Local benefits of community-based management: Using small managed areas to rebuild and sustain some coastal fisheries

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Introduction

Many coastal fisheries around the Pacific are in decline from overfishing (SPC 2013) and are threatened by climate change (Pratchett et al. 2011). Overfishing has been driven by a number of factors, including more people and a greater demand for fish; improvements in technology that make it easier to harvest fish (e.g. monofilament fishing line and nets; snorkelling and scuba equipment, spear guns, underwater diving lights, outboard engines, better boats) and greater access to local, regional and global markets to convert catch into money (Dalzell et al. 1996). Many Pacific Island communities have taken advantage of the economic opportunities that are available by fishing for export markets. Sea cucumber, shark fin and trochus are important export commodities for remote communities because they do not require refrigerated storage. In addition, fishing for grouper and other high-value species, particularly at fish spawning aggregations (FSAs), supplies the live reef food fish trade (LRFFT). All of these fisheries are in trouble in many parts of the Pacific (Bell et al. 2009; Purcell et al. 2013; Sadovy et al. 2003), and it is a high priority to restore their health and devise strategies for sustainability so that they can continue to serve the needs of coastal communities (SPC 2013).

Pacific Island communities have interacted with their fisheries for thousands of years based on accumulated, detailed knowledge about their environment and the animals they harvest (Johannes 1981; Allen et al. 1989). Although traditional forms of community-based management are extremely diverse (Johannes 1981; Ruddle 1996; Veitayaki 1997), the basis for their effectiveness is the ability of certain community members (e.g. community leaders or chiefs, family groups, clans, and whole communities) to control fishing in a particular area (i.e. who can fish, how they can fish, when they can fish, and what they can take). This type of "spatial management" is made possible by the existence of customary marine tenure (CMT) systems that remain common throughout the Pacific (Johannes 2002; Ruddle 1996; Ruddle et al. 1992). A common management strategy is the practice of closing an area to some or all types of fishing for a certain period of time. There are numerous reasons why an area is closed: increasing the number of fish in the area; taming the fish inside the area to make them easier to catch once fishing resumes; allowing for more equitable access to resources; and stockpiling for important events such as funerals, weddings, feasts, or to raise funds for a particular goal such as building a church (Fabinyi et al. 2013; Foale et al. 2011).

More recently, scientists studying Pacific Island cultures and other traditional management systems have suggested using area closures to help rebuild and sustain coastal fisheries in industrialised countries (e.g. European nations, United States and Australia). Although rare in Pacific Island traditional management systems, scientists have suggested that using areas that are permanently closed to fishing — called "reserves" — might be the best way to rebuild and sustain coastal fisheries in the long term. Around the world, there are many barriers to using reserves for fisheries management, including the cultural acceptance of a new practice. But perhaps the largest barrier is that scientists are only now beginning to understand, and more importantly, test through studies, how reserves can rebuild and sustain coastal fisheries.

This article begins with a discussion of how reserves and managed areas could be used to improve coastal fisheries in theory, a summary of some recent scientific evidence about how they work, and

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by highlighting some of the costs and benefits of using reserves for Pacific communities. The results of a recent study are then summarised; the authors worked with five fishing communities on the south coast of Manus Island in Papua New Guinea to test whether and how communities benefit from a small managed area (Almany et al. 2013). The article concludes by reporting on how these five communities and their neighbours, inspired in part by the results of the coralgrouper study, have created a collaborative governance structure to make collective management decisions for their fisheries.

How reserves could rebuild and sustain coastal fisheries – theory and evidence

The life of most fish species can be divided into two distinct phases: the larval phase and the non-larval phase (Leis and McCormick 2002). With only a few exceptions, all fish produce eggs. Some, like damselfish or triggerfish, lay them onto something (e.g. coral, rocks, shells, nests they make in the sand or rubble) and guard the eggs until they hatch. Others, like grouper or snapper, release their eggs directly into the sea, where after a day or so, they hatch. Both types of eggs hatch into tiny fish called larvae, and these larvae — depending on the species — spend days, weeks and even months growing and developing in open waters away from the coast. This period of a fish's life is called the "larval phase." At the end of the larval phase, larvae are much larger and more developed, and if they find a suitable place to live, leave the open water in a brief process called "settlement" and begin the "non-larval phase" of life. This non-larval phase, which from this point on we shall refer to as "fish" (this includes newly-settled larvae known as recruits, as well as juveniles, sub-adults and adults), is the one that scientists are most familiar with, and it takes up the rest of the fish's life. It is during this phase that fish can be caught, managed and studied. The larval phase has been much more difficult to study. Where do these larvae go? How far away from their parents do they travel before they settle? Answering these questions about the larval phase is important for understanding how reserves can work, and how the benefits of reserves are distributed among fishing communities.

When fishing stops on any reef or within a certain area, it is no surprise that with time, the number and size of fish inside that area increases. Numerous scientific studies have shown this effect clearly (e.g. Fenberg et al. 2012; Lester et al. 2009), although depending on species, it may take many years to see that increase after fishing stops (Abesamis et al. 2014). While fishers are not allowed to fish within the reserve itself, reserves can help rebuild and sustain fisheries in two major ways (Gell and Roberts 2003; Russ 2002).

The first way is called "spillover", and this refers to fish leaving the reserve and traveling to fishing areas where they can be harvested by fishers. After the larval phase fish are relatively easy to study, and so there is much evidence that spillover occurs from studies that tag fish within the reserve and then catch or observe them outside the reserve at some later time. However, it is also known from these and other studies that most fish do not move far (Green et al. in press), and so the movement of fish from reserves to fished areas is common over a few hundred meters, but not much farther (Abesamis and Russ 2005; Halpern et al. 2009).

The second way in which reserves can help rebuild and sustain fisheries is through the increased production of larvae from inside the reserve (Russ 2002). Because there are more and larger fish inside the reserve, there are significantly more larvae than a similar sized fished area. Not only do more fish produce more larvae, but also the large fish inside the reserve produce far more larvae than small fish. For example, a 50-cm female leopard coralgrouper (*Plectropomus leopardus*) can produce more than three times the number of eggs than a 35-cm female (Carter et al. 2014). Most of these larvae will die during the larval phase — scientists estimate as much as 99% — because they are eaten by other animals, starve, or are swept far away from suitable coastal habitats by currents and tides. During the larval phase, larvae have the potential to travel far from where they were born as they ride the currents and tides and, after growing, begin swimming. Until recently, answering a seemingly simple question — where do larvae go during the larval phase? — had been impossible.

Recent scientific breakthroughs in several fields, most notably genetics, combined with research partnerships between scientists and fishing communities, have for the first time allowed measurement of where larvae go. These studies began in the late 1990s, and most have worked with a few small, non-fishery species as scientists refine the techniques and methods (see reviews by Green et al. in press; Jones et al. 2009). In recent years, a few studies have measured where larvae go in fishery species such as grouper and snapper on the Great Barrier Reef in Australia (Harrison et al. 2012) and grouper in Papua New Guinea (Almany et al. 2013). Across all these studies on non-fishery and fishery species, and contrary to what was expected, results show that some larvae do not travel far from where they were born, moving only a few hundred meters to several kilometres during the larval phase before they settle. This suggests that reserves can benefit nearby fisheries by supplying larvae to fished areas near the reserve, thereby replacing the fish caught by fishermen and helping to sustain the fishery over the long term.

Costs and benefits of using reserves for Pacific Island communities

As noted previously, community-based fisheries management is widespread in the Pacific. In particular, the concept of customary marine tenure (CMT) is common, and here we define a CMT area as a coastal area that is owned and fished by a particular community, and where that community sets rules that determine who can fish within their CMT area. Depending on the country, the government often officially and legally recognises such community rights over coastal fisheries, and there has been a recent shift in some countries to return to, and strengthen, CMT arrangements to improve management. The key point is that communities have the ability and legal right to make decisions about how to manage the resources in their CMT area — who can fish, and where, when and how. Several fisheries management and non-governmental organisations (NGOs) working in the Pacific have suggested that communities establish permanent no-fishing areas — reserves — within their CMT area to improve fisheries management. However, for a number of reasons, reserves have both known and unknown costs and benefits for communities, and it is important to understand these before communities decide whether to set up a reserve.

Costs of reserves

CMT areas are often small, and many Pacific Island communities rely heavily on harvests from them for food and as a source of income. In many places, CMT areas consist of just a few kilometres of coastline and its associated habitats (e.g. coral reef, mangrove or seagrass). As a result of small CMT area size and heavy reliance on harvests, setting up a reserve represents a significant cost to the community — the community is giving up the ability to obtain food and income from that area. This is a known and obvious cost to the community.

Less understood and unknown is the cost to the community of the reserve underperforming or not performing its function of rebuilding and sustaining that community's fishery. This relates to the two main ways in which a reserve can provide fishery benefits: 1) spillover of fish from the reserve to nearby fished areas, and 2) increased production of larvae by fish living within the reserve.

Spillover of fish from the reserve to fished areas does occur and is likely to benefit the community that established the reserve because fish generally do not move far. Thus, any fish that do move from the reserve are likely to remain within that community's CMT area. However, will spillover be enough to make up for the amount of fish historically taken from the reserve area where fishing is no longer allowed? And if so, how long will it take for the reserve to make up for this lost catch? Answers to these important questions are unknown and require further study. But at least for the first several years after establishing the reserve, we argue that the answer is probably "no" for most small, community-based reserves — the amount of spillover from the reserve will be less than the amount of fish they have lost by establishing the reserve.

However, as we argued above, the key way in which a reserve is likely to benefit fisheries is through the increased production of larvae from the more numerous and larger fish living inside the reserve. Again, depending on species, the build up in abundance and increase in average size will take time (Abesamis et al. 2014), but it is the increased larval production by the reserve that will be the main, lasting fishery benefit of it. Furthermore, once fish abundance and average size increases to its maximum, and provided the reserve remains safe from other disturbances and no fishing occurs, the reserve should continue to produce lots of larvae year after year. But the important question from the community's perspective is, who benefits from the reserve? If all the larvae produced by the reserve are thought of as benefits, and remembering that larvae can travel long distances, then to understand who benefits from a reserve and how much, and where those larvae go, must be determined.

Because many CMT areas are small, and any reserve established within a CMT area will be even smaller, there is a strong possibility that many larvae will leave both the reserve and CMT area during the larval phase. If all the larvae produced by the reserve leave a community's CMT area, then the community that established the reserve receives no larval fishery benefits from its reserve; those larval benefits end up in some other community's CMT area (Foale and Manele 2004). This is clearly a cost to the community that established the reserve and gave up the opportunity to fish inside it. The community to which those larvae travel therefore benefits not from its own actions — after all, they did not set up the reserve — but from the actions of the community that set up a reserve. In this scenario, communities that set up reserves to improve their own fisheries would not receive the benefits from their actions; other communities would realize those benefits wherever those larvae settle.

Benefits of reserves

An alternative scenario is that some larvae produced by the reserve do not travel far during the larval phase, but instead settle somewhere within the CMT area belonging to the community that set up the reserve. In this case, the community that set up the reserve will benefit directly from it. As discussed above, evidence so far suggests that some larvae do indeed travel only short distances before settling, but others will no doubt travel outside a community's CMT area. However, the exchange of larvae between both fish populations and CMT areas can be beneficial. For example, larval exchange between fish populations has important benefits for the long-term persistence and resilience of those fish populations (e.g. Almany et al. 2009). If a fish population declines owing to overfishing, because of a natural disaster, or from some other cause, larvae that come from nearby healthy populations will allow the damaged population to rebuild and recover — something it could not do without those larvae from elsewhere.

From a community perspective, and provided at least some larvae produced by the reserve remain within the CMT area of the community establishing the reserve, the exchange of larvae between CMT areas could be beneficial under certain conditions. For example, in many places adjacent CMT areas consist of communities that are related by a common language, traditions, customs, marriage and trade. These communities, therefore, have a history of working together on some level. Understanding whether and how much these communities and their CMT areas are connected by the exchange of larvae between them — something that will always remain hidden from local knowledge systems because of the difficulty of observing the larval phase — could provide an important foundation for strengthening working relationships among communities, and lead to collaborations between communities to collectively, and therefore more effectively, manage their connected fisheries. When CMT areas are strongly connected to each other by the exchange of larvae, actions taken by one community will affect its neighbours, and collective management decisions taken together by all communities should result in better management outcomes across these connected CMT areas. This last point also emphasises the value of research partnerships between communities and researchers; in working with researchers, communities gain access to important information about their fisheries and how they can best be managed that is not otherwise available through traditional knowledge mechanisms, and researchers benefit from the detailed local ecological knowledge, fishing expertise and assistance of communities (Almany et al. 2010).

Coralgrouper (*Plectropomus areolatus*) study at Manus Island, Papua New Guinea

Here we summarise the results of a study designed to answer some of the questions discussed above and discuss the study's implications for community-based management (Almany et al. 2013). The three main research questions were:

1. How far do larvae that are produced at a small, managed squaretail coralgrouper (*Plectropomus areolatus*) FSA travel?
2. Do some larvae from the managed aggregation settle within that community's CMT area?
3. Do some larvae and fish from the managed aggregation travel to other CMT areas?

We worked with five communities along the south coast of Manus Island, Papua New Guinea in 2010 (Figs 1 and 2). A complete explanation of how we worked with communities can be found in Almany et al. (2010). We also report on information not reported elsewhere, involving the movements of adult fish between their normal home ranges and the aggregation site.

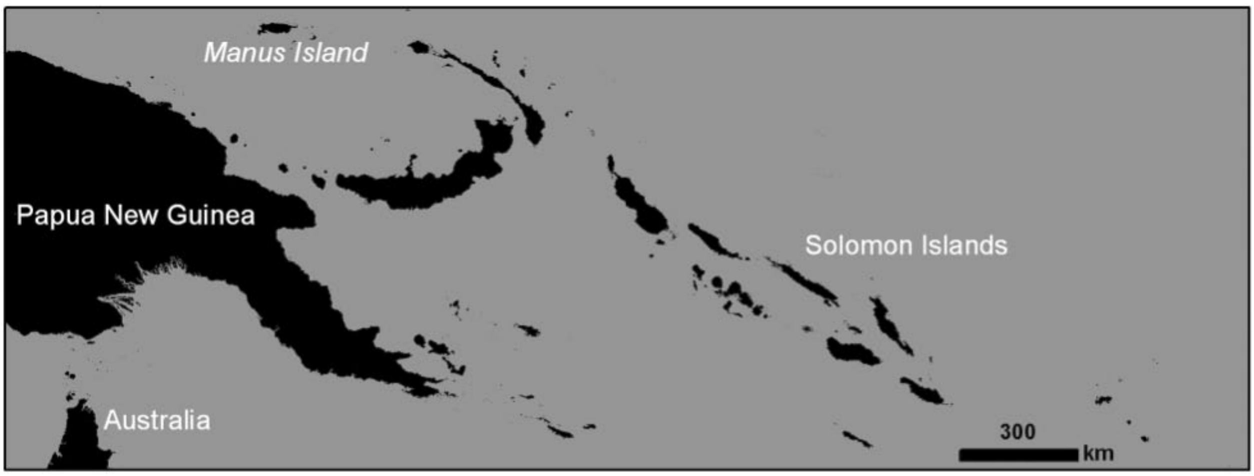


Figure 1. Location of Manus Island, Papua New Guinea within the region. (Land is black, water is light grey.)

The five communities, from west to east, are Timonai, Tawi, Locha, Pere and Mbunai (Fig. 3). These are communities of the Titan people who also occupy several offshore islands to the south and southeast of this area of coastline (Fig. 2: Mbuke, Baluan, Lou, and Rambutyo). Titans are almost exclusively fishermen who rely predominantly on the sea for their livelihoods. They obtain agricultural products and building materials by trading marine resources with inland communities. Each Titan community has its own CMT area and has the customary rights to control fishing and enact management within its area. The boundaries between CMT areas (Fig. 3) are well defined and well known by fishers within all communities. Each of the five community CMT areas includes one or more FSA site where several species of grouper and other species gather for reproduction (i.e. to produce larvae). These FSA sites are well known to fishermen, and some FSAs have been fished to supply the LRFFT in the past few decades (Hamilton and Matawai 2006). The length of the coastline of our study area, between the western boundary of the Timonai CMT area and the eastern boundary of the Mbunai CMT area, is approximately 75 km (Fig. 3).

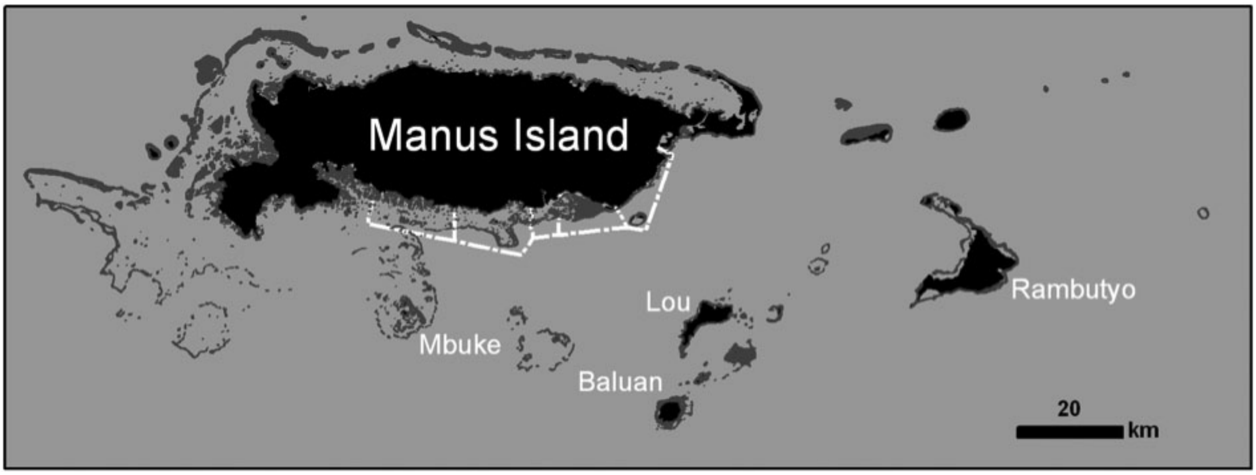


Figure 2. Manus Island, Papua New Guinea, and its offshore islands and coral reefs. White dashed lines on the south coast of Manus Island outline the squaretail coralgrouper study area consisting of five communities and their customary marine tenure areas.
(Land is black, coral reefs medium grey, and water light grey.)

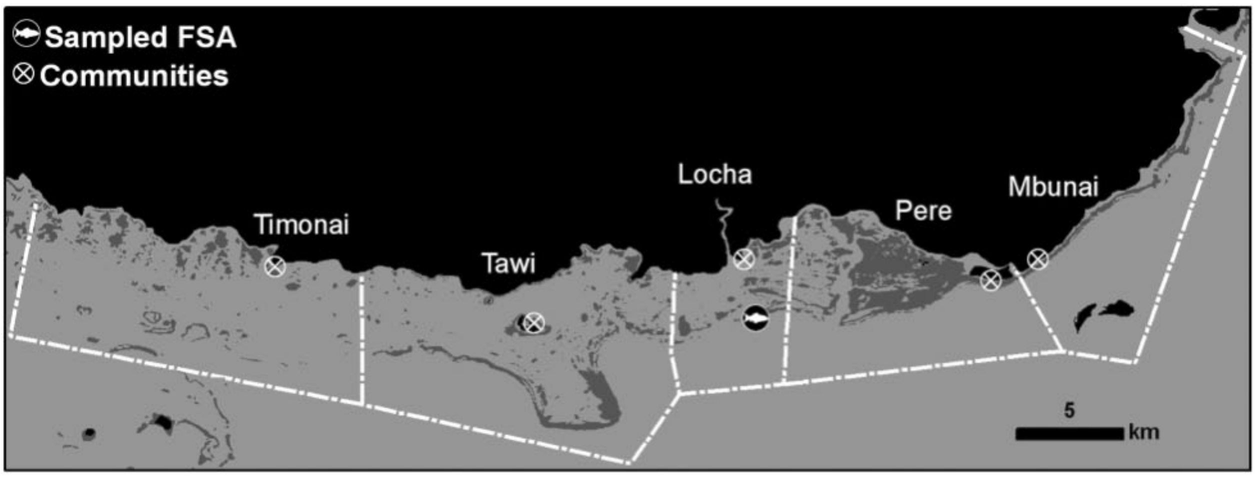


Figure 3. Study area on the south coast of Manus Island, Papua New Guinea. White dashed lines delineate customary marine tenure (CMT) boundaries between communities. A circle with a white X indicates the location of the main population centre in each CMT area, and the name of that population centre and CMT area is in white text. The black circle with the white fish inside indicates the location of the fish spawning aggregation (FSA) within Locha's CMT that we sampled. Note that the locations of eight other FSAs within the study area are not shown.
(Land is black, coral reefs medium grey, and water light grey.)

Figure 4. Small Titan outrigger canoe. These were used by spearfishermen to collect juvenile coralgrouper from the study area (Photo: Glenn Almany).

Figure 5. Fishers record local names of reefs on satellite imagery (Photo: Michael Berumen).

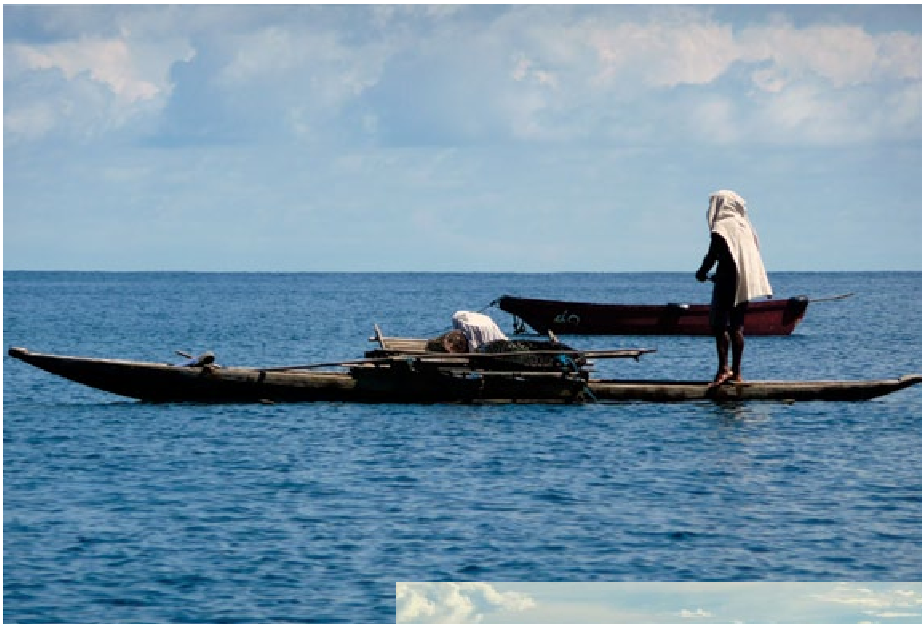
Figure 6. Study authors Hamilton (left) and Almany (right) discussing results with fishermen (Photo: Tom Almany).

We focused our research on one FSA within the Locha community's CMT area (Fig. 3), and we do not show the locations of other FSAs in our study area to prevent exploitation of these sites by outside fishermen. We also focused our research on a single grouper species, the squaretail coralgrouper (*Plectropomus areolatus*), known in the Titan language as *kekwa*. In Manus, this species forms aggregations at FSAs throughout the year, but aggregation size is largest during the peak spawning months of April–August (Hamilton et al. 2012a). Studies from other places show that male and female *P. areolatus* leave their normal home range sites and travel anywhere from 0–30 km to an FSA site for reproduction, after which they return to their normal home range site (Green et al. in press). Local fishers primarily target this species during aggregation periods, using both hook-and-line and spearfishing, both during the day and night. This species is particularly vulnerable to night-time spearfishing as it sleeps in shallow water, often just a few meters deep (Hamilton et al. 2012b). In Manus, some of the catch is consumed locally and some smoked and transported to markets for sale in the provincial capital of Lorengau several hours away by sail (Fig. 4) or outboard engine. In many places in the Pacific, the demand for coralgrouper to supply the LRFFT has driven overfishing of many FSAs and, throughout its range, *P. areolatus* populations are declining (Rhodes and Sadovy de Mitcheson 2012). In 2008, the species was designated as "vulnerable" by the International Union for Conservation of Nature (IUCN) (Chan et al. 2008).

Working with The Nature Conservancy (TNC), some communities in the study area initiated community-based monitoring and management programmes at of three FSAs in 2004 (Hamilton et al. 2005). One community, Locha, responded to declines at its FSA by creating a 36 ha management area around their FSA in 2004, which consists of 13% of their total CMT area. Within this managed area, the community permitted hook-and-line fishing for local consumption and banned all forms of spearfishing.

We worked closely with the Locha community to design the study, and also worked with the four adjacent communities. Fishermen from all five communities provided the local names of all individual reefs and parts of reefs in the study area, which were added to maps based on high-resolution satellite imagery (Figs. 5, and 6). (Copies of these maps were then provided to each community at the beginning of the study.)

From 29 April to 14 May 2010, approximately 20 fishermen from Locha fished for aggregating coralgrouper at the Locha FSA using hook-and-line gear during the day (Figs. 7 and 8). Each captured fish was measured (total length, TL), its sex (male



Figures 7 and 8.
Locha fishers fishing for adult squaretail coralgrouper at the Locha FSA (Photos: Glenn Almany).

or female) was determined by examining a sample of gametes (eggs or sperm), and a small piece (1 cm x 1 cm) of the rear part of the dorsal fin was removed with scissors and preserved in ethanol for genetic analysis (Figs. 9 and 10). Before returning captured adults to the FSA, we tagged each fish with a 100-mm long, individually numbered, external tag (Fig. 10). We asked fishermen from all five communities to provide us with the tags and capture location of any tagged fish that they captured during the 6 months after we sampled adults at the FSA to determine whether adult coralgrouper moved across CMT boundaries when they travelled between their normal home sites and the Locha FSA.

From 04 November to 15 December 2010, approximately 100 spearfishermen from all five communities collected juvenile coralgrouper from their respective CMT areas and, using the maps we created, recorded the name of the reef from which each fish was collected. For collected juveniles, each fish was measured (total length, TL) and a small piece (1 cm x 1 cm) of the dorsal fin was removed with scissors and preserved in ethanol for genetic analysis. In the laboratory, the DNA from the tissue samples taken from adults and juveniles were compared to each other using a method called parentage analysis. Specific details about this analysis can be found in other publications (Harrison et al. 2013; Saenz-Agudelo et al. 2009), but essentially this method compares the DNA of adults with those of juveniles, and can determine parent–offspring relationships. In other words, by comparing DNA taken from adults and juveniles, it can be determined whether those adults are the parents of those juveniles. Because we know both the location of the Locha FSA from which we sampled adults and the location from which each juvenile was collected, for any juvenile born from parents sampled at the Locha FSA, we can measure the distance it travelled during its larval phase.

Figure 9. Research team members measuring and tagging an adult squaretail coralgrouper captured at the Locha FSA (Photo: Glenn Almany).

Figure 10. Tagged adult squaretail coralgrouper about to be released back to the Locha FSA (Photo: Glenn Almany).

Results

Fishermen captured 416 adult coralgrouper from the Locha FSA. We used underwater visual census surveys of the FSA to determine the total number of adults present, and estimate that there were approximately 967 coralgrouper present at the FSA. We therefore captured and sampled approximately 43% of all coralgrouper at the FSA. Six months later, spearfishermen collected 782 juvenile coralgrouper from the five community CMT areas: 43 from Timonai, 221 from Tawi, 204 from Locha, 235 from Pere and 79 from Mbunai.

Using genetic parentage analysis, we identified 76 juveniles that were born from adults at the Locha FSA. From these data, we estimated how many

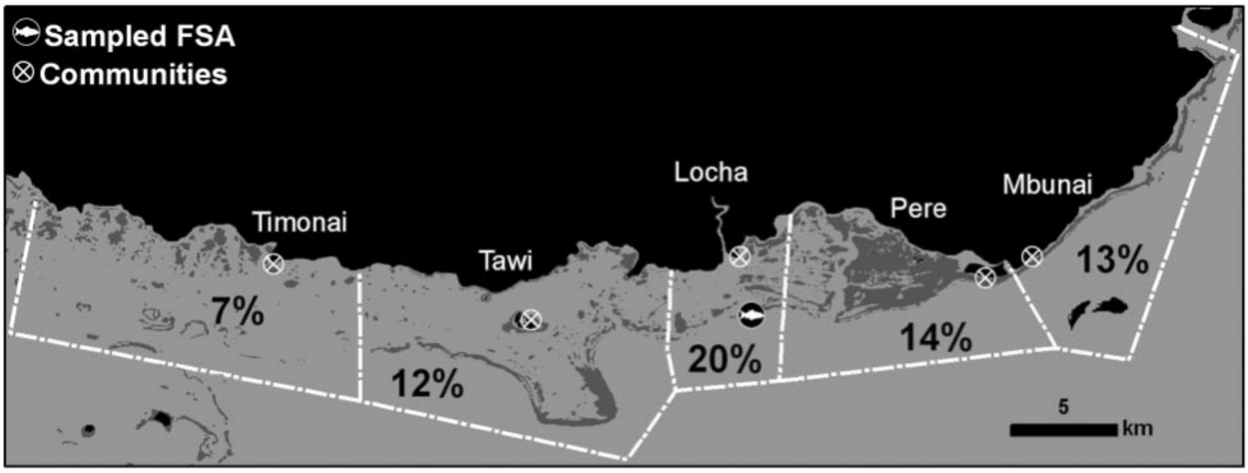


Figure 11. Results of the study measuring the dispersal of squaretail coralgrouper (*Plectropomus areolatus*) larvae from Locha's FSA to each of the five CMT areas. Black numbers are the estimated percentage of all juvenile coralgrouper in each CMT area that were born at Locha's FSA. (Land is black, coral reefs medium grey, and water light grey.)

Figure 12. Capture locations of 10 adult squaretail coralgrouper (*Plectropomus areolatus*) that were tagged at the Locha FSA in May 2010 and were captured by fishers during the following six months. Males (N=5) are indicated by circles with a solid white centre, females (N=5) by solid white diamonds. Five adults, all males, left the Locha FSA and returned to home sites within Locha's CMT area. Five adults, four females and one male, left the Locha FSA and returned to home sites within Pere's CMT area. (Land is black, coral reefs medium grey, and water light grey.)

larvae were produced by the 551 adults (57%) that we did not capture and sample from the Locha FSA (see Almany et al. 2013 for details), we calculated the percentage of juveniles in each of the five CMT areas that came from Locha's FSA (Fig. 11). This analysis indicates that 20% of all juveniles in Locha's CMT area were born at Locha's FSA. The percentage of juveniles born at Locha's FSA in the other four CMT areas decreased with distance from Locha's FSA, indicating that fewer larvae successfully travelled long distances during the larval phase (Fig. 11). Using the distances measured between the locations where the 76 parentage-assigned juveniles were collected and the Locha FSA, we modelled the relationship between the distance larvae travelled and the percentage of larvae that travel that distance. Results from this analysis predict that 50% of all larvae produced at the Locha FSA travel less than 14 km before they settle (Almany et al. 2013).

During the six months after capturing and tagging adult coralgrouper at the Locha FSA, fishers captured 10 tagged adults on other reefs (Fig. 12). Five tagged fish, all males, were captured from reefs within the Locha CMT area. The remaining five tagged fish, one male and four females, were captured from reefs to the east of the Locha FSA, from within Pere's CMT area. The average distance travelled by the 10 tagged adults was 2.8 km (range = 1.3 to 4.9 km).

Conclusions and recommendations

Locha, the community that protected its FSA, received the greatest benefit from its actions — we estimate that 20% of all juvenile coralgrouper in Locha's CMT area were born at Locha's FSA. Some larvae from Locha's FSA travelled to other CMT areas to the east and west, and so these neighbouring communities also benefited from Locha's actions to protect its FSA. Importantly, our results demonstrate that some coralgrouper larvae do not travel far from where they were born are similar to results observed in previous studies on both small, non-fishery species and larger fishery species (Jones et al. 2009; Green et al. in press). This suggests that short-distance movements by at least some larvae are common, and that communities can benefit from setting up reserves in their CMT areas.

We recognise that setting aside no-fishing areas can be difficult for coastal communities because their CMT areas are already small and they rely heavily on their CMT areas for food and income. As a result, any no-fishing area will be small. However, our study suggests that these small no-fishing (or restricted-fishing) areas could be very effective for rebuilding and sustaining the populations of some species, such as those that form FSAs. Increased fishing pressure on FSAs has led to rapid declines of these species in many locations around the Pacific (e.g. Hamilton and Matawai 2006). Protecting FSAs is wise because most (perhaps all) reproduction for these species occurs at the FSA site; so this is only source of larvae for replacing the fish taken by fishers. Community protection of FSAs works well, as shown in a recent study from New Ireland Province in Papua New Guinea where protection of grouper FSAs resulted in substantial increases in grouper abundance after five years (Hamilton et al. 2011). Furthermore, as our coralgrouper study from Manus demonstrates, some larvae stay close to the FSA and replenish local fisheries, and under many scenarios these larval benefits should increase with time. For example, if fishing pressure on FSA species is not too high after they leave the FSA site, then both the number of adults and average adult size should increase at the FSA (up to a point at which it reaches its natural capacity). This will result in a greater number of larvae produced by the protected FSA. Because, as we have shown, many of these larvae travel short distances, the coralgrouper population within the study area will increase, thereby rebuilding and sustaining this important fishery.

Our results also suggest that increased cooperation between communities in managing their fisheries would benefit both fish populations and communities. First, each of the five CMT areas contains one or more coralgrouper FSAs, and based on our results, it is almost certain that larvae are exchanged between, and connect together, all five CMT areas to each other. If each of the five communities provided some protection for its FSAs, each community could expect to directly benefit from its actions (the larvae that stay within that community's CMT area), and indirectly all communities would benefit together (by exchanging larvae between CMT areas). Furthermore, the coralgrouper populations in each CMT area would benefit from an increased exchange of larvae, which would increase their resilience to and recovery from decreases caused by disturbance (e.g. storms, overfishing). Under this scenario, where all communities provide some protection to their FSAs, we would expect the entire coralgrouper population within the study area to increase, ultimately providing more fish to fishers. Second, some adult coralgrouper moved between their normal home sites in one CMT area (Pere) and travelled to an FSA in another CMT area (Locha) for reproduction. By taking similar management actions across all CMT areas and FSA sites, communities would ensure that all adult coralgrouper have the same chance to reproduce successfully, no matter which CMT area or FSA site they use. These observations reinforce our conclusion that cooperation and collective decision-making between communities should result in better outcomes for fish and fishers.

Governance and management responses by Manus communities

After obtaining the final results of this study, we presented and discussed our findings and recommendations in November 2011 at all five communities that participated in the research and at Mbuke, the largest community among the offshore islands to the south of the study area (Fig. 13). We emphasised three main conclusions from this work. First, small managed areas that protect FSAs can help rebuild and sustain a community's coralgrouper fishery because many larvae stay close to the FSA. Second, because some larvae and fish travel across CMT boundaries, the coralgrouper fishery represents one large stock that would be better managed collectively. Third, the results of our coralgrouper study are similar to results from other studies on both fishery and non-fishery species, all of which suggest that some larvae travel only short distances from their parents (see reviews by Green et al. in press; Jones et al. 2009). As a result, we conclude that community-based management can definitely provide local benefits for some fishery species, and possibly for a wide range of fishery species. The authors and other researchers around the world are conducting similar studies on other fish species and invertebrates (e.g. sea cucumber) to test whether this third point is indeed true.

Although many community members immediately saw the value in collective community-based fisheries management, in 2011 there was no formal framework in place to support collective management. Communities had traditionally made independent decisions about the fisheries within their CMT area. However, two of the authors who are from southern Manus (Matawai and Kichawen) were convinced of the need for collective management, and were inspired by an example of an effective tribal governance network, the Lauru Land Conference of Tribal Communities in Choiseul, Solomon Islands (Kereseka 2014). They travelled throughout the communities of southern Manus to discuss the idea of establishing a tribal network to make collective decisions about resource management and other issues that would benefit network members. Those communities in support of the idea, which consisted of eight Titan tribal areas, including the five CMT areas that participated in the coralgrouper study, sent 70 leaders to a gathering in June 2013 to officially establish the MwanusEndrasAsi Resource Development Network (MEnARDev NET). Hereafter, we refer to MEnARDev NET as the "Network."

Figure 13. Study authors Hamilton and Matawai presenting results to the Tawi community (Photo: Tom Almany).

The eight tribal areas of the Network contain more than 10,000 people spread across approximately a third of Manus province (Fig. 14). The Network was established around existing socio-cultural boundaries, with all members sharing a common language (Titan), common religion (WIN Nation) and a maritime culture. The stated mission of the Network is: "We will build the resilience of our people through sustainable use of our ocean, our land and our natural resources that we depend on for our survival." Some of the Network's strategies for achieving its mission include: advocating for and supporting equitable and sustainable development to improve livelihoods; preservation of cultural heritage; developing a learning forum to share experiences among Network members

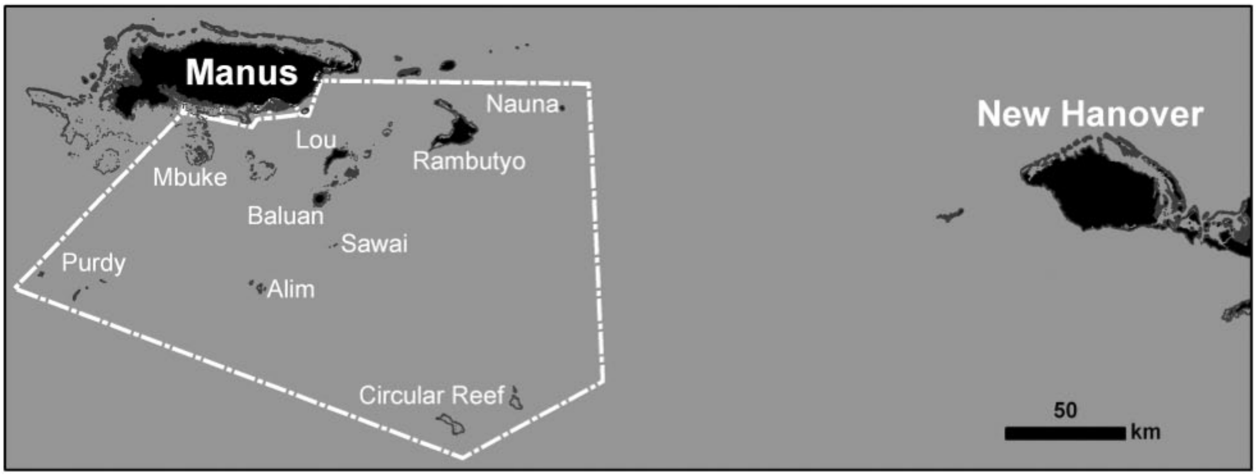


Figure 14. Approximate boundaries of the new MwanusEndrasAsi Resource Development Network (MEnARDev NET) are shown as a white dashed line, and encompass a total area of ~24 000 km2. The Network consists of eight tribal areas and includes the five coastal communities that participated in the squaretail coralgrouper study, several communities on offshore islands (Mbuke, Baluan, Lou, Rambutyo and Nauna), uninhabited islands (Purdy, Alim and Sawai), and two submerged reefs (Circular Reef). All communities in the Network are Titan and share a common language, religion and ethnic identity. (Land is black, coral reefs medium grey, and water light grey.)

to build local capacity; improving communities' resilience to climate change through community-based projects; supporting research partnerships between communities and scientists that benefit communities; and establishing a network of managed and protected areas.

The governance structure of the Network is as follows. Voting members are elected individuals who represent the interests of three groups from each of the eight Titan tribal areas: 1) the Tribal Council of Chiefs, 2) Women Leaders (Pilapan) and 3) Youth Leaders (Wuluo-Pinchuel). These elected representatives report to the Board, and the Board is chaired by the elected Secretariat (currently one of the authors, Kichawen). The Secretariat coordinates Network activities and chairs meetings. Network meetings occur approximately every six months, which has allowed for rapid progress; since its inception in June 2013, the Network has crafted and signed an official charter establishing the Network, registered as a business, developed and agreed on a strategic plan, and established a formal relationship with the Papua New Guinea National Fishieries Authority (NFA) to coordinate fisheries management activities. A recent outcome of this link with NFA has been a pledge from NFA to provide shallow water fish aggregating devices to each community in the Network to reduce fishing pressure on reefs.

At the September 2014 Network meeting, the Tribal Council of Chiefs, acting as representatives of their tribal areas, approved the establishment of a comprehensive system of managed and protected areas across the entire area under Network jurisdiction (Fig. 14). The two main goals of this system of managed and protected areas are to ensure the sustainability of a range of fishery resources and to protect cultural heritage sites. A participatory planning workshop is scheduled for May 2015 to integrate community priorities and conservation targets, local knowledge, and scientific data into a comprehensive spatial management plan for the area (see Game et al. 2011; Peterson et al. 2012 for examples of this process).

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