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Connectivity of Coral Reefs and other Nearshore Habitats: Implications for Marine Resource Management in the Philippines

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ABSTRACT

Marine protected areas (MPAs) have become a mainstay of marine resource management in the Philippines in the past three decades and there is growing advocacy to implement MPA networks — systems of MPAs that effectively protect sufficient proportions of the populations of targeted species. MPA networks aim to reduce fishery-induced mortality of targeted species during critical life stages. Thus, a primary consideration of protecting populations using MPA networks is connectivity — the linking of local populations through the movement of adults or juveniles and the dispersal of larvae. This paper discusses the implications of emerging new knowledge on connectivity for MPA-centric marine resource management in the Philippines, with focus on demersal fishes inhabiting coral reefs, seagrass beds, algal beds, mangroves, and other vital nearshore habitats. The major successes and shortcomings of implementing MPAs are summarized and the evidence for MPA networks improving fisheries via connectivity is assessed. Highlighted are five major challenges for managing marine resources using MPA networks.

Keywords:
coastal resources, fish home range, larval dispersal, population dynamics

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INTRODUCTION

Marine protected areas (MPAs), defined here as sea areas that are fully or partially protected from fishing, are a key approach in managing marine fishery resources worldwide (Kelleher 1999; Mora et al. 2006). MPAs usually have two management objectives: first is to facilitate the recovery of populations of heavily-targeted species inside MPA boundaries and second is to let this build-up of the population boost depleted fisheries through the net export of adults, juveniles, or larvae from MPAs to fishing grounds (Sale et al. 2005; Russ 2006). For demersal marine fish species that have a more site-attached adult phase but highly dispersive larval phase, these two objectives assume that the MPAs are large enough to encompass the home range of most adults and juveniles in the local population and the extent of dispersal of some of the larvae produced by the same population, but small enough to allow export of some adults or juveniles and a large number of larvae (Sale et al. 2005; Moffitt et al. 2011). MPAs that achieve these two objectives are important tools for both marine biodiversity conservation and fisheries management because they may allow populations to thrive within their boundaries and improve, or even sustain, fishery yields (Gaines et al. 2010).

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Fisheries productivity and overall ecosystem health of Philippine coral reefs and associated nearshore habitats have significantly declined over the past half-century due to anthropogenic stressors such as overfishing, sedimentation, and habitat destruction as well as the effects of climate change (Fortes 1988; Primavera 2000; Aliño et al. 2004; Nañola et al. 2011; Licuanan et al. 2017). Currently, MPAs are by far the most widely implemented approach for mitigating overfishing and there is growing interest to scale-up Philippine MPAs into "MPA networks" (Horigue et al. 2012) — systems of many MPAs that protect a sufficient proportion of the population of at least one species. Effective management using MPA networks also means that species are sufficiently protected over their life cycle. Thus, a primary consideration in designing MPA networks is "connectivity", which is the linking of local populations through the movement or dispersal of adults, juveniles or larvae (Sale et al. 2005). As such, connectivity is crucial to making sound decisions not only about the individual sizes of MPAs but also the locations (e.g. vital adult or juvenile habitats) and spacing between MPAs in the network (Green et al. 2014). In theory, MPA networks that consider connectivity would result in faster population recovery and stronger positive effects on fisheries than a collection of MPAs that do not (Gaines et al. 2010).

The main objective of this paper is to highlight the implications of connectivity for MPA-based marine resource management in the Philippines, focusing on demersal fishes that inhabit nearshore habitats such as coral reefs, seagrass beds, algal beds, and mangroves. This paper consists of three sections: (a) summary of the major successes and shortcomings of our MPAs; (b) evaluation of the available evidence for MPA networks benefiting Philippine fisheries through connectivity; and (c) underscoring major challenges for policy-makers, decision-makers, fisheries managers, and marine scientists given the current deficiencies in managing Philippine marine resources using MPAs.

MPAS: SUCCESSES AND SHORTCOMINGS

Successes

Two major indicators for the success of MPAs in the Philippines are the large number of existing MPAs and the long history of MPA establishment (Fig. 1a). Close to 1800 MPAs have been created

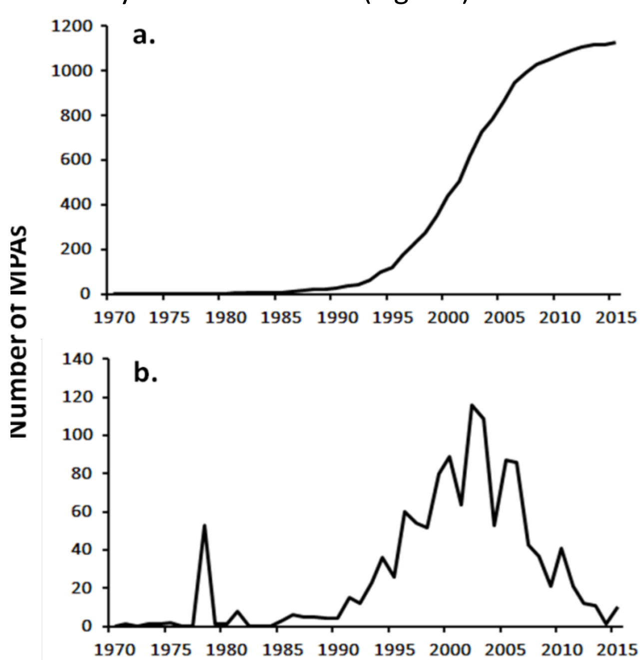

Figure 1. Cumulative number of MPAs (a) and number of new MPAs (b) that were established in the Philippines annually from 1974 (Sumilon Island) to 2016. Data used for these graphs were limited to the 1,255 (out of 1,776) MPAs that had information on the date or year of establishment. Data from Cabral et al. (2014).

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around the country in almost all major islands over a period spanning more than four decades (Cabral et al. 2014). Most (~95%) of these were established as small "no-take" or fully protected MPAs co-managed by local government units (LGUs) and constituent barangays, suggesting that MPAs are widely accepted by coastal communities (Weeks et al. 2010).

The roots of local community support for Philippine MPAs can be traced back to two small islands in the central Philippines. The first is Sumilon Island in southern Cebu, where a small no-take MPA was created in 1974 through the efforts of then Professor Angel C. Alcala of Silliman University (Russ and Alcala 1999). Pioneering scientific studies showed that this MPA, which protected about a quarter of the coral reef area that surrounds Sumilon, sustained the catch of local fishers during the first decade of its existence (Alcala and Russ 1990). However, protective management of the Sumilon MPA failed in late 1983 due to political pressure (Russ and Alcala 1999). The second is Apo Island in southeastern Negros Oriental, not very far from Sumilon. A small no-take MPA that protected about a tenth of local coral reef area was established by the resident fishing community at Apo in 1982 (Russ and Alcala 1999). Long-term monitoring showed that strict protection of the Apo MPA resulted in a steady build-up of fish populations inside the MPA for almost three decades (Russ and Alcala 2010; Russ et al. 2015). Net export or "spillover" of adult fish from the MPA benefiting the local fishery at Apo also developed through time (Russ and Alcala 1996; Russ et al. 2004; Abesamis and Russ 2005).

Arguably, the early social and ecological lessons gained from the experiences at Sumilon and Apo provided the blueprint for the MPA movement in the Philippines (Russ and Alcala 1999; Alcala and Russ 2006). By the mid-1990s and early 2000s, MPA establishment in the Philippines rapidly increased (Weeks et al. 2010; Cabral et al. 2014) (Fig. 1a). This proliferation of MPAs was catalyzed by the devolution of marine resource management to LGUs from the national government, which was made possible by the Local Government Code of 1991 (RA 7160) and strengthened by the NIPAS Act of 1992 (RA 7586) and the Fisheries Code of 1998 (RA 8550) (Alcala and Russ 2006).

Shortcomings

The shortcomings of MPAs in the Philippines may be summarized in five aspects. First is the usual size of individual MPAs. Most (~90%) of our existing MPAs are much smaller than 1 km^2 or 100 ha, which is not surprising given that their day-to-day management occurs at the barangay level (Weeks et al. 2010). The median size of community-based MPAs in the Philippines is about 12 ha (Weeks et al. 2010), or equivalent to an area with a length of 0.4 km and width of 0.3 km (or 400 m x 300 m). A recent review of movement patterns in demersal fishes suggest that MPA sizes of this order offer limited protection to many mobile demersal fish taxa that are targeted by nearshore fisheries in the Philippines (Green et al. 2014).

Second is the proportion of essential fish habitats occupied by existing no-take MPAs, which is a proxy for the proportion of fish populations that is given full protection from fishing. Population theory suggests that MPA networks should effectively protect at least 20-30% of all essential fish habitats in order to ensure fish population sustainability when fishing pressure is moderate to high (White et al. 2010; Hopf et al. 2016). However, the total habitat coverage of no-take MPAs in the Philippines falls short of this threshold, which is a direct consequence of the small sizes of the numerous MPAs. For instance, it is estimated that only about 0.5% of municipal waters in the Philippines are covered by MPAs (Weeks et al. 2010) despite legislation (RA 8550) recommending LGUs to protect at least 15%. If only coral reef habitat were considered, MPAs are estimated to protect only about 3% of total coral reef area regionally (e.g., Visayas region; Alcala et al. 2008) or nationally (Weeks et al. 2010).

Third is management effectiveness. In an evaluation of 564 MPAs in the Visayas, Alcala et al. (2008) concluded that only about one-third were effectively managed based on a set of social criteria (e.g. presence of guards or patrols, sustained funding mechanisms) and ecological indicators (fish

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density or biomass or species richness, and coral cover). This finding implies that the majority of MPAs exist only on paper. Nonetheless, increased fish density, biomass, species richness, and habitat condition have been documented in a good number of MPAs around the Philippines where management had been more effective (PhilReefs 2005; Alcala et al. 2008; Maliao et al. 2009; Maypa et al. 2012).

Fourth are the types of habitat that are protected within MPAs. Most MPAs protect coral reefs and very few include other essential fish habitats such as seagrass beds, algal beds, and mangroves (Alcala et al. 2008; Cabral et al. 2014). These other fish habitats harbor distinct species assemblages that are obviously important in their own right (Fortes 1988; Primavera 2000; Rossier and Kulbicki 2000). They may also serve as nursery or foraging habitats for some target fish species and play a critical role in inter-habitat energy transfers and nutrient dynamics (Mumby et al. 2004; Berkström et al. 2013).

The fifth major shortcoming is the rate of MPA establishment. Available data indicate that in the past two decades, the number of MPAs created annually has decreased dramatically (Cabral et al. 2014). In fact, the data show that the number of new MPAs established in recent years (2010-2015) is similar to those at the start of rapid MPA growth (1990-1995) (Fig. 1b). This may be indicative of declining interest in MPAs as a resource management approach, which is alarming given all of the abovementioned shortcomings, particularly the very low proportion of essential fish habitats effectively protected by existing MPAs.

MPA NETWORKS: EVIDENCE FOR POPULATION AND FISHERIES ENHANCEMENT

As mentioned earlier, faster population recovery and stronger fisheries enhancement can be expected from MPA networks that were designed with connectivity as a primary consideration. In evaluating the evidence for these expectations, it is useful to distinguish two types of connectivity that occur at different stages of the life cycle of many demersal fishes targeted by fisheries: larval connectivity and habitat connectivity.

Larval connectivity is driven by dispersal during the larval stage, which in tropical demersal fishes usually lasts from about 1 to 14 weeks, depending on the species (Lester and Ruttenberg 2005) (Fig. 2). Larval connectivity occurs when the larvae produced by one population disperse and successfully recruit to another population, thereby linking the dynamics of the two (Sale et al. 2005). Therefore, larval connectivity can result in synergistic population recovery within MPAs in a network if the usual distances among MPAs are well within the spatial extent of the larval dispersal envelope (Gaines et al. 2010) (Fig. 2).

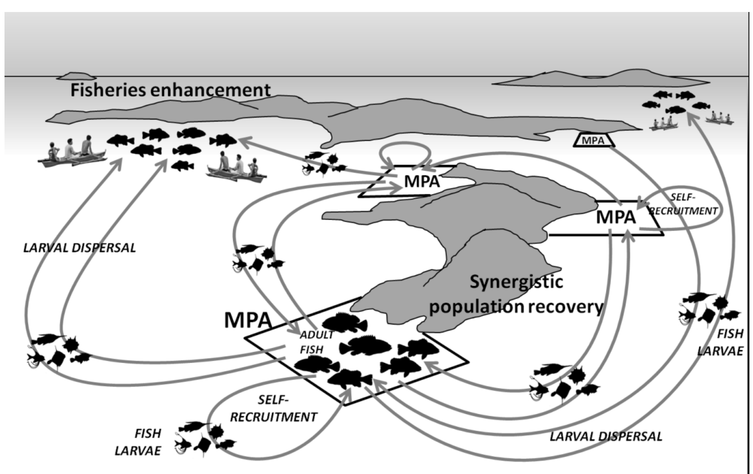

Figure 2. Diagram of larval connectivity (the linking of local populations through larval dispersal) in a system of MPAs that may function as an MPA network. Larval connectivity may result in synergistic population recovery inside MPAs and fisheries enhancement in fishing grounds (Drawn by R. Abesamis).

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Larval connectivity also drives the fisheries enhancement effect of MPAs by subsidising recruitment to fishing grounds (Fig. 2). The "shape" of the larval dispersal envelope (i.e., how the probability of larval settlement changes with increasing distance from the site of fish spawning) can determine the strength and spatial extent of recruitment subsidies to other MPAs and surrounding fishing grounds (Jones et al. 2009). In highly overfished situations, larval connectivity is crucial because the synergy among MPAs will be more strongly driven by population recovery within the MPAs themselves and not the areas that are open to fishing where larval production would be much less per unit area (Pelc et al. 2010). However, the larvae of demersal fishes are not just passively carried away by sea currents (Cowen 2006). They possess sensory and swimming abilities that may allow them to also return to their natal population (Leis et al. 2005). Thus, local fish populations can be sustained both by recruitment through larval connectivity and "self-recruitment" (Sale et al. 2005; White et al. 2010) (Fig. 2).

To date, there is no direct evidence for larval connectivity within MPA networks accelerating population recovery or enhancing fisheries in the Philippines. In fact, globally, the empirical evidence for such effects is very sparse especially for fish (Pelc et al. 2010; Grorud-Colvert et al. 2014). This is due to the fact that the dispersal patterns of fish larvae and the strength of recruitment subsidies originating from MPAs are inherently difficult to measure (Jones et al. 2009; Pelc et al. 2010). Most studies on fish have focused on demonstrating patterns of larval dispersal and estimating the shape of the larval dispersal envelope (Planes et al. 2009; Harrison et al. 2012; Almany et al. 2013). So far, only one study has attempted to demonstrate patterns of fish larval dispersal within an MPA network in the Philippines (Abesamis et al. 2017). This study inferred larval dispersal amongst populations of one species of coral reef fish inside and outside small (typically <0.6 km wide) no-take MPAs in Negros Oriental, including the MPA at Apo Island, spread across approximately 90 km of coastline. A genetic method that can directly match juvenile fish to their parents was used, which enabled the measurement of inferred larval dispersal distances between the sites where the juveniles and parents lived. Inferred larval dispersal distances were found to range from <1 to almost 50 km, linking the local fish populations of several LGUs and many coastal barangays. The study demonstrated for the first time in the Philippines that MPAs (including the Apo MPA) can provide recruitment subsidies to other MPAs and surrounding fishing grounds.

Importantly, the study also provided a first estimate of the shape of the larval dispersal envelope of the fish species for the region (Abesamis et al. 2017). The dispersal envelope suggested that 50% of larvae spawned from an MPA could settle within 33 km; that 95% would settle within 83 km; and that the average dispersal distance was 36.5 km. On the one hand, these figures suggest that the MPAs would strongly depend upon larval connectivity from surrounding MPAs and fishing grounds because the typical sizes of the MPAs are much smaller than the usual larval dispersal distance. On the other hand, they also indicate that larval connectivity amongst all the MPAs and fishing grounds within the study region is strong and can create some degree of population synergy among the MPAs. However, the study emphasized that less than 1% of the coral reef habitat in the study region is protected by MPAs (i.e., 99% of the reefs are open to intensive fishing). This suggests that if fish populations outside the MPAs were already at very low levels due to heavy fishing pressure, system-wide larval connectivity may not be adequate to sustain the fish populations inside the small MPAs over the long term.

Habitat connectivity, in contrast to larval connectivity, can occur within the same local population. In tropical demersal fishes, the main driver of habitat connectivity is the movement of juvenile or adult fish amongst different types of habitat such as coral reefs, seagrass beds, algal beds, and mangroves (Berkström et al. 2013; Green et al. 2014) (Fig. 3). These movements may be related to ontogenetic development, daily foraging, or periodic spawning (Nagelkerken and van der Velde 2004; Jones et al. 2010). By ensuring habitat

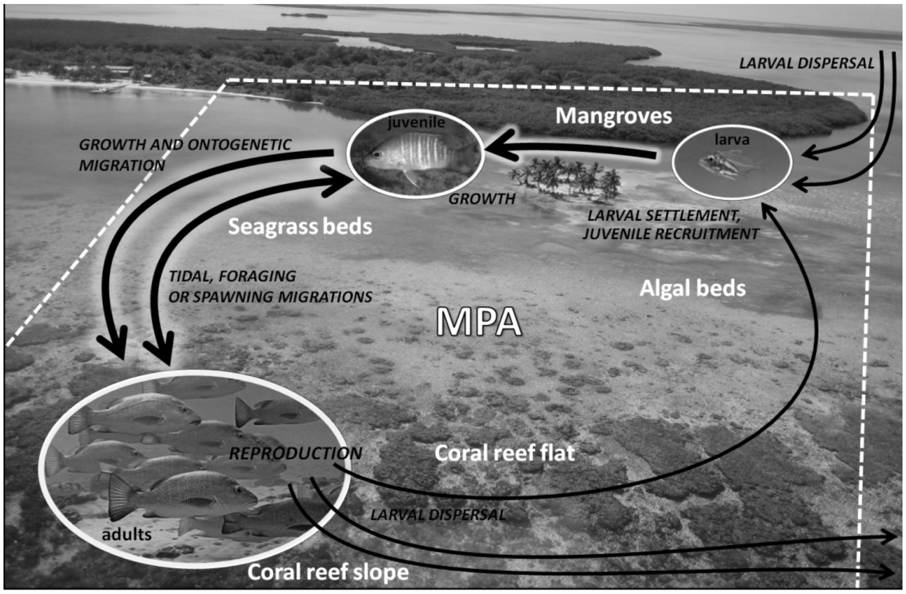

Figure 3. Diagram of habitat connectivity (the linking of habitats through the movement of juveniles and adults) occurring within an MPA that protects different kinds of nearshore habitats used by a fish species during its life cycle (background photo © Jason Valdez/Marine Photobank).

connectivity within individual MPAs or between neighboring MPAs, population recovery will almost certainly be enhanced because fish are protected throughout the longer part of their life cycle during the juvenile and adult stages, which in targeted demersal fish species may last from a few years to several decades (as opposed to weeks for the larval stage) (Choat and Robertson 2006; Grüss et al. 2011; Nagelkerken et al. 2012). Evidence for enhanced fish populations resulting from the presence or protection of habitat connectivity has grown in the past 15 years. For instance, one very highly-cited study demonstrated that coral reefs in the Caribbean had higher fish biomass where mangroves were present near reefs because the mangroves serve as nursery habitats (Mumby et al. 2004). A more recent study in Australia and the Solomon Islands suggested that fish population recovery was stronger within MPAs near mangroves compared to MPAs far from mangroves (Olds et al. 2013).

In the Philippines, no study has shown evidence for enhanced fish population recovery within individual or networks of MPAs resulting from the protection of habitat connectivity. The available studies so far have only described patterns of assemblage structuring, habitat use or movement of fish across coral reefs, seagrass beds, and mangroves. For instance, Honda et al. (2013) showed that assemblages of fish in coral reef, seagrass, and mangrove areas were distinct from each other regardless of geographic location (Puerto Galera, Mindoro Oriental versus Laguindingan, Misamis Oriental). Furthermore, they showed that 23% of the targeted fish species at these locations used multiple habitats. In a related study in one location (Laguindingan), they used acoustic telemetry to show that individuals of three targeted fish species moved daily between coral reef and seagrass habitats encompassed by an MPA but the temporal pattern (daytime versus nighttime) of these movements varied among the species (Honda et al. 2016). In a different study within the Mantalip reef system in Negros Oriental, Ramos et al. (2015) showed that about 53% of the coral reef-associated fish catch (pelagic species excluded) were composed of species that also utilized seagrass and mangrove habitats. The preliminary results of my own studies in a reef complex off the southwestern coast of Siquijor show that about 12% of the total annual fish yield (pelagic species included) consisted of coral reef-associated fish species that

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are known to also utilize seagrass beds, algal beds, and mangroves (Abesamis et al. unpublished data). All of these aforementioned studies suggest that non-trivial positive effects on nearshore fisheries in the Philippines can be expected if individual and networks of MPAs effectively protect habitat connectivity.

CHALLENGES FOR MARINE RESOURCE MANAGEMENT

Despite the shortcomings and lack of unequivocal evidence for MPA networks enhancing fish populations and fisheries, MPAs remain as important and potent tools for marine resource management in the Philippines due to widespread acceptance by LGUs. In this section, highlighted are five challenges that must be addressed in order to improve the current situation with MPAs and to help ensure that networks of MPAs will be more effective in fisheries management. The first four are challenges that are more relevant to policy-makers, decision-makers, and fisheries managers while the fifth is directed more towards marine conservation and fisheries scientists.

Challenge 1: Create, and strictly protect, more and larger no-take MPAs that encompass greater scales of adult fish home ranges, where feasible

As mentioned above, the usual size of no-take MPAs in the Philippines is about 12 ha (linear dimensions in the order of <0.5 km). MPAs of around this size can protect highly site-attached fish species that are not usually targeted for food (e.g. damselfishes, butterflyfishes, and angelfishes) but would be less effective for small (20–30 cm body length), medium (30–50 cm), and large (>50 cm) targeted species that are more mobile (Green et al. 2014). Creating more MPAs of sizes in the order of 30 to 60 ha (e.g. longest dimensions of one to two km of coastline assuming a seaward length of 0.3 km) would offer greater protection for many small and some medium species (e.g. parrotfishes, surgeonfishes, snappers, groupers). Much bigger MPAs in the order of 60 to >150 ha (e.g. longest dimensions of two to >five km of coastline) can effectively protect larger target species (snappers, groupers, jacks) (Green et al. 2014). However, large fish species that can move tens of km will require much larger MPAs that are less likely to be feasible at the level of LGUs. For these species, protection of critical spawning or juvenile habitats that may be smaller in size would be critical.

Strict protection of no-take MPAs cannot be overemphasized. In fact, no-take MPAs should be protected permanently to allow fish populations to fully recover. In highly overfished regions, full population recovery of both highly productive shorter-lived species and less productive longer-lived species may be quite slow and could take several years to several decades (Abesamis et al. 2014). For instance, Russ and Alcala (2010) suggest that populations of large predatory fishes (snappers, groupers, emperors) may take up to 40 years to fully recover inside the no-take MPA at Apo Island. Strict protection is also paramount because poaching or illegal fishing can rapidly remove fish biomass that had accumulated inside MPAs at very slow rates. Studies at Sumilon Island before and after the failure of protective management in late 1983 provide an extreme but important example. Strong declines in fish density of up to >90% for some longer-lived species were documented inside Sumilon MPA after it was opened to intensive fishing including *muro-ami* and dynamite fishing (Russ and Alcala 1989). These declines occurred within a time scale of weeks to months, negating fish population gains over ten years of protection that enabled Sumilon MPA to export fish biomass (Alcala and Russ 1990).

Challenge 2: Where applicable, include all essential nearshore fish habitats in no-take MPAs in a continuous swath rather than protecting these habitats in isolation

Establishing no-take MPAs that encompass mangroves, seagrass beds, macroalgal (e.g. *Sargassum*) beds, soft-bottoms, and other essential fish habitats in a continuous swath together with nearby coral reefs will help ensure the protection of habitat connectivity. This is highly relevant for LGUs that have within their jurisdiction large reef complexes composed of a mosaic of different habitats

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for demersal fish (e.g., Bolinao in Pangasinan, San Juan in Siquijor, Panglao in Bohol,Bindoy and Bais in Negros Oriental, and many others). However, this does not mean that MPAs would be less effective in coastal areas where a variety of essential fish habitats is not present. Mangroves, seagrass beds, macroalgal beds, and soft-bottom habitats are important in themselves and a significant proportion of these habitats should be protected in MPAs even if not in combination with other habitats. The main point is to ensure representation within MPAs of all essential fish habitats that are present in the LGU's jurisdiction and avoid limiting MPAs to just coral reefs.

Challenge 3: Create dense systems of closely-spaced no-take MPAs that protect at least 20% of all essential fish habitats within several LGUs that span more than 50–100 km of coastline

A recent review of the empirical evidence for the spatial scale of larval dispersal in coral reef fishes suggested that the spacing of MPAs within a network should not be more than 15 km in order to help ensure strong larval connectivity (Green et al. 2014). This review further recommended that in regions where MPAs tend to be small (e.g. <100 ha or 1 km^2), spacing should be much less than 15 km because smaller MPAs would produce less larvae compared to larger ones. Spacing MPAs much less than 15 km to enhance larval connectivity seems very feasible for LGUs that commit to establishing MPA networks because the usual coastline length of coastal municipalities in the Philippines is in the order of <10 to a few tens of km. However, most empirical studies on fish larval dispersal indicate that larval connectivity can still be substantial within 50 km and that dispersal has a long "tail" (the farthest distance that a larva can probably reach), which can extend to more than 100 km (Green et al. 2014). In the archipelagic setting of the Philippines, this implies that larvae from the MPA network of one LGU can enhance the fish populations of nearby LGUs along the same coast or seed those LGUs further away on a different island in another province. Thus, one way to harness the synergistic effect of larval connectivity more effectively is for several neighboring LGUs that span a coastline length of 50–100 km or more to each create a network of closely-spaced MPAs that protects at least 20% of all essential fish habitats within their respective jurisdictions. This synergistic effect is a primary ecological basis for forming "alliances" among LGUs when scaling up to MPA networks (Horigue et al. 2012).

Challenge 4: Manage fisheries outside of no-take MPAs especially if there are still big shortcomings in Challenges 1 to 3

LGUs will take some time to achieve targets for optimal size, habitat representation, minimum habitat, or population coverage and strict enforcement of no-take MPAs. For instance, Weeks et al. (2010) showed that to achieve the target of 10% MPA coverage of the Philippines' total coral reef area (Arceo et al. 2004), each coastal barangay would have to establish at least one new no-take MPA of about 30 ha each to boost the coverage of existing MPAs. They estimated that it would take until 2076 (from a starting point of 2009) to achieve this target if new MPAs were created at a rate equivalent to the maximum historical rate in 2002 (Fig. 1b). Projections by Aliño et al. (2006) also suggested that it would take 100 years (from a starting point of 2001) to achieve the 10% MPA coverage target. If an LGU cannot achieve an MPA coverage target of 20% within a more reasonable period (e.g., within 10 years) and fishing pressure in surrounding fishing grounds remains unregulated, then fish stocks will continue to decline or even collapse (White et al. 2010; Hopf et al. 2016). Therefore, it is crucial for LGUs to enforce fisheries management measures other than MPAs to boost spawning stocks outside of MPAs and maintain adequate connectivity. Strict enforcement of fishery laws that ban illegal fishing methods such as the use of explosives, poisons, and active gears is a good starting point. Where feasible, other measures such as seasonal closures, gear-based controls (e.g., mesh size limits), size limits (e.g., minimum body size of fish), "slot" limits (i.e., minimum and maximum body size of fish for species that exhibit sequential hermaphroditism), and catch quotas should also be implemented. However, in many situations, there will be a need to decrease or re-allocate fishing effort. One way to do

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this is to employ participatory or consensus-based approaches guided by ecological and fisheries data (Armada et al. 2018).

Challenge 5. Empirically evaluate if and to what extent consideration of Challenges 1 to 4 can enhance MPA network performance and surrounding fisheries

There is an urgent need for well-designed studies that aim to measure the synergistic connectivity effects of MPA networks because good empirical evidence for such effects is still lacking (Grorud-Colvert et al. 2014). These studies are crucial because they can show why some MPA networks are more (or less) effective depending on the degrees to which they have met the four preceding challenges. Effectiveness will also vary because MPA networks will largely differ in terms of local ecological setting (e.g., open coast vs. bays vs. inter-island) and social conditions (e.g., coordinated alliances vs. incidental networks). The lessons gained from empirical studies can provide improved guidance for designing new MPA networks and adaptive management of existing ones.

Ideally, empirical studies will require regular (e.g., annual) monitoring of fish populations inside all of the no-take MPAs within the network and appropriate control sites in areas that remain open to fishing (Fig. 4). Moreover, regular monitoring of fish catch (e.g., catch per unit effort and total yield) will have to be conducted at many replicate sites distributed across the region encompassed by the MPA network. Monitoring will have to be conducted over the long term (decades) due to the intrinsic rates of fish population recovery (Abesamis et al. 2014), significant recruitment variability (Pelc et al. 2010), environmental disturbances, and lag effects (Graham et al. 2007). This indicates that research

a.

Challenges	Network A	Network B
1. More and larger MPAs in network	Yes	No
2. Critical habitats included in MPA network	Yes	No
3. Dense MPA network protect at least 20%	No (10%)	No (1%)
4. Fisheries management outside MPAs	Yes	No

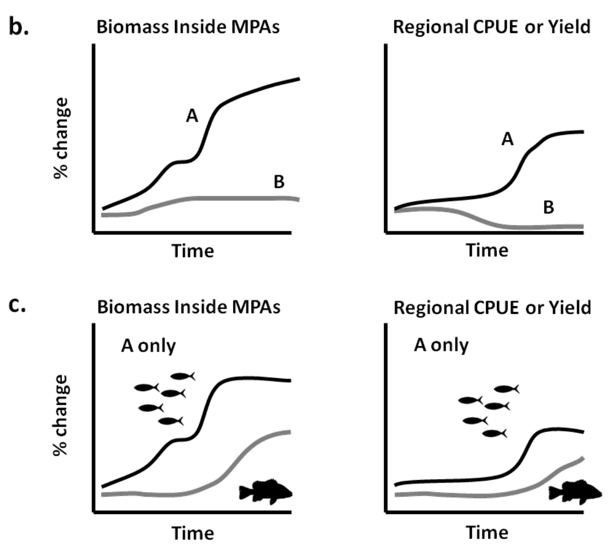

Figure 4. Possible hypotheses that can be tested empirically in evaluating the synergistic effects of MPA networks. This example depicts a comparison of two MPA networks (A and B) that differ in the extent to which four management challenges have been addressed (a). One hypothesis is that the MPA network that was more successful in protecting connectivity will show faster population recovery and fisheries enhancement (b). Another hypothesis is that highly productive fish species will show faster and more significant population recovery and fisheries enhancement than less productive fish species in the more successful MPA network (c).

funding over several phases that encompass 10–20 years or more will have to be secured.

Hypotheses about the rates of population recovery and fisheries enhancement have to be tested. For example, two MPA networks with different management histories can be compared, with one network having more success in addressing the four preceding challenges compared to the other (Fig. 4a). In this comparison, one hypothesis would be that population recovery and fisheries enhancement would be much more significant and faster in the MPA network that protects connectivity more effectively, assuming all else equal (Fig. 4b). The MPA network which had less success in addressing the challenges may show weaker recovery inside MPAs and fish catch per unit effort or yield could decline through time (Fig. 4b). A sub-hypothesis for the more successful MPA network may be that population recovery will occur earlier in the more productive fish species (e.g., smaller, more abundant, and shorter-lived planktivorous species such as fusiliers) than in the less productive fish species (e.g., larger, less abundant, and longer-lived carnivorous species such as snappers), with fisheries enhancement occurring later in both species groups but reflecting the lag between the two groups, assuming all else equal (Fig. 4c).

CONCLUSION

MPAs are not a panacea for declining marine biodiversity and fisheries productivity but they should remain as an important rallying point for marine conservation and fisheries management efforts in the Philippines. Implementing well-designed MPA networks that take into consideration larval and habitat connectivity can result in synergistic effects that are likely to have substantial positive impacts on fisheries over broader spatial scales. However, there is an urgent need to address the major shortcomings in implementing MPAs (i.e., the small sizes, low representation, coverage of habitats, and lack of strict protection), reverse the declining trend in the establishment of new MPAs, and empirically evaluate the synergistic effects of MPA networks. It must be stressed that MPAs represent only one of the many tools that can be used for managing marine resources. <u>MPA networks will become more effective if combined with conventional fisheries management approaches that can lessen harvesting pressure in the larger surrounding areas outside of MPAs that are open to fishing.</u>

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