolentino-Zondervan and Zondervan, 2022), a designated UNESCO "Man and Biosphere Reserve" and is home to two UNESCO World Heritage sites - the Tubbataha Reefs Natural Park (TRNP) and the Puerto Princesa Subterranean River National Park - and 155 Marine Protected Areas (MPAs) (PCSDS, 2015). Palawan harbours at least 89 % of the total number of the Philippines reef fish species, and around 1158 fish species have been recorded there. As an island community, Palawan's economy is dependent on this rich natural capital, with fisheries as one of the main sectors. As much as 93 % of the fisheries production in this region of the Philippines comes from Palawan (PSA, 2020), making it one of the most productive fisheries areas in the country (BFAR, 2022).

Capture fisheries in the Philippines are legally categorized as either municipal or commercial. Municipal fisheries (including subsistence fishers) operate within 15 km of the coast with or without fishing vessels, while commercial fisheries use fishing vessels of more than three gross tonnes and operate legally in fishing areas outside of the 15 km municipal boundary (Balisco et al., 2019; Pomeroy et al., 2010). Fisheries management in the Philippines has historically been divided between local governments, which manage municipal fisheries, and the Bureau of Fisheries and Aquatic Resources (BFAR), which is responsible for all waters outside the 15 km municipal boundary (Pomeroy et al., 2015). However, in 2019, in an effort to improve fisheries sustainability, halt the decline of overexploited stocks and curb IUU, the Philippine Government established 12 Fisheries Management Areas (FMAs). The aim of these FMAs is to allow for better cooperation between BFAR and local governments sharing the same stocks, for a more participatory and transparent management of fisheries among stakeholders, and to follow an ecosystem based approach to fisheries management (BFAR, 2019).

2.2. Biogeochemical model summary

Changes in key physical and biogeochemical properties (bottom and surface temperature, salinity, oxygen, pH, currents, primary production and mixed layer depth) were taken from the Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS) (Holt and James, 2001) coupled to the European Regional Seas Ecosystem Model (ERSEM) (Butenschön et al., 2016) for Southeast Asian seas (Kay, 2021). The model was driven by outputs from a global climate model drawn from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al., 2012). Together, these models simulate the movement of water, energy, and dissolved and suspended matter through the sea, along with the cycling of carbon and nutrients through the marine ecosystem. Full details of this regional POLCOMS-ERSEM model can be found in Kay et al. (2023).

2.3. Fish species distribution model

We used outputs from a size-spectrum dynamic bioclimate envelope model (SS-DBEM). This model, driven by the above selected outputs from POLCOMS-ERSEM, projects changes in fish species distribution and abundances while explicitly considering known mechanisms of population dynamics, dispersal, eco-physiological changes caused by shifting ocean conditions, habitat suitability and species interactions (e.g. predation, competition - following the size-spectrum approach) (Cheung et al., 2011; Fernandes et al., 2013). The SS-DBEM is a combined mechanistic-statistical approach that has been applied to a large

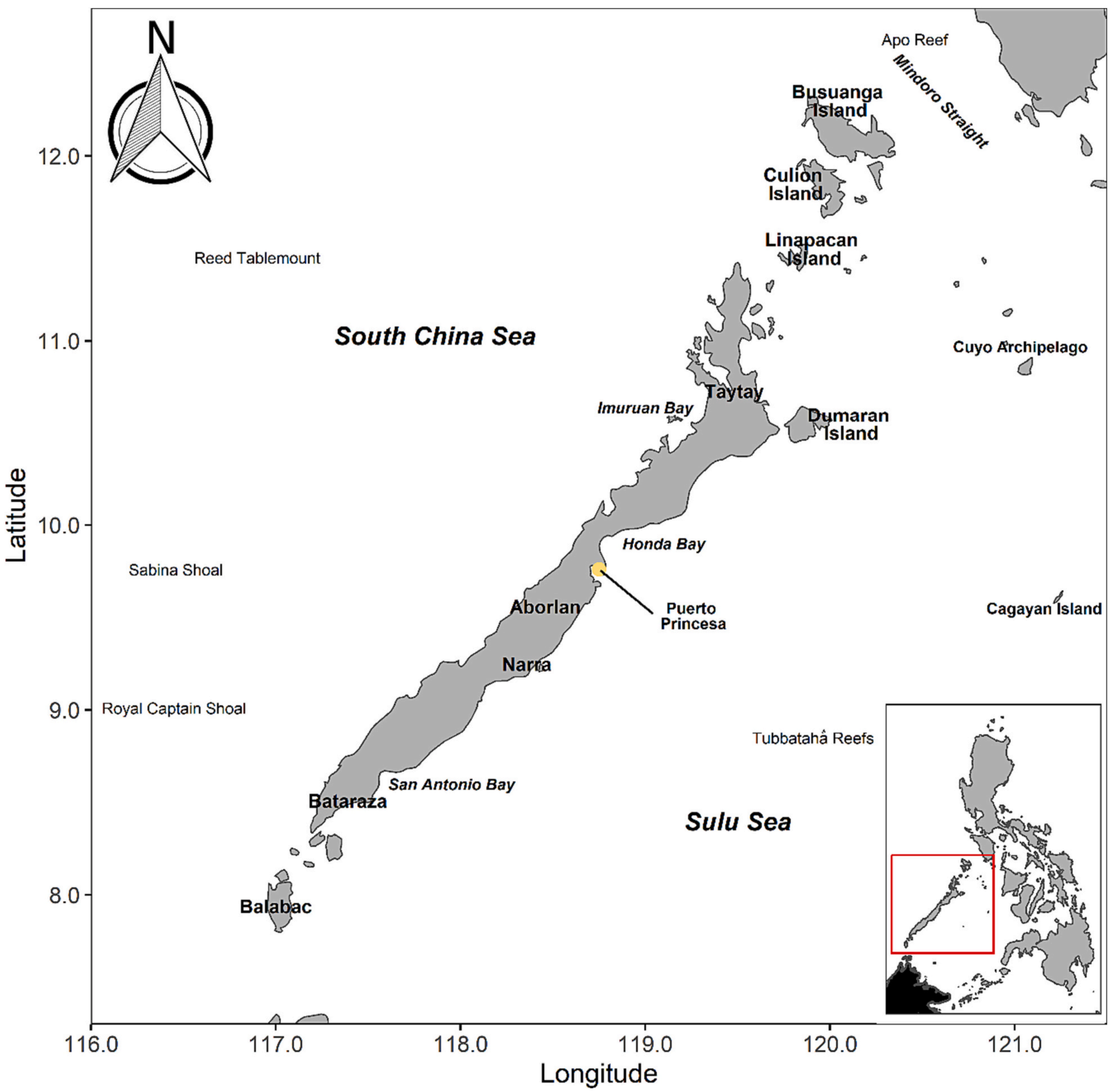

Fig. 1. Map of the Palawan case study area and its location within the Philippines.

number of marine species globally (Cheung et al., 2008; Fernandes et al., 2013) and regionally (Fernandes et al., 2015; Fernandes et al., 2017; Jones et al., 2013), and is one of the models contributing to the Fisheries and Marine Ecosystem Model Intercomparison Project (Fish-MIP) (Lotze et al., 2019; Tittensor et al., 2018).

Present distributions of species in the model were estimated using an algorithm developed by the "Sea Around Us" (www.seaaroundus.org). The relative abundance of each species on a 0.5° latitude x 0.5° longitude grid were predicted based on the species known occurrence regions, latitudinal range and depth range. Distributions were further refined using data derived from FishBase (www.fishbase.org) and SeaLifeBase (www.sealifebase.org) to assign habitat preferences to each species (e.g. affinity to inner/outer shelf, coral reefs etc.). Taken together with the projections from POLCOMS-ERSEM, the tolerance of each species to different environmental conditions was determined (Cheung et al., 2009), thereby creating seed populations. The model was initialized with these seed populations using the estimated present distribution and then driven by ocean model outputs to evaluate the possible impacts of future changes in environmental conditions on population distributions (Fernandes et al., 2015). The model projected future distributions of species abundance and biomass by combining ocean dynamics such as advection with mortality, growth and dispersal processes. The carrying capacity of each species was dependent on the environmental conditions and limited by primary production (Cheung et al., 2009; Wilson et al., 2021). The size-spectra component of SS-DBEM compared the biomass that can be supported in a given area (based on primary production and the derived size spectrum) to the energy demand of the species that were projected to be present in the area. Energy was distributed to species in proportion to their energy demand and growth rate (Fernandes et al., 2013). By accounting for both environmental preference and population dynamics in the SS-DBEM, any changes in environmental conditions resulted in changes in life history, carrying capacity and ultimately, on the abundance and distribution of fish species. In order to overcome any boundary condition issues, the model was run on a global configuration in which all of the world's oceans were represented. It should be noted that the model is capable of running several hundred species globally (Cheung et al., 2019) and as such does not need specific parameterization for regional applications.

2.4. Climate change and fishing scenarios

All modelling projections were produced using global greenhouse gas concentration pathways described by Representative Concentration Pathways ("RCPs", Van Vuuren et al., 2011) as forcing. Global greenhouse gas concentrations described by the RCPs used in this analysis diverge by 2050, declining sharply under RCP4.5, and continuing to rise steadily through the 21st century under RCP8.5 (Van Vuuren et al., 2011). It is worth noting that the RCPs have been superseded by Shared Socio-economic Pathways (SSPs) since the advent of the more advanced CMIP6 global climate models. However, at the time the modelling was produced for this study, there were no regionally-downscaled versions of the CMIP6 models available, so climate change was applied to the biogeochemical model (and consequently the SS-DBEM) using a CMIP5 model and the RCPs.

In addition to the two climate change scenarios, two fishing scenarios were also applied in order to provide a means of comparing the relative importance of climate change and fisheries management in determining future species abundances. This model considers fishing pressure in relation to maximum sustainable yield (MSY), defined as the highest average theoretical equilibrium catch that can be taken continuously from a stock under average environmental conditions (Hilborn and Walters, 1992). The two fishing scenarios used here were MSY0, which represents a situation in which no fishing mortality occurs, and which therefore allows the effects of climate change to be assessed alone; and MSY1, which represents a situation in which fishing effort is maintained at the theoretical MSY, and so is assumed to be sustainable. Fishing mortality in the model was calculated on a global basis and does not represent present fishing levels in the region, but rather is indicative of the broader impacts of fishing in addition to any climate change effects on species abundances. There were two reasons for this choice: first, fishing levels vary year on year; and second, the purpose of this study was to look at mid-century species abundances, so projections made using current fishing pressures would only provide so much information compared to using multiple scenarios. The resulting dataset gives annual projections of fish abundance/biomass under each climate change and fishing scenario (Sailley, 2021).

The modelling datasets selected for analysis are detailed in Supplementary Material Table S1. Species used in the analysis were identified as key species targeted by both commercial and municipal vessels by project partners in the Philippines, based on their expert opinions of capture fisheries in Palawan. The combined climate and fishing scenarios are termed throughout using the acronym of the RCP and either MSY0 or MSY1 to denote no or sustainable fishing effort. For instance, RCP4.5/MSY1 denotes projections of species abundances under the climate forcing of the RCP4.5 emissions scenario and moderate fishing effort at MSY. Separate analyses of fishing projections were undertaken for pelagic (17 species, Table S1) and demersal species (15 species, Table S1). The projected distributions of pelagic and demersal species for the reference decade (2011–2020) under RCP4.5/MSY0 are shown in Fig. 2.

2.5. Model validation

Spatial model validation was not possible in this study, as stock assessment in the Philippines is measured from landings data (NFRDI, 2022), and consequently spatially explicit distribution data for fished species was not available. However, in order to assess whether the model captured temporal changes in species abundances, we examined capture fisheries production data for administrative region IV-B, of which Palawan is a part, between 2004 and 2020 (annual fisheries profiles available from www.bfar.da.gov.ph), and visually compared it to model hindcasts (under RCP4.5/MSY1) aggregated across the whole model domain for the same period in order to see if trends in fisheries production were reflected in projected changes in abundance. Both timeseries were smoothed by calculating 10 year moving averages, and both were scaled between 0 and 1 to make visual comparison easier. Scaled changes in abundance/production biomass for each dataset are shown in Supplementary Material Fig. S1.

2.6. Spatial meta-analysis of modelling datasets

The spatial meta-analysis technique applied here estimates the overall change in the mean of a family of individual distributions composed of all the SS-DBEM datasets in the future, compared to the present reference period, considering their within and across dataset variability (Queirós et al., 2021). In short, the algorithm compares current (projected) abundances with those at a specified point in the future. For each grid cell in the SS-DBEM domain we constructed a random-effects meta-analysis model which tested the null hypothesis that change in species abundances (described by all the model projections for the species included in the analysis) was zero. The change in abundance of each species over the period of analysis (the individual effects size) was estimated by calculating the unbiased standardized mean difference estimator Hedges' g (Hedges, 1982) in each grid cell of the model domain. The variance of the individual effect sizes was calculated as the sum of (i) the variance of Hedges' g for each dataset; and (ii) the variance between datasets, for each grid cell, employing the Der Simonian Laird method (Borenstein et al., 2011; DerSimonian and Laird, 1986). The test statistic resulting from the meta-analysis model in each grid cell is the summary effect (M). Three outcomes were possible for each analysis, in each grid cell. 1) the cell was identified as a climate

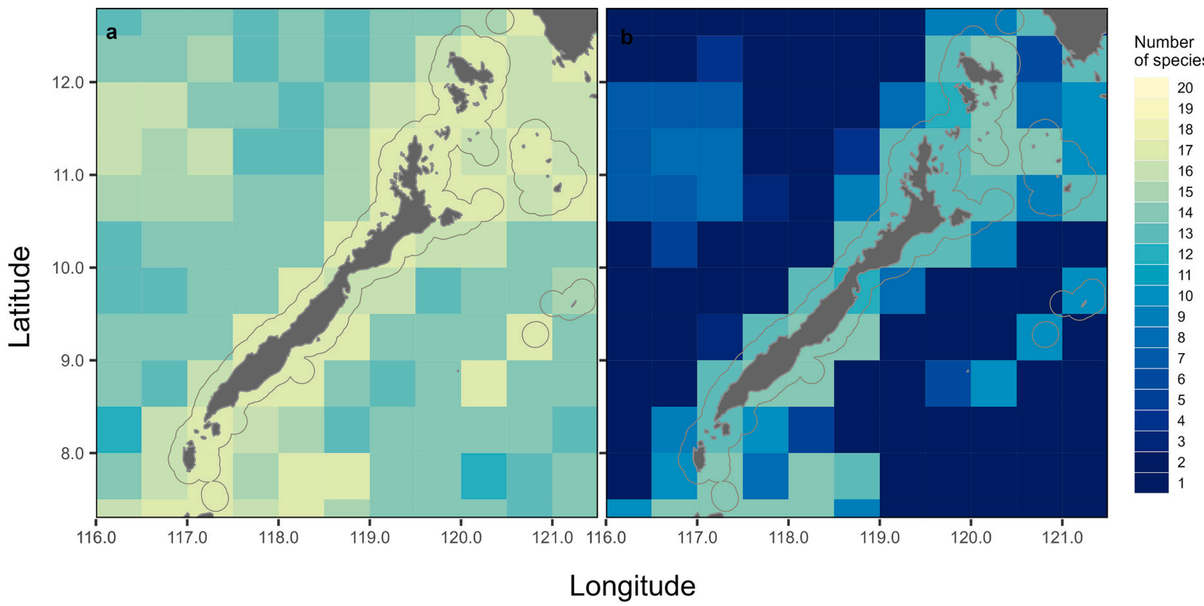

Fig. 2. Projected distributions of pelagic (a) and demersal (b) species in the reference decade (2011–2020) under RCP4.5/MSY0.

change refuge – i.e. species abundances may be resilient to climate change – where change around the mean was small and/or variability was high, suggesting that species abundances had a high probability of remaining within the range of variability projected at present. 2) The grid cell was identified as a climate change hotspot – i.e. species abundances are climate vulnerable - expressing large change beyond the present time variability that was consistent with climate change trends for many of the datasets considered; or 3) the cell was identified as a climate change bright spot, indicating an increase in species abundances (outside of present day variability) in opposition to predicted climate change trends. The mathematical definition of each category is based on calculation of the 95 % confidence interval for the summary effect M, which quantifies change between the two time periods considered in each analysis (present and future) (Borenstein et al., 2011). We assume that M has a normal distribution: when M is less than zero and its confidence interval does not contain zero, we have a hotspot; when M's confidence interval contains zero we have a climate refuge; when M is greater than zero and its confidence interval does not contain zero we have a bright spot. All analyses and plotting was carried out using author-led R core scripts (R Core Team, 2020).

3. Results

Visual comparison between changes in capture fisheries production (originally measured in metric tonnes biomass) and projected changes in species abundances between 2004 and 2020 showed that abundances projected by the SS-DBEM model used in this analysis broadly reflect trends in catch in the region (SM Fig. S1). Both production and abundances increased in the first half of the 21st century, with total catches peaking in 2009 (SM Fig. S1). Projected abundances peaked a little later in 2012, and remained steady for several years before decreasing from 2015 onwards (SM Fig. S1). This pattern is not reflected in total catches, which start to decrease immediately after the 2009 peak. The general shape of the data (i.e. increases in the first decade of the century followed by decreases to the present day) are similar enough for us to argue that abundance projections made by the model for future time periods are robust enough to support our conclusions. It is worth noting that while the biogeochemical model (originally run on a 0.1° lat * 0.1° lon grid) driving the SS-DBEM has been regionally validated for the Palawan area (Kay et al., 2023), spatial validation of the SS-DBEM itself was not possible, and the resolution of this model is coarser (0.5° lat * 0.5° lon grid). With this in mind, we suggest that some processes in nearshore waters, where land-based influences and structured coastal habitats can shape conditions, may not be fully captured. This in turn could affect input conditions for the SS-DBEM and subsequent responses of modelled species in coastal areas.

When considering only climate forcing, our analysis showed that a climate signal emerges in the distribution of pelagic species by the 2040s under both RCP4.5/MSY0 and RCP8.5/MSY0, with hotspots evident across the majority of the case study area. These included the Tubbataha Reefs Natural Park in the Sulu Sea (see Fig. 1 for location), which is the largest marine reserve in the Philippines (Fig. 3). Demersal species appeared to be less severely affected under the lower emissions scenario RCP4.5/MSY0, with abundances remaining comparable to those seen in the present day around much of Palawan. In this case, some bright spots were apparent in the Sulu Sea to the south and east of Taytay and Dumaran, and around the southern islands of the Cuyo Archipelago (Fig. 3). Bright spots for demersal species were also projected in Honda Bay and Puerto Princesa Bay, south of Aborlan and Narra, and further offshore to the south and east of Balabac (Fig. 3). The Mindoro Straight, which is a major fishing ground, may also remain climate resilient under this scenario (Fig. 3). Without fishing pressure, it may therefore be possible that all of these areas could support climate resilient demersal populations in the medium term. Under the higher emissions scenario RCP8.5/MSY0 however, the bright spots for demersal species distributions disappeared, resulting in the potential loss of abundances of demersal species around the whole island. In the same analysis, the Mindoro Straight and areas around the Reed Tablemount and Sabina Shoal (see Fig. 1 for locations) also became climate change hotspots (Fig. 3). Losses from municipal waters could be particularly pronounced under RCP8.5/MSY0, with the only climate resilient areas remaining located in Honda and Puerto Princesa Bays (pelagic and demersal species, Fig. 3). Interestingly, with the addition of moderate fishing pressure, climate resilient areas for both pelagic and demersal species were evident along much of the southern coast of Palawan Island under RCP4.5/MSY1 (Fig. 3). However, the bright spots for demersal species that were apparent under the RCP4.5/MSY0 scenario (Fig. 3) disappeared. As before, climate change hotspots for pelagic species could occur across much of the case study area outside of the 15 km municipal boundary (Fig. 3). Under RCP8.5/MSY1 however, the climate signal could emerge for both pelagic and demersal species: climate change hotspots for pelagic species could potentially be located within all

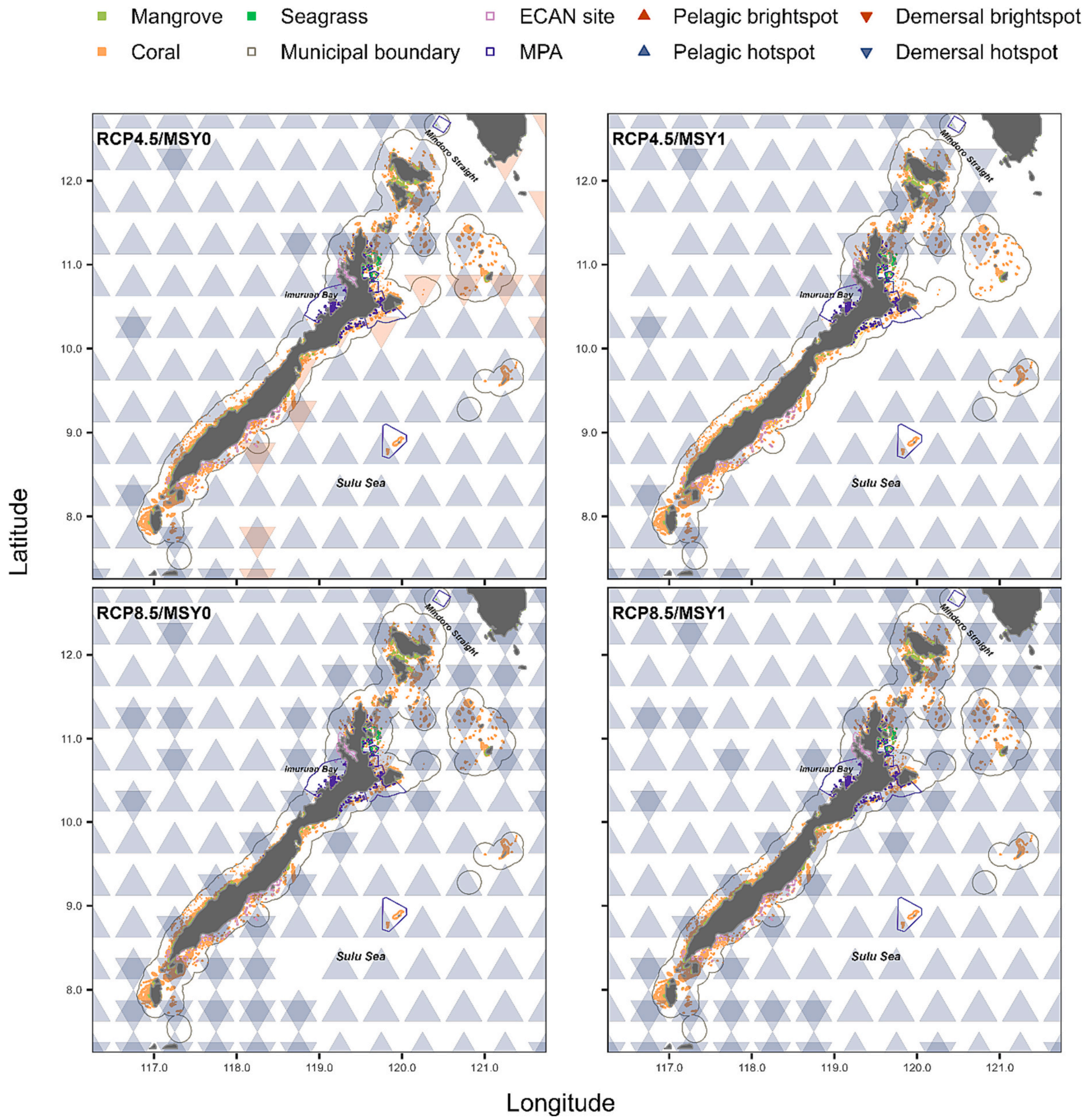

Fig. 3. The projected effect of climate change on the abundances of fish species targeted by the Philippines fleet by the 2040s, under RCP4.5/MSY0, RCP4.5/MSY1, RCP8.5/MSY0 and RCP8.5/MSY1. The colour of triangles denotes climate change hotspots (blue) or bright spots (orange) in the time-period and scenario analysed, with no triangles denoting climate change refugia. Upward triangles represent pelagic species, and downward triangles represent benthic/demersal species. Overlapping triangles indicate where hotspots or bright spots occur in both pelagic and benthic/demersal analyses.

municipal waters along the south coast of Palawan; for demersal species, hotspots could occur around the northern and southern ends of the island (Fig. 3). Outside of municipal waters, while the Mindoro Straight appeared to remain climate resilient for pelagic species under RCP4.5/MSY1, it seemed to become a climate change hotspot for both pelagic and demersal species under RCP8.5/MSY1 (Fig. 3).

Looking further ahead to the 2060s, under RCP4.5/MSY0, bright spots for demersal species abundances around the southern Cuyo Archipelago and in Honda and Puerto Princesa Bays which were present in the 2040s were no longer apparent, although the areas remained climate resilient (Fig. 4). Those areas around Aborlan, Narra and south east of Balabac which were previously either climate resilient or bright spots for demersal species could become hotspots by the 2060s (Fig. 4). The pattern for pelagic species under RCP4.5/MSY0 was similar to that seen in the earlier time frame, with widespread declines in abundances projected (Fig. 4). The addition of sustainable fishing (RCP4.5/MSY1), however, seemed to result in the disappearance of previously identified inshore climate resilient areas for both pelagic and demersal species, and climate change hotspots for demersal abundances could instead occur outside of the 15 km municipal boundary to the south east of Balabac (Fig. 4). Under the higher emissions scenario, projections for demersal species abundances under RCP8.5/MSY0 were comparable to those for the 2040s, but climate resilient areas for pelagic species abundances could potentially disappear (Fig. 4). When fishing was also considered in the analysis (RCP8.5/MSY1), areas previously identified as climate resilient for demersal species in the southern Cuyo Archipelago became, in turn, climate change hotspots, along with an expansion of hotspots around the Reed Tablemount area (Fig. 4).

4. Discussion

Our results suggest that climate change presents a significant

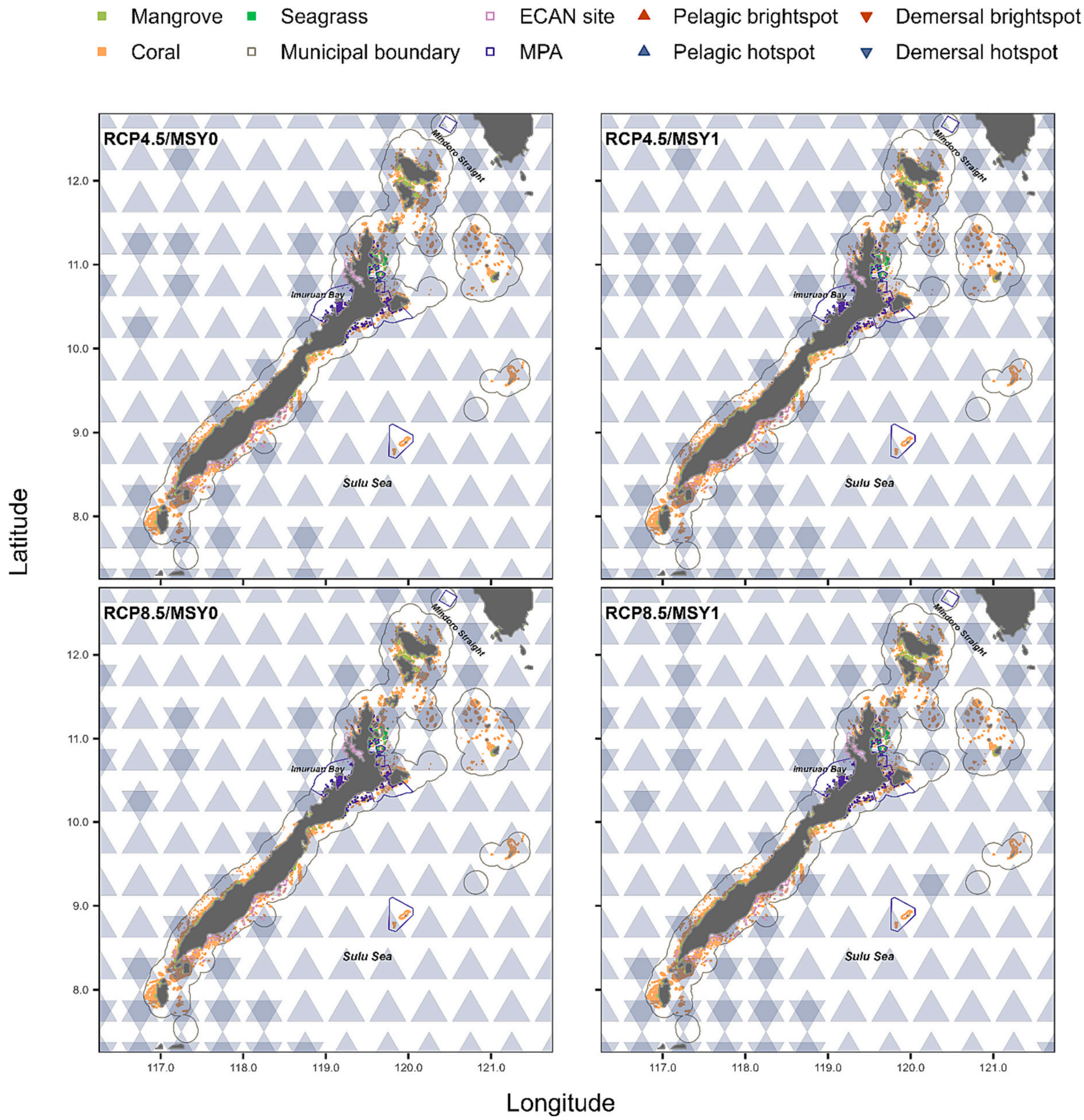

Fig. 4. The projected effect of climate change on the abundances of fish species targeted by the Philippines fleet by the 2060s, under RCP4.5/MSY0, RCP4.5/MSY1, RCP8.5/MSY0 and RCP8.5/MSY1. The colour of triangles denotes climate change hotspots (blue) or bright spots (orange) in the time-period and scenario analysed, with no triangles denoting climate change refugia. Upward triangles represent pelagic species, and downward triangles represent benthic/demersal species. Overlapping triangles indicate where hotspots or bright spots occur in both pelagic and benthic/demersal analyses.

challenge to Palawan fisheries. Key pelagic species such as scads (*Selar crumenophthalmus*, *Megalaspis cordyla*, *Selaroides leptolepis*) and tunas (*Auxis rochei*, *Thunnus* spp.) targeted by both the municipal and commercial fleets are likely to exhibit significant, widespread reductions in abundance by the 2040s (SM Fig. S2), even under the lower emissions scenario (RCP4.5) considered here. By the 2060s, similar reductions were also seen in demersal species such as threadfin bream (*Nemipterus* spp.) and some snappers (*Lutjanus malbricus*) (SM Fig. S11), both of which are targeted by municipal fishers in particular. This is in keeping with previous studies of the effects of climate change on fisheries in the area, which suggested that catch potential in the Philippines could decrease on average by between ~8 % (under the IPCC's strong emissions reduction scenario RCP2.6) and 24 % (under RCP8.5) by 2050 (Cheung et al., 2018). This could have implications for the Philippines economy as a whole (e.g. tuna exports were worth ~US$379 million in 2021) (BFAR, 2022) and it is possible that abundance reductions in those smaller pelagic and demersal species targeted by the municipal fleet and traded within the Philippines could affect local nutrition (~12 % of Filipinos daily food intake is comprised of fish and fishery products) and incomes (BFAR, 2022; Fabinyi et al., 2019). It is also important to note that our results may be conservative, as: 1) potential impacts of climate change on coral habitats (key habitats for many of the species targeted by fishers in Palawan (Fabinyi and Dalabajan, 2011), and which are themselves under threat from climate change (Eddy et al., 2021; Hoey et al., 2016; Hughes et al., 2017)) are not quantified directly by the model that generated the species distribution projections analysed here (Sailley, 2021), so any decreases in coral associated species caused by loss of habitat may not be captured and 2) the fishing level simulated is an underestimate (Anticamara and Go, 2016; Coastal Resources Center, 2021; Muallil et al., 2014). For all these reasons, we suggest that a full climate risk assessment (Payne et al., 2021) of Palawan fisheries would be beneficial.

Philippines fisheries are widely thought to be overfished (Lavides et al., 2016; Muallil et al., 2019; Nañola et al., 2011) and we suggest that addressing overexploitation in the near term could be key in promoting the future sustainability of the sector in the face of climate change. Overfishing often has major ecosystem effects and is considered to be one of the greatest threats to ocean health (Sumaila and Tai, 2020). Direct impacts of overexploitation can reduce commercially important fish biomass to vulnerable levels, which affects the biodiversity and sustainability of capture fisheries (Sumaila and Tai, 2020). Less valuable species are negatively impacted due to bycatch or habitat degradation as a result of destructive fishing practices (Faruque and Matsuda, 2021; Kaiser et al., 2003). Reducing exploitation to end overfishing has therefore been widely discussed as a climate change mitigation strategy. Encouragingly, ambitious actions to address overexploitation are already planned in the Philippines, with the establishment of twelve Fisheries Management Areas (FMAs), and the proposed development of an ecosystem based approach to fisheries management (BFAR, 2019). Management strategies such as the establishment of biological reference points based on national stock assessments, and the implementation of harvest control measures are proposed as part of these reforms (BFAR, 2019). Furthermore, the rollout of the FMAs aims to encourage more cooperative management of those stocks that move between the jurisdictions of different municipalities (BFAR, 2019). Historically, measures such as these, which are set by data-intensive assessments and monitoring that require consistent funding and institutional support, would have been challenging to implement in Philippines fisheries (Anticamara and Go, 2016). Conducting these assessments is imperative to improving management however, and a recent new initiative, funded by the World Bank and aiming to finance improved fisheries management, enforcement, capacity building and other necessary investments in the sector (World Bank, 2023), may be beneficial in securing better outcomes in the future. Recent research suggests that the implementation of measures such as these, which aim to address both productivity and range shifts within Philippines capture fisheries, may help to mitigate some of the effects of climate change, particularly under lower emissions scenarios (Free et al., 2020). However, even with better management, it is likely that catches in the Philippines, as in other tropical areas, will decrease in the future as a result of climate change driven changes in biological productivity. Indeed, our analysis suggests that species abundances will decline by mid-century under both RCP4.5 and RCP8.5 even without added fishing pressure, which is in line with other studies projecting declining catches for the Philippines under a range of climate change scenarios (Cheung et al., 2018; Free et al., 2020). While implementing climate-adaptive management reforms now will undoubtedly prove to be more beneficial than any "business-as-usual" management strategy, it is likely that the Philippines will need to look to other food production sectors to offset the losses in capture fishery production (Free et al., 2020). Further development of aquaculture technology and production could help minimize fishing pressures while sustaining fishing supply and market demands (Malayang III et al., 2020), although it also poses a number of threats to biodiversity, such as eutrophication caused by aquaculture effluents, conversion of ecologically sensitive habitats, disease and parasite transmission, escape leading to species invasions and an increased demand for fishmeal (Diana, 2009). The further expansion of large-scale aquaculture for increased food production in the Philippines will therefore require a better understanding of these environmental trade-offs and the best practices for managing them (Klinger and Naylor, 2012).

In addition to aquaculture expansion, the introduction of policies to promote catch diversification (e.g. targeting multiple species, use of different gear types) may also help to buffer fishers from environmental variability and changing fisheries resources (Free et al., 2020). This might be particularly beneficial in Palawan as our analysis suggested some inter-specific variability in the spatial patterns of responses of different populations to climate change (SM Figs. S2–S17). In this case, providing fishers with a portfolio of fishing opportunities may help to decrease reliance on those species whose abundances are projected to be more sensitive to climate change. For example, some species of sardine, mackerel, snapper and grouper are projected to increase in some areas around Palawan under RCP4.5/MSY1. All these groups are targeted by both municipal and commercial fishers already, and although the particularly high value species such as Indian mackerel (*Rastrelliger kanagurta*) and big-eye scad (*Selar crumenophthalmus*) are not among those with projected increases, other species with commercial value such as yellowtail scad (*Atule mate*) and short mackerel (*Rastrelliger brachysoma*) may increase, and could be preferentially targeted instead (Balisco et al., 2019). Furthermore, because many gears operated in the Philippines target multiple species, some existing gears can be modified to target underexploited species, which may aid in catch diversification (Balisco et al., 2019). However, it is important note that not all fishers will be able to target new species with gear they are already operating (modified or otherwise), and the high incidence of poverty recorded among Filipino fishers (BFAR, 2022) may limit investment in boats or diverse gears, which in turn serves as a barrier to catch diversification (Taylor et al., 2021). These limitations need to be acknowledged in any management strategies promoting catch diversification in the Philippines. Nevertheless, recent research of East African fisheries suggests that higher levels of species diversification can substantially reduce variability in fishers' incomes (Robinson et al., 2020) and that fishers with more diverse portfolio strategies generally had higher levels of adaptive capacity (e.g. the conditions that enable people to anticipate and respond to change, minimize the consequences, enable recovery, and take advantage of new opportunities) than those with less diverse fishing portfolios (Taylor et al., 2021).

We would also recommend spatial management strategies that preserve population resilience, age structure, and genetic diversity. For instance, MPAs are a well-established fisheries management and conservation tool in the Philippines (Espenilla, 2020), primarily used to enhance fish biomass, improve fish catch for adjacent fisheries, protect fish populations from decline, and restore and preserve natural ecosystems (Alcala and Russ, 2006; Cabral et al., 2019; Caselle et al., 2015; Halpern et al., 2010). They may also be particularly useful for protecting the big, old, fecund females that disproportionately contribute to stock productivity (Hixon et al., 2013). By identifying areas where species abundances may remain climate resilient in the future, such as those areas along the Sulu Sea coast in RCP4.5/MSY1, our analysis could help managers select sites for MPA designation. Bringing some of these areas into an MPA network may present important opportunities to improve fisheries sustainability while helping to support the fishing sector in the face of changing ocean conditions. It is important to note that in order for MPAs to be truly effective in maintaining healthy habitats and fish populations, they need to be large (2–10 km wide for at least partial protection of commercially important reef fishes (Krueck et al., 2018)) and ideally, scaled up into networks (Horigue et al., 2015). Historically, this has not been the case in the Philippines, where many existing MPAs are small (Bayley et al., 2020) and fragmented, with individual sites bearing little or no relationship to other protected areas (Espenilla, 2020). While these small MPAs can have benefits in terms of increasing fish biomass and abundance when compared to unprotected sites in the Philippines (Bayley et al., 2020), new designations should consider size (e.g. 10s km^2) and connectivity (e.g. covering home range habitats, migratory corridors and spawning aggregation sites) of sites to ensure maximum fishery benefits (Krueck et al., 2018). In these cases, the recovery of spawning stock biomass could potentially be promoted for commercially valuable climate-resilient species such as the squaretail coral grouper (*Plectropomus areolatus*) (Hutchinson and Rhodes, 2010) and the mangrove red snapper (*Lutjanus argentimaculatus*) (Honda et al., 2016; Honda et al., 2017) within the boundaries of the MPA itself (McClure et al., 2020; Russ and Alcala, 2004). Catches in the wider area could further benefit due to the potential positive impacts of spill-over, a process by which biomass is exported to adjacent fishing grounds (Di Lorenzo et al., 2016). Evidence of spill-over effects after long-term protection have been documented in several tropical fisheries in East Africa (da Silva et al., 2015; Kaunda-Arara and Rose, 2004; McClanahan, 2021), South America (Francini-Filho and Moura, 2008) and SE Asia (Dygico et al., 2013; Russ et al., 2003; Russ et al., 2004).

Despite these possible benefits however, given the projected climate change driven declines in species abundances and catches suggested by this work and others (Cheung et al., 2018; Free et al., 2020), it may be necessary to remove overcapacity from Philippines capture fisheries permanently. In this case, the provision of alternative livelihood capacity building programs to diversify and secure incomes could be beneficial in encouraging fishers to exit the sector (Cusack et al., 2021; Jalotjot and Cervantes, 2016). For example, elsewhere in the Philippines (Moalboal, Central Visayas region), ecotourism has emerged as an alternative to fishing due to a combination of nearshore fringing reefs, the establishment of coastal MPAs and the occurrence of a consistently large and charismatic herring aggregation which provides a tourism draw to the area (Cusack et al., 2021). This case serves to show that where there is strong community engagement in governance and management strategies, and where the economic benefits are retained and distributed within the local community, the economic reliance of fishers on the fishery is reduced, and long-term livelihood options beyond fishing may be facilitated (Cusack et al., 2021). Similarly, there is some evidence to suggest that in the Philippines, fishers who are involved in alternative employment have lower fishing effort compared to those that are not (Muallil et al., 2013). Nonetheless, while some instances of alternative income generation are successful, the ability of livelihood diversification projects more generally to reduce vulnerability and alleviate pressure on overexploited fishery resources remains inconsistent (Roscher et al., 2022), perhaps because of the non-material benefits that fisheries provide, such as contributions to cultural or personal identity (Cinner, 2014). Evidently, these issues need to be considered by managers and policymakers when alternative livelihood polices are developed if they are to effectively foster transitions away from fisheries.

4.1. Conclusions

Evidently, there are several challenges to overcome before the goal of climate-ready sustainable fisheries in the Philippines can be achieved. As is the case in many tropical reef fisheries, the stocks are overexploited (Ablan et al., 2004; Gonzales et al., 2019), stock assessment data is seen as insufficient or under-utilized, and fisheries managers have difficulty setting sustainable harvesting targets (Campos and Bagarinao-Regalado, 2021). Furthermore, interaction and co-operation between stakeholders is seen to be low at present (Fabinyi, 2008; Tupper et al., 2015), and governance and enforcement remain challenging due to limited capacity, resources, and sustainable financing mechanisms at the local level (Maypa et al., 2012; Tupper et al., 2015). This background challenges the development of strategies and the implementation of management measures for future climate conditions, although the designation of the new FMAs and a focus on the implementation of an ecosystem based approach to fisheries management, supported by new investment from the World Bank, may be beneficial in addressing these issues and promoting sustainability and resilience to climate change in managed stocks. We argue the method presented here represents an important addition to the decision support toolkit of fisheries managers and practitioners in the Philippines, as our work, specifically designed to support the spatial management of maritime sectors (Queirós et al., 2021), provides a simple and easily interpretable means to answer important questions: where are species abundances likely to remain resilient to climate change within a given time frame, where are they vulnerable to climate change, and do any new opportunities for the sector emerge? This in turn allows managers to consider spatial management policies that will remain effective under future climate change scenarios, highlighting what can be done to support sustainability, rather than focussing only on what will be lost.

CRediT authorship contribution statement

Elizabeth Talbot: Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Jean-Beth S. Jontila:** Funding acquisition, Writing – review & editing. **Benjamin J. Gonzales:** Funding acquisition, Writing – review & editing. **Roger G. Dolorosa:** Funding acquisition, Writing – review & editing. **Edgar D. Jose:** Funding acquisition, Writing – review & editing. **Recca Sajorne:** Funding acquisition, Writing – review & editing. **Sevrine Sailley:** Data curation, Funding acquisition, Resources, Writing – review & editing. **Susan Kay:** Data curation, Funding acquisition, Resources, Writing – review & editing. **Ana M. Queirós:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The modelling data used in this study are openly available on Zenodo at https://doi.org/10.5281/zenodo.4775853 (Kay, 2021, ERSEM) and https://doi.org/10.5281/zenodo.4281146 (Sailley, 2021, SS-DBEM).

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Appendix A. Supplementary data

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References

Ablan, M.C.A., McManus, J.W., Viswanathan, K., 2004. Indicators for management of coral reefs and their applications to marine protected areas. NAGA WorldFish Center Quarterly 27, 31–39.

Alcala, A.C., Russ, G.R., 2006. No-take marine reserves and reef fisheries management in the Philippines: a new people power revolution. AMBIO J. Hum. Environ. 35 (5), 245–254.

Anticamara, J.A., Go, K.T.B., 2016. Spatio-temporal declines in Philippine fisheries and its implications to coastal municipal fishers' catch and income. Front. Mar. Sci. 3 https://doi.org/10.3389/fmars.2016.00021.

Balisco, R.A.T., Tahajudjin, C.J.D., Claire, A., Vigonte, M., 2019. Fishing gears and their common catch in two coastal areas of Palawan, Philippines: implications to fisheries management. Int. J. Fish. Aquat. Stud. 7 (2), 216–222.

Barange, M., Bahri, T., Beveridge, M.C., Cochrane, K.L., Funge-Smith, S., Poulain, F., 2018. Impacts of climate change on fisheries and aquaculture. In: Synthesis of Current Knowledge, Adaptation and Mitigation Options. Food and Agriculture Organization of the United Nations, Rome.

Bayley, D.T.I., Purvis, A., Nellas, A.C., Arias, M., Koldewey, H.J., 2020. Measuring the long-term success of small-scale marine protected areas in a Philippine reef fishery. Coral Reefs 39 (6), 1591–1604. https://doi.org/10.1007/s00338-020-01987-7.

Bell, J.D., Allain, V., Gupta, A.S., Johnson, J.E., Hampton, J., Hobday, A.J., Lehodey, P., Lenton, A., Moore, B.R., Pratchett, M.S., Senina, I., Smith, N., Williams, P., 2018. Climate change impacts, vulnerabilities and adaptations: Western and Central Pacific Ocean marine fisheries. In: Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.), Impacts of Climate Change on Fisheries and Aquaculture. Synthesis of Current Knowledge, Adaptation and Mitigation Options. FAO Fisheries and Aquaculture Technical Paper 627. Food and Agriculture Organization of the United Nations.

BFAR, 2019. Toolkit on Rolling-Out Fisheries Management Area Implementing FAO No. 263, s. 2019. https://www.bfar.da.gov.ph/files/img/photos/FAQsonFMA_August2019.pdf.

BFAR, 2022. Philippines Fisheries Profile 2021. https://www.bfar.da.gov.ph/wp-content/uploads/2022/11/2021-Fisheries-Profile-FINAL-FILE.pdf.

Black, R.E., Victora, C.G., Walker, S.P., Bhutta, Z.A., Christian, P., de Onis, M., Ezzati, M., Grantham-McGregor, S., Katz, J., Martorell, R., Uauy, R., 2013. Maternal and child undernutrition and overweight in low-income and middle-income countries. Lancet 382 (9890), 427–451. https://doi.org/10.1016/S0140-6736(13)60937-X.

Borenstein, M., Hedges, L.V., Higgins, J.P., Rothstein, H.R., 2011. Introduction to meta-Analysis. John Wiley & Sons.

Butenschön, M., Clark, J., Aldridge, J.N., Allen, J.I., Artioli, Y., Blackford, J., Bruggeman, J., Cazenave, P., Ciavatta, S., Kay, S., 2016. ERSEM 15.06: a generic model for marine biogeochemistry and the ecosystem dynamics of the lower trophic levels. Geosci. Model Dev. 9 (4), 1293–1339.

Cabral, R.B., Halpern, B.S., Lester, S.E., White, C., Gaines, S.D., Costello, C., 2019. Designing MPAs for food security in open-access fisheries. Sci. Rep. 9 (1), 8033. https://doi.org/10.1038/s41598-019-44406-w.

Campos, W.L., Bagarinao-Regalado, A., 2021. Climate change and the Philippine sardine fisheries: status of stocks, stressors, threats and measures for sustainability. In: Bahri, T., Vasconcellos, M., Welch, D.J., Johnson, J., Perry, R.I., Ma, X., Sharma, R. (Eds.), Adaptive Management of Fisheries in Response to Climate Change. FAO Fisheries and Aquaculture Technical Paper No. 667. FAO.

Caselle, J.E., Rassweiler, A., Hamilton, S.L., Warner, R.R., 2015. Recovery trajectories of kelp forest animals are rapid yet spatially variable across a network of temperate marine protected areas. Sci. Rep. 5 (1), 1–14.

Cattano, C., Claudet, J., Domenici, P., Milazzo, M., 2018. Living in a high CO_2 world: A global meta-analysis shows multiple trait-mediated fish responses to ocean acidification. Ecol. Monogr. 88 (3), 320–335.

Cheung, W.W., Lam, V.W., Pauly, D., 2008. Modelling present and climate-shifted distribution of marine fishes and invertebrates. In: Fisheries Centre Research Reports 1198-6727, 16 (3).

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., Pauly, D., 2009. Projecting global marine biodiversity impacts under climate change scenarios. Fish Fish. 10, 235–251.

Cheung, W.W.L., Dunne, J., Sarmiento, J.L., Pauly, D., 2011. Integrating ecophysiology and plankton dynamics into projected maximum fisheries catch potential under climate change in the Northeast Atlantic. ICES J. Mar. Sci. 68 (6), 1008–1018. https://doi.org/10.1093/icesjms/fsr012.

Cheung, W.W., Sarmiento, J.L., Dunne, J., Frölicher, T.L., Lam, V.W., Palomares, M.D., Watson, R., Pauly, D., 2013. Shrinking of fishes exacerbates impacts of global ocean changes on marine ecosystems. Nat. Clim. Change 3 (3), 254–258.

Cheung, W.W.L., Bruggeman, J., Butenschön, M., 2018. Projected changes in global and national potential marine fisheries catch under climate change scenarios in the twenty-first century. In: Barange, M., Bahri, T., Beveridge, M.C.M., Cochraine, K.L., Funge-Smith, S., Poulain, F. (Eds.), Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options. Food and Agriculture Organization of the United Nations.

Cheung, W.W., Bruggeman, J., Butenschön, M., 2019. Projected changes in global and national potential marine fisheries catch under climate change scenarios in the twenty-first century. In: Impacts of Climate Change on Fisheries and Aquaculture, 63.

Chevin, L.M., Collins, S., Lefèvre, F., 2013. Phenotypic plasticity and evolutionary demographic responses to climate change: taking theory out to the field. Funct. Ecol. 27 (4), 967–979.

Cinner, J., 2014. Coral reef livelihoods. Curr. Opin. Environ. Sustain. 7, 65–71. https://doi.org/10.1016/j.cosust.2013.11.025.

Coastal Resources Center, 2021. Quantifying the Prevalence and Impact of Illegal, Unreported and Unregulated Fishing in the Philippines Workshop Report.

Cusack, C., Sethi, S.A., Rice, A.N., Warren, J.D., Fujita, R., Ingles, J., Flores, J., Garchitorena, E., Mesa, S.V., 2021. Marine ecotourism for small pelagics as a source of alternative income generating activities to fisheries in a tropical community. Biol. Conserv. 261, 109242 https://doi.org/10.1016/j.biocon.2021.109242.

da Silva, I.M., Hill, N., Shimadzu, H., Soares, A.M.V.M., Dornelas, M., 2015. Spillover effects of a community-managed marine reserve. PloS One 10 (4), e0111774. https://doi.org/10.1371/journal.pone.0111774.

DerSimonian, R., Laird, N., 1986. Meta-analysis in clinical trials. Control. Clin. Trials 7 (3), 177–188.

Di Lorenzo, M., Claudet, J., Guidetti, P., 2016. Spillover from marine protected areas to adjacent fisheries has an ecological and a fishery component. J. Nat. Conserv. 32, 62–66.

Diana, J.S., 2009. Aquaculture production and biodiversity conservation. BioScience 59 (1), 27–38. https://doi.org/10.1525/bio.2009.59.1.7.

du Pontavice, H., Gascuel, D., Reygondeau, G., Maureaud, A., Cheung, W.W.L., 2020. Climate change undermines the global functioning of marine food webs. Glob. Chang. Biol. 26 (3), 1306–1318. https://doi.org/10.1111/gcb.14944.

Dyck, A.J., Sumaila, U.R., 2010. Economic impact of ocean fish populations in the global fishery. J. Bioecon. 12 (3), 227–243. https://doi.org/10.1007/s10818-010-9088-3.

Dygico, M., Songco, A., White, A.T., Green, S.J., 2013. Achieving MPA effectiveness through application of responsive governance incentives in the Tubbataha reefs. Mar. Policy 41, 87–94. https://doi.org/10.1016/j.marpol.2012.12.031.

Eddy, T.D., Lam, V.W.Y., Reygondeau, G., Cisneros-Montemayor, A.M., Greer, K., Palomares, M.L.D., Bruno, J.F., Ota, Y., Cheung, W.W.L., 2021. Global decline in capacity of coral reefs to provide ecosystem services. One Earth 4 (9), 1278–1285. https://doi.org/10.1016/j.oneear.2021.08.016.

Esbaugh, A.J., 2018. Physiological implications of ocean acidification for marine fish: emerging patterns and new insights. J. Comp. Physiol. B 188 (1), 1–13.

Espenilla, J.J.F., 2020. Area-based marine protection in the Philippines: the mpa experience. Asia-Pac. J. Ocean Law Policy 5 (1), 99–117. https://doi.org/10.1163/24519391-00501006.

Exton, D.A., Ahmadia, G.N., Cullen-Unsworth, L.C., Jompa, J., May, D., Rice, J., Simonin, P.W., Unsworth, R.K.F., Smith, D.J., 2019. Artisanal fish fences pose broad and unexpected threats to the tropical coastal seascape. Nat. Commun. 10 (1), 2100. https://doi.org/10.1038/s41467-019-10051-0.

Fabinyi, M., 2008. Dive tourism, fishing and marine protected areas in the Calamianes Islands, Philippines. Mar. Policy 32 (6), 898–904. https://doi.org/10.1016/j.marpol.2008.01.004.

Fabinyi, M., 2010. The intensification of fishing and the rise of tourism: competing coastal livelihoods in the Calamianes Islands, Philippines. Hum. Ecol. 38 (3), 415–427.

Fabinyi, M., Dalabajan, D., 2011. Policy and practice in the live reef fish for food trade: A case study from Palawan, Philippines. Mar. Policy 35 (3), 371–378. https://doi.org/10.1016/j.marpol.2010.11.001.

Fabinyi, M., Dressler, W., Pido, M., 2019. Access to fisheries in the maritime frontier of Palawan Province, Philippines. Singapore J. Trop. Geogr. 40 (1), 92–110. https://doi.org/10.1111/sjtg.12260.

FAO, 2020. The State of World Fisheries and Aquaculture 2020. In: Sustainability in Action.

Faruque, H., Matsuda, H., 2021. Assessing the vulnerability of bycatch species from Hilsa gillnet fishing using productivity susceptibility analysis: insights from Bangladesh. Fish. Res. 234, 105808 https://doi.org/10.1016/j.fishres.2020.105808.

Fernandes, J.A., 2018. Climate change impacts, vulnerabilities and adaptations: Southern Asian fisheries in the Arabian Sea, Bay of Bengal and East Indian Ocean. In: Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.), Impacts of Climate Change on Fisheries and Aquaculture. Synthesis of Current Knowledge, Adaptation and Mitigation Options. FAO Fisheries and Aquaculture Technical Paper 627. Food And Agriculture Organization of the United Nations.

Fernandes, J.A., Cheung, W.W., Jennings, S., Butenschön, M., de Mora, L., Frölicher, T.L., Barange, M., Grant, A., 2013. Modelling the effects of climate change on the distribution and production of marine fishes: accounting for trophic interactions in a dynamic bioclimate envelope model. Glob. Chang. Biol. 19 (8), 2596–2607.

Fernandes, J.A., Kay, S., Hossain, M.A., Ahmed, M., Cheung, W.W., Lazar, A.N., Barange, M., 2015. Projecting marine fish production and catch potential in Bangladesh in the 21st century under long-term environmental change and management scenarios. ICES J. Mar. Sci. 73 (5), 1357–1369. https://doi.org/10.1093/icesjms/fsv217.

Fernandes, J.A., Papathanasopoulou, E., Hattam, C., Queirós, A.M., Cheung, W.W.L., Yool, A., Artioli, Y., Pope, E.C., Flynn, K.J., Merino, G., Calosi, P., Beaumont, N., Austen, M.C., Widdicombe, S., Barange, M., 2017. Estimating the ecological, economic and social impacts of ocean acidification and warming on UK fisheries. Fish Fish. 18, 389–411. https://doi.org/10.1111/faf.12183.

Francini-Filho, R.B., Moura, R.L., 2008. Evidence for spillover of reef fishes from a no-take marine reserve: an evaluation using the before-after control-impact (BACI) approach. Fish. Res. 93 (3), 346–356. https://doi.org/10.1016/j.fishres.2008.06.011.

Free, C.M., Mangin, T., Molinos, J.G., Ojea, E., Burden, M., Costello, C., Gaines, S.D., 2020. Realistic fisheries management reforms could mitigate the impacts of climate change in most countries. PloS One 15 (3), e0224347. https://doi.org/10.1371/journal.pone.0224347.

Golden, C.D., Allison, E.H., Cheung, W.W.L., Dey, M.M., Halpern, B.S., McCauley, D.J., Smith, M., Vaitla, B., Zeller, D., Myers, S.S., 2016. Nutrition: fall in fish catch threatens human health. Nature 534 (7607), 317–320. https://doi.org/10.1038/534317a.

Gonzales, B.J., Bolen, E., Matillano, M.V., Cadigal, G.M., Plasus, M.M.G., 2019. Live grouper fisheries and population assessment using fishery-dependent and non-fishery-dependent indicators: Northwest Sulu Sea, Philippines. Asian J. Biodiversity 10 (1).

Halpern, B.S., Lester, S.E., McLeod, K.L., 2010. Placing marine protected areas onto the ecosystem-based management seascape. Proc. Natl. Acad. Sci. 107 (43), 18312–18317.

Halpern, B.S., Frazier, M., Potapenko, J., Casey, K.S., Koenig, K., Longo, C., Lowndes, J. S., Rockwood, R.C., Selig, E.R., Selkoe, K.A., Walbridge, S., 2015. Spatial and temporal changes in cumulative human impacts on the world's ocean [article]. Nat. Commun. 6, 7615. https://doi.org/10.1038/ncomms8615. https://www.nature.com/articles/ncomms8615#supplementary-information.

Hedges, L.V., 1982. Statistical Methodology in Meta-Analysis.

Hilborn, R., Walters, C., 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman and Hall.

Hill, T.S., Hoogenboom, M.O., 2022. The indirect effects of ocean acidification on corals and coral communities. Coral Reefs. https://doi.org/10.1007/s00338-022-02286-z.

Hixon, M.A., Johnson, D.W., Sogard, S.M., 2013. BOFFFFs: on the importance of conserving old-growth age structure in fishery populations. ICES J. Mar. Sci. 71 (8), 2171–2185. https://doi.org/10.1093/icesjms/fst200.

Hoey, A.S., Howells, E., Johansen, J.L., Hobbs, J.-P.A., Messmer, V., McCowan, D.M., Wilson, S.K., Pratchett, M.S., 2016. Recent advances in understanding the effects of climate change on coral reefs. Diversity 8 (2), 12. https://www.mdpi.com/1424-2818/8/2/12.

Holsman, K.K., Hazen, E.L., Haynie, A., Gourguet, S., Hollowed, A., Bograd, S.J., Samhouri, J.F., Aydin, K., 2019. Towards climate resiliency in fisheries management. ICES J. Mar. Sci. 76 (5), 1368–1378. https://doi.org/10.1093/icesjms/fsz031.

Holsman, K.K., Haynie, A.C., Hollowed, A.B., Reum, J.C.P., Aydin, K., Hermann, A.J., Cheng, W., Faig, A., Ianelli, J.N., Kearney, K.A., Punt, A.E., 2020. Ecosystem-based fisheries management forestalls climate-driven collapse. Nat. Commun. 11 (1), 4579. https://doi.org/10.1038/s41467-020-18300-3.

Holt, J.T., James, I.D., 2001. An s coordinate density evolving model of the northwest European continental shelf: 1. Model description and density structure. J. Geophys. Res. Oceans 106 (C7), 14015–14034. https://doi.org/10.1029/2000JC000304.

Honda, K., Uy, W.H., Baslot, D.I., Pantallano, A.D.S., Nakamura, Y., Nakaoka, M., 2016. Diel habitat-use patterns of commercially important fishes in a marine protected area in the Philippines. Aquat. Biol. 24 (3), 163–174. https://www.int-res.com/abstracts/ab/v24/n3/p163-174/.

Honda, K., Uy, W.H., Baslot, D.I., Pantallano, A.D.S., Sato, M., Nakamura, Y., Nakaoka, M., 2017. Importance of outer reef slopes for commercially important fishes: implications for designing a marine protected area in the Philippines. Fish. Sci. 83 (4), 523–535. https://doi.org/10.1007/s12562-017-1082-4.

Horigue, V., Pressey, R.L., Mills, M., Brotánková, J., Cabral, R., Andréfouët, S., 2015. Benefits and challenges of scaling up expansion of marine protected area networks in the Verde Island passage, Central Philippines. PLOS ONE 10 (8), e0135789. https://doi.org/10.1371/journal.pone.0135789.

Hughes, T.P., Kerry, J.T., Álvarez-Noriega, M., Álvarez-Romero, J.G., Anderson, K.D., Baird, A.H., Babcock, R.C., Beger, M., Bellwood, D.R., Berkelmans, R., 2017. Global warming and recurrent mass bleaching of corals. Nature 543 (7645), 373–377.

Hutchinson, N., Rhodes, K., 2010. Home range estimates for squaretail coralgrouper, Plectropomus areolatus (Rüppell 1830). Coral Reefs 29, 511–519. https://doi.org/10.1007/s00338-010-0584-7.

IPCC, 2021. Climate change 2021: the physical science basis. In: Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. C. U. Press.

Jalotjot, H.C., Cervantes, C.P., 2016. Income and Livelihood Impacts of the Clsoed Fishing Season Policy for Sardines in Zamboanga Peninsula, Philippines (Working Paper No. 2016-10).

Jones, M.C., Dye, S.R., Fernandes, J.A., Frölicher, T.L., Pinnegar, J.K., Warren, R., Cheung, W.W., 2013. Predicting the impact of climate change on threatened species in UK waters. PloS One 8 (1), e54216.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., Poiner, I.R., 2003. 12 impacts of fishing gear on marine benthic habitats. Responsible Fish. Mar. Ecosyst. 57 (3), 197.

Kaunda-Arara, B., Rose, G.A., 2004. Effects of marine reef National Parks on fishery CPUE in coastal Kenya. Biol. Conserv. 118 (1), 1–13. https://doi.org/10.1016/j.biocon.2003.06.001.

Kay, S., 2021. Marine Environment Climate Change Projections for Southeast Asian Seas. https://doi.org/10.5281/zenodo.4775853.

Kay, S., Avillanosa, A.L., Cheung, V.V., Dao, H.N., Gonzales, B.J., Palla, H.P., Praptiwi, R. A., Queirós, A.M., Sailley, S.F., Sumeldan, J.D.C., Syazwan, W.M., Then, A.Y.-H., Wee, H.B., 2023. Projected effects of climate change on marine ecosystems in Southeast Asian seas [original research]. Front. Mar. Sci. 10 https://doi.org/10.3389/fmars.2023.1082170.

Klinger, D., Naylor, R., 2012. Searching for solutions in aquaculture: charting a sustainable course. Annu. Rev. Env. Resour. 37 (1), 247–276. https://doi.org/10.1146/annurev-environ-021111-161531.

Kovach-Orr, C., Fussmann, G.F., 2013. Evolutionary and plastic rescue in multitrophic model communities. Philos. Trans. R. Soc., B 368 (1610), 20120084. https://doi.org/10.1098/rstb.2012.0084.

Krueck, N.C., Ahmadia, G.N., Possingham, H.P., Riginos, C., Treml, E.A., Mumby, P.J., 2017. Marine reserve targets to sustain and rebuild unregulated fisheries. PLoS Biol. 15 (1), e2000537 https://doi.org/10.1371/journal.pbio.2000537.

Krueck, N.C., Legrand, C., Ahmadia, G.N., Estradivari, Green, A., Jones, G.P., Riginos, C., Treml, E.A., Mumby, P.J., 2018. Reserve sizes needed to protect coral reef fishes. Conserv. Lett. 11 (3), e12415 https://doi.org/10.1111/conl.12415.

Lam, V.W., Allison, E.H., Bell, J.D., Blythe, J., Cheung, W.W., Frölicher, T.L., Gasalla, M. A., Sumaila, U.R., 2020. Climate change, tropical fisheries and prospects for sustainable development. Nat. Rev. Earth Environ. 1 (9), 440–454.

Lavides, M.N., Polunin, N.V., Stead, S.M., Tabaranza, D.G., Comeros, M.T., Dongallo, J. R., 2009. Finfish disappearances around Bohol, Philippines inferred from traditional ecological knowledge. Environ. Conserv. 36 (3), 235–244.

Lavides, M.N., Molina, E.P.V., de la Rosa Jr., G.E., Mill, A.C., Rushton, S.P., Stead, S.M., Polunin, N.V.C., 2016. Patterns of coral-reef finfish species disappearances inferred from fishers' knowledge in global epicentre of marine Shorefish diversity. PloS One 11 (5), e0155752. https://doi.org/10.1371/journal.pone.0155752.

Lenoir, J., Bertrand, R., Comte, L., Bourgeaud, L., Hattab, T., Murienne, J., Grenouillet, G., 2020. Species better track climate warming in the oceans than on land. Nat. Ecol. Evol. 4 (8), 1044–1059. https://doi.org/10.1038/s41559-020-1198-2.

Link, J.S., Watson, R.A., 2019. Global ecosystem overfishing: clear delineation within real limits to production. Sci. Adv. 5 (6), eaav0474. https://doi.org/10.1126/sciadv.aav0474.

Lomonico, S., Gleason, M.G., Wilson, J.R., Bradley, D., Kauer, K., Bell, R.J., Dempsey, T., 2021. Opportunities for fishery partnerships to advance climate-ready fisheries science and management. Mar. Policy 123, 104252. https://doi.org/10.1016/j.marpol.2020.104252.

Lotze, H.K., Tittensor, D.P., Bryndum-Buchholz, A., Eddy, T.D., Cheung, W.W., Galbraith, E.D., Barange, M., Barrier, N., Bianchi, D., Blanchard, J.L., 2019. Global ensemble projections reveal trophic amplification of ocean biomass declines with climate change. Proc. Natl. Acad. Sci. 116 (26), 12907–12912.

Malayang III, B.S., Oracion, E.G., Bomediano, M.R., Calumpong, H.P., Abesamis, R.A., Montebon, R.D., 2020. Opportunities and challenges to fisheries policy in the Philippines today. J. Environ. Sci. Manag. 23 (1), 111–126.

Maypa, A.P., White, A.T., Cañares, E., Martinez, R., Eisma-Osorio, R.L., Aliño, P., Apistar, D., 2012. Marine protected area management effectiveness: progress and lessons in the Philippines. Coast. Manag. 40 (5), 510–524. https://doi.org/10.1080/08920753.2012.709465.

McClanahan, T.R., 2021. Marine reserve more sustainable than gear restriction in maintaining long-term coral reef fisheries yields. Mar. Policy 128, 104478. https://doi.org/10.1016/j.marpol.2021.104478.

McClanahan, T., Allison, E.H., Cinner, J.E., 2015. Managing fisheries for human and food security. Fish Fish. 16 (1), 78–103. https://doi.org/10.1111/faf.12045.

McClure, E.C., Sievers, K.T., Abesamis, R.A., Hoey, A.S., Alcala, A.C., Russ, G.R., 2020. Higher fish biomass inside than outside marine protected areas despite typhoon impacts in a complex reefscape. Biol. Conserv. 241, 108354 https://doi.org/10.1016/j.biocon.2019.108354.

Morgan, R., Finnøen, M.H., Jensen, H., Pélabon, C., Jutfelt, F., 2020. Low potential for evolutionary rescue from climate change in a tropical fish. Proc. Natl. Acad. Sci. 117 (52), 33365–33372. https://doi.org/10.1073/pnas.2011419117.

Muallil, R.N., Cleland, D., Aliño, P.M., 2013. Socioeconomic factors associated with fishing pressure in small-scale fisheries along the West Philippine Sea biogeographic region. Ocean Coast. Manag. 82, 27–33. https://doi.org/10.1016/j.ocecoaman.2013.04.013.

Muallil, R.N., Mamauag, S.S., Cabral, R.B., Celeste-Dizon, E.O., Aliño, P.M., 2014. Status, trends and challenges in the sustainability of small-scale fisheries in the Philippines: insights from FISHDA (Fishing Industries' Support in Handling Decisions Application) model. Mar. Policy 44, 212–221.

Muallil, R.N., Deocadez, M.R., Martinez, R.J.S., Campos, W.L., Mamauag, S.S., Nañola, C. L., Aliño, P.M., 2019. Effectiveness of small locally-managed marine protected areas for coral reef fisheries management in the Philippines. Ocean Coast. Manag. 179, 104831 https://doi.org/10.1016/j.ocecoaman.2019.104831.

Nañola, C.L., Aliño, P.M., Carpenter, K.E., 2011. Exploitation-related reef fish species richness depletion in the epicenter of marine biodiversity. Environ. Biol. Fishes 90, 405–420.

NFRDI, 2022. National Stock Assessment Program (NSAP). https://nfrdi.da.gov.ph/national-stock-assessment-program-nsap/.

Oremus, K.L., Bone, J., Costello, C., García Molinos, J., Lee, A., Mangin, T., Salzman, J., 2020. Governance challenges for tropical nations losing fish species due to climate change. Nat. Sustain. 3 (4), 277–280. https://doi.org/10.1038/s41893-020-0476-y.

Pauly, D., Cheung, W.W., 2018. Sound physiological knowledge and principles in modeling shrinking of fishes under climate change. Glob. Chang. Biol. 24 (1), e15–e26.

Payne, M.R., Kudahl, M., Engelhard, G.H., Peck, M.A., Pinnegar, J.K., 2021. Climate risk to European fisheries and coastal communities. Proc. Natl. Acad. Sci. 118 (40), e2018086118 https://doi.org/10.1073/pnas.2018086118.

PCSDS, 2015. State of the Environment 2015 Updates, Province of Palawan (UNESCO Man and Biosphere Reserve), Philippines.

Pinsky, M.L., Worm, B., Fogarty, M.J., Sarmiento, J.L., Levin, S.A., 2013. Marine taxa track local climate velocities. Science 341 (6151), 1239–1242.

Poloczanska, E.S., Brown, C.J., Sydeman, W.J., Kiessling, W., Schoeman, D.S., Moore, P. J., Brander, K., Bruno, J.F., Buckley, L.B., Burrows, M.T., Duarte, C.M., Halpern, B.S., Holding, J., Kappel, C.V., O'Connor, M.I., Pandolfi, J.M., Parmesan, C., Schwing, F., Thompson, S.A., Richardson, A.J., 2013. Global imprint of climate change on marine life. Nat. Clim. Chang. 3, 919. https://doi.org/10.1038/nclimate1958.

Pomeroy, R., Garces, L., Pido, M., Silvestre, G., 2010. Ecosystem-based fisheries management in small-scale tropical marine fisheries: emerging models of governance arrangements in the Philippines. Mar. Policy 34 (2), 298–308.

Pomeroy, R., Phang, K.H.W., Ramdass, K., Saad, J.M., Lokani, P., Mayo-Anda, G., Lorenzo, E., Manero, G., Maguad, Z., Pido, M.D., Goby, G., 2015. Moving towards an ecosystem approach to fisheries management in the Coral Triangle region. Mar. Policy 51, 211–219. https://doi.org/10.1016/j.marpol.2014.08.013.

Pörtner, H.O., Farrell, A.P., 2008. Physiology and climate change. Science 322 (5902), 690–692. https://doi.org/10.1126/science.1163156.

Pörtner, H.-O., Berdal, B., Blust, R., Brix, O., Colosimo, A., De Wachter, B., Giuliani, A., Johansen, T., Fischer, T., Knust, R., 2001. Climate induced temperature effects on growth performance, fecundity and recruitment in marine fish: developing a hypothesis for cause and effect relationships in Atlantic cod (*Gadus morhua*) and common eelpout (*Zoarces viviparus*). Cont. Shelf Res. 21 (18–19), 1975–1997.

Pörtner, H.-O., Bock, C., Mark, F.C., 2017. Oxygen-and capacity-limited thermal tolerance: bridging ecology and physiology. J. Exp. Biol. 220 (15), 2685–2696.

PSA, 2020. Fisheries Statistics of the Philippines 2018–2020.

Purcell, S.W., Ngaluafe, P., Aram, K.T., Lalavanua, W., 2016. Trends in small-scale artisanal fishing of sea cucumbers in Oceania. Fish. Res. 183, 99–110. https://doi.org/10.1016/j.fishres.2016.05.010.

Queirós, A.M., Fernandes, J., Genevier, L., Lynam, C.P., 2018. Climate change alters fish community size-structure, requiring adaptive policy targets. Fish Fish. 19 (4), 613–621. https://doi.org/10.1111/faf.12278.

Queirós, A.M., Talbot, E., Beaumont, N.J., Somerfield, P.J., Kay, S., Pascoe, C., Dedman, S., Fernandes, J.A., Jueterbock, A., Miller, P.I., Sailley, S.F., Sará, G., Carr, L.M., Austen, M.C., Widdicombe, S., Rilov, G., Levin, L.A., Hull, S.C., Walmsley, S.F., Nic Aonghusa, C., 2021. Bright spots as climate-smart marine spatial planning tools for conservation and blue growth. Glob. Chang. Biol. 27 (21), 5514–5531. https://doi.org/10.1111/gcb.15827.

R Core Team, 2020. R: A language and environment for statistical computing, R Foundation for Statistical Computing. https://www.R-project.org/.

Ramírez, F., Shannon, L.J., van der Lingen, C.D., Julià, L., Steenbeek, J., Coll, M., 2022. Climate and fishing simultaneously impact small pelagic fish in the oceans around the southernmost tip of Africa [original research]. Front. Mar. Sci. 9 https://doi.org/10.3389/fmars.2022.1031784.

Robinson, J.P.W., Robinson, J., Gerry, C., Govinden, R., Freshwater, C., Graham, N.A.J., 2020. Diversification insulates fisher catch and revenue in heavily exploited tropical fisheries. Sci. Adv. 6 (8), eaaz0587 https://doi.org/10.1126/sciadv.aaz0587.

Roman, M.R., Brandt, S.B., Houde, E.D., Pierson, J.J., 2019. Interactive effects of hypoxia and temperature on coastal pelagic zooplankton and fish. Front. Mar. Sci. 6 https://doi.org/10.3389/fmars.2019.00139.

Roscher, M.B., Eriksson, H., Harohau, D., Mauli, S., Kaltavara, J., Boonstra, W.J., van der Ploeg, J., 2022. Unpacking pathways to diversified livelihoods from projects in Pacific Island coastal fisheries. Ambio 51 (10), 2107–2117. https://doi.org/10.1007/s13280-022-01727-x.

Russ, G.R., Alcala, A.C., 2004. Marine reserves: long-term protection is required for full recovery of predatory fish populations. Oecologia 138 (4), 622–627. https://doi.org/10.1007/s00442-003-1456-4.

Russ, G.R., Alcala, A.C., Maypa, A.P., 2003. Spillover from marine reserves: the case of Naso vlamingii at Apo Island, the Philippines. Mar. Ecol. Prog. Ser. 264, 15–20. https://www.int-res.com/abstracts/meps/v264/p15-20/.

Russ, G.R., Alcala, A.C., Maypa, A.P., Calumpong, H.P., White, A.T., 2004. Marine reserves benefit local fisheries. Ecol. Appl. 14 (2), 597–606. https://doi.org/10.1890/03-5076.

Sailley, S., 2021. Model Projection of the Effect of Climate Change and Fishing Pressure on Key Species of the South East Asia Seas (1.0). https://doi.org/10.5281/zenodo.4281146.

Santos, C.F., Agardy, T., Andrade, F., Calado, H., Crowder, L.B., Ehler, C.N., García-Morales, S., Gissi, E., Halpern, B.S., Orbach, M.K., 2020. Integrating climate change in ocean planning. Nat. Sustain. 3 (7), 505–516.

Sumaila, U.R., Tai, T.C., 2020. End overfishing and increase the resilience of the ocean to climate change. Front. Mar. Sci. 7, 523.

Sumaila, U.R., Zeller, D., Hood, L., Palomares, M., Li, Y., Pauly, D., 2020. Illicit trade in marine fish catch and its effects on ecosystems and people worldwide. Sci. Adv. 6 (9), eaaz3801.

Swartz, W., Sala, E., Tracey, S., Watson, R., Pauly, D., 2010. The spatial expansion and ecological footprint of fisheries (1950 to present). PloS One 5 (12), e15143.

Taylor, K.E., Stouffer, R.J., Meehl, G.A., 2012. An overview of CMIP5 and the experiment design. Bull. Am. Meteorol. Soc. 93 (4), 485–498.

Taylor, S.F.W., Aswani, S., Jiddawi, N., Coupland, J., James, P.A.S., Kelly, S., Kizenga, H., Roberts, M., Popova, E., 2021. The complex relationship between asset wealth, adaptation, and diversification in tropical fisheries. Ocean Coast. Manag. 212, 105808 https://doi.org/10.1016/j.ocecoaman.2021.105808.

Teh, L.C.L., Pauly, D., 2018. Who brings in the fish? The relative contribution of small-scale and industrial fisheries to food security in Southeast Asia [original research]. Front. Mar. Sci. 5 (44) https://doi.org/10.3389/fmars.2018.00044.

Tickler, D., Meeuwig, J.J., Palomares, M.-L., Pauly, D., Zeller, D., 2018. Far from home: distance patterns of global fishing fleets. Sci. Adv. 4 (8), eaar3279 https://doi.org/10.1126/sciadv.aar3279.

Tittensor, D.P., Eddy, T.D., Lotze, H.K., Galbraith, E.D., Cheung, W., Barange, M., Blanchard, J.L., Bopp, L., Bryndum-Buchholz, A., Büchner, M., 2018. A protocol for the intercomparison of marine fishery and ecosystem models: Fish-MIP v1. 0. Geoscientific Model Develop. 11 (4), 1421.

Tolentino-Zondervan, F., Zondervan, N.A., 2022. Sustainable fishery management trends in Philippine fisheries. Ocean Coast. Manag. 223, 106149.

Tupper, M., Asif, F., Garces, L.R., Pido, M.D., 2015. Evaluating the management effectiveness of marine protected areas at seven selected sites in the Philippines. Mar. Policy 56, 33–42. https://doi.org/10.1016/j.marpol.2015.02.008.

Van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F., 2011. The representative concentration pathways: an overview. Clim. Change 109 (1–2), 5.

Verba, J.T., Pennino, M.G., Coll, M., Lopes, P.F.M., 2020. Assessing drivers of tropical and subtropical marine fish collapses of Brazilian Exclusive Economic Zone. Sci. Total Environ. 702, 134940 https://doi.org/10.1016/j.scitotenv.2019.134940.

Wilson, R.J., Sailley, S.F., Jacobs, Z.L., Kamau, J., Mgeleka, S., Okemwa, G.M., Omukoto, J.O., Osuka, K.E., Samoilys, M., Sauer, W., Silas, M.O., Sululu, J.S., Roberts, M.J., 2021. Large projected reductions in marine fish biomass for Kenya and Tanzania in the absence of climate mitigation. Ocean Coast. Manag. 215, 105921 https://doi.org/10.1016/j.ocecoaman.2021.105921.

World Bank, 2023. New Fisheries Initiative Will Benefit Over a Million People in the Philippines. https://www.worldbank.org/en/news/press-release/2023/05/31/new-fisheries-initiative-will-benefit-over-a-million-people-in-the-phi.