Locally-managed marine areas: multiple objectives and diverse strategies

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Community-based management and co-management are mainstream approaches to marine conservation and sustainable resource management. In the tropical Pacific, these approaches have proliferated through locally-managed marine areas (LMMAs). LMMAs have garnered support because of their adaptability to different contexts and focus on locally identified objectives, negotiated and implemented by stakeholders. While LMMA managers may be knowledgeable about their specific sites, broader understanding of objectives, management actions and outcomes of local management efforts remain limited. We interviewed 50 practitioners from the tropical Pacific and identified eight overarching objectives for LMMA establishment and implementation: (1) enhancing long-term sustainability of resource use; (2) increasing short-term harvesting efficiency; (3) restoring biodiversity and ecosystems; (4) maintaining or restoring breeding biomass of fish or invertebrates; (5) enhancing the economy and livelihoods; (6) reinforcing customs; (7) asserting access and tenure rights; and (8) empowering communities. We reviewed outcomes for single or multiple objectives from published studies of LMMAs and go on to highlight synergies and trade-offs among objectives. The management actions or 'tools' implemented for particular objectives broadly included: permanent closures; periodically-harvested closures; restrictions on gear, access or species; livelihood diversification strategies; and participatory and engagement processes. Although LMMAs are numerous and proliferating, we found relatively few cases in the tropical Pacific that adequately described how objectives and management tools were negotiated, reported the tools implemented, or empirically tested outcomes and seldom within a regional context. This paper provides some direction for addressing these research gaps.

Key words: community-based natural resource management, fisheries management, biodiversity conservation, livelihoods, customary management, tropical Pacific

INTRODUCTION

COMMUNITY-BASED and co-management approaches are key strategies for marine conservation and sustainable management (Evans *et al.* 2011; Gutierrez *et al.* 2011). Consequently, they are an increasing proportion of coastal and marine management in the tropical Pacific (Govan *et al.* 2009a; Johannes 2002) and elsewhere (Chape *et al.* 2008). This is particularly prevalent in the tropical Pacific (Govan 2009), where centralized management has typically failed in managing subsistence and domestically-marketed fisheries (Ruddle 1998; Gillett and Cartwright 2010).

Many local management initiatives are recognized within a regional practitioner's network, the Locally-Managed Marine Area (LMMA) network (Parks and Salafsky 2001). Founders of the term LMMA deliberately chose "local" over "community", recognizing co-management arrangements involving communities partnering with government or other external agencies such as non-government organizations (NGOs) (Pomeroy and Rivera-Guieb 2006). An LMMA is an "area of nearshore waters being actively managed by local communities or resource-owning groups, or being collaboratively managed by resident communities with local government and/or partner organizations" (Govan *et al.* 2006; Govan *et al.* 2009a). In addition to sites within, there are probably hundreds to thousands of communities implementing their own coastal and marine management which may fall within this definition, but are not on any official lists (Govan *et al.* 2009a). Commonly, LMMAs are designed to meet local management objectives, managed through locally negotiated rules that integrate customary or local governance, often established without formal legal status, and adaptively managed through learning-by-doing (Govan *et al.* 2009a). LMMAs are synonymous with community-based marine resource or fisheries management. Management focusses on resource-use and access rules and other management measures, within a defined space, typically including village fishing areas often bounded by local land and marine tenure (Figure 1). Sometimes, these local management boundaries cover ecologically meaningful scales, linking watersheds to downstream marine ecosystems (Ruddle *et al.* 1992), while in other cases tenure areas are much smaller.

Throughout the Pacific, resource use can be controlled through a diversity of local institutions, including customary governance and tenure systems, bans on sectors of society consuming or fishing certain species, restrictions on certain gear types, and spatial and temporal

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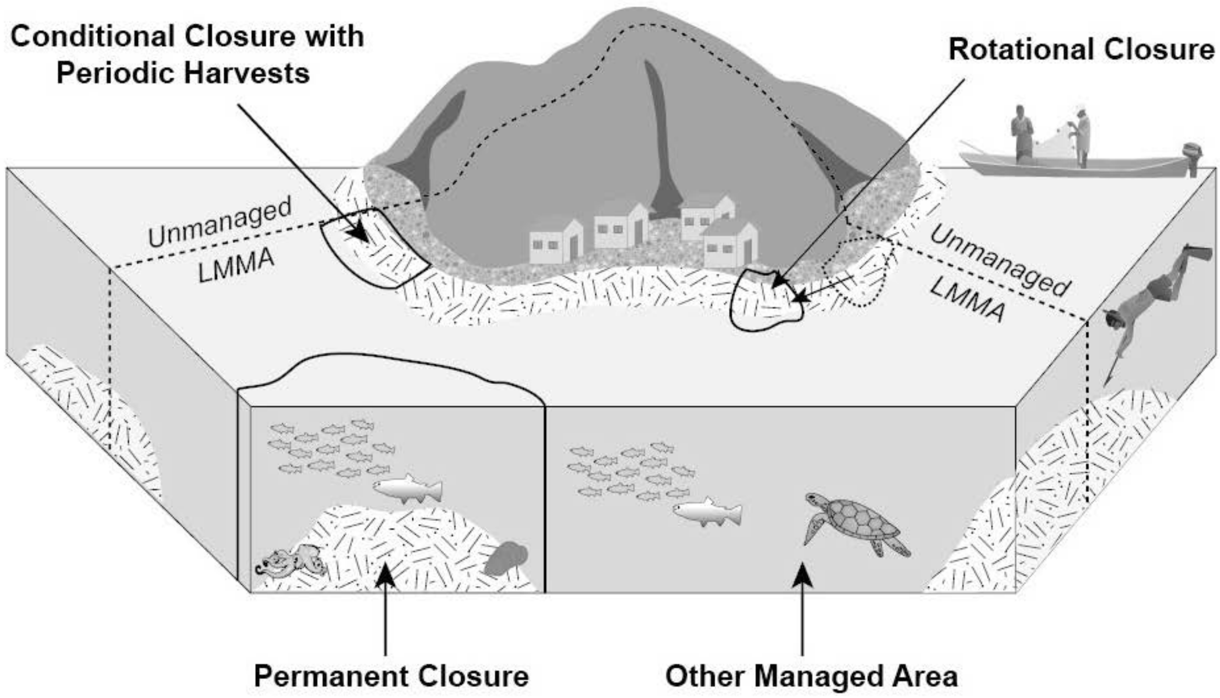

Fig. 1. Schematic of management actions that may be employed within a locally-managed marine area (LMMA) on a Pacific Island, showing the boundary of the LMMA and adjacent land tenure area (dashed line). Permanent closures have complete prohibitions on resource extraction in perpetuity. Conditional closures with periodic harvests are no-take areas occasionally opened for socio-cultural needs. Rotational closures are no-take closures that are lifted and moved after a pre-defined time. Other managed area indicates space inside LMMA boundaries outside of spatial closures that may include other management actions such as gear restrictions or species harvest bans. Adapted from Govan and Jupiter (2013).

closures, placed over specific fishing grounds (Figure 1; Johannes 1978; Johannes 1982; Cinner and Aswani 2007). Tenure regimes can allow the community, clan or family with primary rights to a particular area to create access and use rules (Macintyre and Foale 2007), though these may be difficult to enforce (Aswani 2002). Spatial and temporal closures have long been practiced in the Pacific, respecting the death of prominent community members, protecting sacred sites, affirming rights and controlling access to fishing grounds, or for preparing customary feasts (Johannes 1978; Hviding 1998). While tenure, closures and other regulatory institutions control access to and use of resources, their historical use was more socially and culturally motivated, rather than to manage resources sustainably (Ruttan 1998; Foale *et al.* 2011). With contemporary, competitive resource use, local institutions may not achieve sustainability or conservation outcomes without some integration of contemporary scientific knowledge and management practice (Polunin 1984; Foale *et al.* 2011). Improving management and conservation often will entail strengthening governance of local tenure or rights-based regimes and other local institutions to provide a regulatory framework that reinforces or introduces stewardship of resources (Baines 1990; Johannes 2002; Bell *et al.* 2008; Govan 2009). By building on this framework, LMMAs can integrate local and scientific knowledge with customary and contemporary practices.

To achieve this, LMMAs are often supported and guided by co-management partners (e.g., NGOs, government agencies or research institutes) who promote a diverse range of objectives, including biodiversity conservation, fisheries management, livelihood diversification and climate change adaptation (Green *et al.* 2013; Weeks and Jupiter 2013). Yet, community-based management is not a panacea (Berkes 2007), and there are inherent trade-offs among multiple objectives. For example, LMMA objectives for enhanced fisheries-supported livelihoods may clash with conservation of biodiversity, while LMMAs established to promote short-term increases in catch may not be able to also enhance long-term sustainability of fisheries. To explore these trade-offs and potential synergies among objectives, we first examined the diversity of contemporary objectives for LMMAs and then reviewed published progress towards single and multiple objectives for LMMAs. We then examined the management actions or 'tools' used to progress objectives and evaluated the empirical evidence for their effectiveness.

METHODS

In December 2011, we facilitated a workshop with 50 people, including four from governments, 20 from academia and 26 people who represented NGOs, regional organizations or were consultants focussed on improved effectiveness of LMMAs in the tropical Pacific for biodiversity conservation, fisheries management, and climate adaptation. Each participant identified at least three objectives for LMMAs, articulated by communities with whom they worked or based on their knowledge of the literature. We grouped these into eight overarching objectives that we cross-checked against the published literature and our own personal experience working directly with local communities (Table 1). Participants then described which resource management actions or tools were used within LMMAs. We grouped these into six categories (permanent closures, periodically-harvested closures, species-specific restrictions, gear restrictions, access restrictions, alternative livelihood strategies). We then ranked the relative effectiveness of management actions for addressing each of the eight objectives, using the workshop rankings and reports of effectiveness from the published literature (Table 2).

We used the eight overarching objectives, commonly identified management tools and the qualitative assessments of management effectiveness to structure our review. We used peer-reviewed primary and openly accessible grey literature to highlight: (a) where local management pursued each of the eight objectives; and (b) the effectiveness of this management in achieving objectives, reflected in tools and actions used.

Table 1. Overarching objectives, in relation to specific objectives for Locally-Managed Marine Areas (LMMAs), refined from those proposed by 50 workshop participants. Case studies from the tropical Pacific are listed that report each overarching objective, and/or empirically examine or explore outcomes towards each objective.

Overarching objective	Specific objectives	Case studies
(1) Increase long-term sustainable fisheries yield for cash and food	Increase catch abundance/size for sustainable livelihoods Increase catch abundance/size for food security	Cinner *et al.* 2006; Weiant and Aswani 2006; Aswani and Furusawa 2007; Bartlett *et al.* 2009b; Jupiter *et al.* 2012; Cohen and Alexander 2013; Cohen *et al.* 2013
(2) Increase efficiency of harvests and recovery of fish and invertebrate populations for short-term gain/contingency needs	Ensure adequate fish and invertebrates to meet fundraising targets Provide adequate stock for village feasts Ensure resource availability as contingency for bad weather Decrease variability in food supply Ensure resource availability for unplanned community event/needs	Polunin 1984; Neitschmann 1985; Wright 1985; Tawake *et al.* 2001; Cinner *et al.* 2005b; Cinner *et al.* 2006; Bartlett *et al.* 2009b; Feary *et al.* 2011; Januchowski-Hartley *et al.* 2011; Jupiter *et al.* 2012; Cohen and Alexander 2013; Cohen *et al.* 2013; Januchowski-Hartley *et al.* 2013
(3) Maintain/restore biodiversity, habitats and ecosystem function; improve resilience	Conserve biodiversity/species Protect/restore habitats Maintain/restore ecosystem functions (e.g., productivity, herbivory, water filtration) Maintain/restore ecosystem services (e.g., coastal protection) Maintain/restore ecosystem resilience Adapt to climate change	Aswani *et al.* 2007; Jupiter and Egli 2011; Goetze and Fullwood 2013; Rasher *et al.* 2013; Weeks and Jupiter 2013
(4) Maintain/restore biomass and breeding populations of targeted species	Protect habitat for sensitive life history stages (breeding and nursery grounds) Increase stock of targeted species Maintain/increase size for greater reproductive capacity	Tawake *et al.* 2001; Weiant and Aswani 2006; Aswani and Hamilton 2004; Caillaud *et al.* 2004; Aswani *et al.* 2007; Bartlett *et al.* 2009a; Dumas *et al.* 2010; Hamilton *et al.* 2011; Jupiter and Egli 2011; Clements *et al.* 2012; Friedlander *et al.* 2013
(5) Enhance economy and livelihoods	Earn income from participation in management (e.g., paid ranger position) Earn income from access fees Earn income through ecotourism activities (e.g., guided tours) Earn income through alternative livelihood activities (e.g., sewing cooperatives)	Aswani 2000; Foale 2001; Aswani and Weiant 2003; Horowitz 2008; Bartlett *et al.* 2009a; Neisten and Gjertsen 2010; Weeks and Jupiter 2013
(6) Maintain or reinforce customs and tradition	Preserve traditional practice Demonstrate stewardship Protect sacred sites Secure or enhance respect for traditional leaders Enforce custom, magic, or totems as part of cultural practice	Hviding 1989; Veitayaki 1997; Johannes 1998; Bartlett *et al.* 2009a; Léopold *et al.* 2010

Table 1 continued overleaf

Table 1 continued

Overarching objective	Specific objectives	Case studies
(7) Assert access rights	Limit or exclude outsiders from accessing resources Assert tenure rights	Anderson and Mees 1999; Bartlett *et al.* 2009a; Steenbergen 2011
(8) Increase community organization, cohesiveness and empowerment	Provide equitable access to resources Strengthen community governance Strengthen community participation Strengthen engagement with community support networks Obtain access to information to support management decisions Attract NGO support and their resources	Anderson and Mees 1999; Cohen *et al.* 2012; Cohen *et al.* 2013

OVERARCHING OBJECTIVES FOR LMMAS

Objectives for establishing LMMAs vary between communities and partner organizations, as well as within and among communities. Supporting partners may have objectives ranging from enhancing livelihoods and food security to sustainable community development and/or biodiversity conservation (Axford *et al.* 2008; Govan *et al.* 2009a). Community objectives may not be explicit, with communities articulating coincident objectives with partners to access benefits (e.g., knowledge, cash, prestige, travel opportunities) or show agreement with management or conservation initiatives (Macintyre and Foale 2004). It is vital to understand explicit and implicit objectives, those pursued by communities, and those influenced or promoted by partner agencies, because the success and longevity of LMMAs depends on perceptions or real benefits to community or key stakeholders outweighing the opportunity costs (Lal and Keen 2002).

Workshop participants perceived that explicit community objectives tend to focus on maintaining or improving fisheries and livelihood benefits, while biodiversity or species-specific protection objectives are more often promoted through the conservation discourse of external agencies (see also Govan *et al.* 2009b). Implicit objectives often emerge later during LMMA implementation, and can include: restricting access of immigrant or neighbouring communities to resources; garnering ‘project’ benefits; gaining prestige; reinforcing or establishing property rights; recovering traditional knowledge or reinforcing local governance; improving community organization and identity; improving human and social capital; and responding to stewardship of traditional Pacific people (Govan *et al.* 2009a; O’Garra 2012). We discuss the pursuit and progress towards some of these objectives below and highlight cases where they are described (Table 1).

(1) Increase long-term sustainability of fisheries

Communities across the tropical Pacific rely heavily on marine resources for food and income, but coastal fisheries may not sustain growing populations and developing markets (Bell *et al.* 2009; Brewer *et al.* 2009). LMMAs are a common response, particularly where there are local declines in abundance of fisheries resources (e.g., Bartlett *et al.* 2009a) whose long-term sustainability needs to be secured to support associated livelihoods and food security (Table 1). Objectives such as “ensure fish for the future” are commonly cited as a primary objective of local communities and co-management partners (Table 1; Parks and Salafsky 2001). Management tools promoted within LMMAs, such as banning the use of destructive or non-selective harvesting methods and the capture of juvenile fish and invertebrates (Govan *et al.* 2008), are well regarded in contemporary fisheries science as effective (e.g., Cochrane and Garcia 2009). Where implemented, long-term sustainability of fisheries should be enhanced, but this is not guaranteed. There is limited empirical evidence suggesting that short-term localized increases in abundance improve fisheries-supported livelihoods and food security. Some suggest that nutrition is better in communities employing local management (e.g., Weiant and Aswani 2006; Aswani and Furusawa 2007), but causal links are yet to be well understood and demonstrated. Coastal fisheries may not meet the needs of many Pacific countries by 2030, even if well managed (Bell *et al.* 2009). While improving management should help to minimize this deficit, pressures at local (e.g., increased fishing pressure) and global scales (e.g., climate change) threaten long-term sustainability (Bell *et al.* 2011). In addition, other factors operating beyond local scales (e.g., interactions with commercial fisheries, government policies) or outside of fisheries systems (e.g., market fluctuations, population growth, natural disasters) also strongly influence fisheries sustainability, and therefore food security and livelihoods

(Andrew *et al.* 2007; Schwarz *et al.* 2011). The cumulative impact of multiple LMMAs in contributing towards such broad objectives is worthy of future analysis.

(2) Increase efficiency of harvests for short-term yield

Many communities use LMMAs, and most commonly periodically-harvested closures, to act as a "bank in the water" to ensure a supply of fish and invertebrates for special occasions (Table 1; Govan 2009). Catch efficiency has been observed to increase, particularly for spearfishing, after a period of closure (Cinner *et al.* 2006; Gelcich *et al.* 2010; Foale *et al.* 2011) for three reasons. First, fish and mobile invertebrates may move into closed areas where disturbance is low ("spill-in"), elevating localized abundance (Denny *et al.* 2004; Eggleston and Parsons 2008). Second, the behaviour of individual fish can change during periods of closure (i.e., reduced flight distance), making them easier for spear-fishers to catch (Feary *et al.* 2011; Januchowski-Hartley *et al.* 2011). This was the explicit objective in Muluk, Papua New Guinea, where an area was closed to fishing to "tame" fish and make them easier to catch when the reef was re-opened (Cinner *et al.* 2006). This increased catchability benefits fishers in the short term but could lead to overharvesting (Feary *et al.* 2011; Jupiter *et al.* 2012). Finally, catch rates may be elevated because reproduction and growth have increased abundance and size of taxa (Cohen and Alexander 2013). Whether short-term improvements in catch efficiency correspond with sustainable or improved yields in the long term is a pressing question for managers.

(3) Maintain/restore biodiversity and ecosystem functions

Conservation is defined under the IUCN protected area guidelines as the "in-situ maintenance of ecosystems and natural and semi-natural habitats and of viable populations of species in their natural surroundings" (Dudley 2008). Despite this reported objective of some LMMAs (Table 1; e.g., Aswani *et al.* 2007; Bartlett *et al.* 2009a; Jupiter and Egli 2011), this is not typically a primary objective of communities (Govan and Jupiter 2013). It is difficult to discern if this objective is truly locally motivated or heavily influenced by the conservation discourse of partners. Nonetheless, there is some limited evidence that various LMMA tools could contribute towards main-tenance of biodiversity and ecosystem function. For example, sufficiently representing different habitat types within protected areas is often a surrogate measure for biodiversity protection (Margules and Pressey 2000). By this measure, LMMAs in Fiji contributed substantially to the government's target to protect 30% of marine habitats (Mills *et al.* 2011). In addition, management actions that reduce fishing pressure may have cascading impacts to other biodiversity and ecosystem function. For example, increased biomass of top predators has been associated with increases in prey abundance following local management (Goetze and Fullwood 2013). Further, observed increases in herbivory within no-take areas (Rasher *et al.* 2013) reduced harmful interactions between algae and corals, reduced sediment accumulation and increased crustose coralline algae establishment (Rasher *et al.* 2012), supporting ecosystem function and potentially increasing resilience (McClanahan *et al.* 2012). However, local management efforts may not mitigate chronic or intense disturbance from fishing or climate change, explosions of coral predators, or land-based runoff (Jones *et al.* 2004; Halpern *et al.* 2013). Understanding the relative impact of these large-scale disturbances would be benefitted by further research.

(4) Maintain/restore biomass and breeding populations

A commonly voiced community objective for LMMAs is to restore abundance and biomass of harvested species of fish and invertebrates. Some longstanding local traditions regulate the harvest of important species and are incorporated into contemporary management (Johannes 1978; Caillaud *et al.* 2004). For example, indigenous Hawaiians traditionally restricted the harvest of large female moi (*Polydactylus sexfilis*) to protect breeding stock, including during their spawning season, a measure now integrated into local management (Friedlander *et al.* 2013). However, local ecological knowledge often focusses on enhancing catch efficiency and maximizing catch (Foale 1998), which can intensify pressure on resources and lead to depletion, particularly of fish spawning aggregations (Sadovy and Domeier 2005). Where contemporary scientific understandings are integrated with local knowledge, local fishers recognize the problems associated with removing large numbers of reproductive adults from the population (e.g., Fox *et al.* 2012), but often do not stop their intensive fishing (Kinch *et al.* 2006). Increasing understandings of reproductive and ecological processes is a common strategy, intended to influence local management for long-term sustainability objectives (e.g., Parks and Salafsky 2001; Foale *et al.* 2011). Where co-management partners have explained ecological processes, some communities have established spatial and/or seasonal management over breeding and nursery sites for vulnerable species (e.g., bumphead parrotfish: *Bolbometopon muricatum*, large aggregating grouper: *Epinephelus fuscoguttatus*, *E. polyphekadion*, *Plectropomus areolatus*; Aswani and Hamilton 2004; Hamilton *et al.* 2011).

(5) Enhance economy and livelihoods

Many tropical Pacific countries are developing nations, where many people are highly reliant on natural resources with relatively few alternatives for food and income (Bell *et al.* 2009). Not surprisingly, many local communities are amenable to LMMA establishment, hoping to improve local economies and livelihoods (Table 1). Livelihood objectives are based on explicit arrangements (or expectations) including: receiving payments to cease extraction of resources; generating revenue from eco-tourism (e.g., tourist access fees for diving, fishing and surfing); employment associated with management; or participating in alternative income-generating activities (e.g., from sewing cooperatives, handicraft production) introduced by co-management partners. For example, potential financial gain from tourism convinced local communities to participate in co-management for conservation in the Loyalty Islands of New Caledonia (Horowitz 2008). LMMAs and their eco-tourism arrangements have produced: user fee payments from divers in the Namena Marine Reserve, Fiji (Weeks and Jupiter 2013); a 25 year lease agreement to establish the 425 km^2 Misool EcoResort No-Take Zone in Raja Ampat, Indonesia (Niesten and Gjertsen 2010); and cash payments in exchange for agreements not to fish and for exclusive access rights for a tourism operator to bring divers to Shark Reef Marine Reserve, Fiji (Brunnschweiler 2010). Sometimes, tourism employs community members and introduces markets for fish and handicrafts (Horowitz 2008; Niesten and Gjertsen 2010; Vianna *et al.* 2012). However, tourism will not provide widespread opportunities, particularly in remote or environmentally degraded areas. In a remote region in the Solomon Islands, co-management partners established alternative livelihood activities, including women's sewing projects and payment for community health and education services (Aswani 2000; Aswani and Weiant 2003).

(6) Maintain or reinforce customs

Practices that control resource use (e.g., asserting tenure claims, protection of sacred areas, restrictions on harvesting particular species) occur across the tropical Pacific (Hviding 1989; Zann 1989; Veitayaki 1997; Colding and Folke 2001). Yet, as belief systems have evolved, including increasing incorporation of Christian values and Western norms of capitalism and acculturation, many traditional practices are eroding (Foale 2006; Bartlett *et al.* 2010). For example, a longstanding ban on mullet net fishing in the Teuta LMMA of New Caledonia, linked to the tribe's allegiance to local chiefly leaders, was lifted due to weakening social hierarchies and loss of local ecological knowledge (Léopold *et al.* 2010). Nevertheless, contemporary LMMAs can often strengthen, re-establish or further evolve customary practices (Table 1; Johannes 2002). For example, the communities of Totoya Island, Fiji, originally declared the Daveta Tabu a sacred passage following the sea burial of the stillborn child of a chief, and later reinforced this closure within their LMMA arrangements (J. Cinavilakeba, pers. comm.). The adaptation and application of periodically-harvested closures with historical origins are common in contemporary community-based management (Cohen and Foale 2013). Sometimes, customary practices, such as customary marine tenure to restrict access, have strengthened through a fusion of Christian doctrines, ancestor worship and authority of the chiefs (Hviding 1998). However, few cases adequately describe the processes and nature of these hybridizations with LMMA frameworks.

(7) Assert access rights

LMMAs are generally established adjacent to communities, often including areas over which tenure rights are held by community members. Customary marine tenure systems are recognized in the constitution of some Pacific countries (e.g., Solomon Islands, Lane 2006) while others legally recognize traditional fishing rights (e.g., Fiji; Clarke and Jupiter 2010) or ways for establishing community rights to explicitly manage coastal areas (e.g., Tonga; Govan 2009). These systems allow the community, clan or family with primary rights to a particular area to limit access and regulate overuse (Macintyre and Foale 2007), essential foundations for LMMAs. Tenure arrangements for rights (i.e., their custodians, nature, and location) are dynamic and informal because they are generally unwritten (Baines 1990), allowing flexible responses to new environmental pressures or changed social, economic or ecological conditions (Hviding 1998). Codifying and/or clarifying tenure claims may be an important, but perhaps not overtly stated, local objective for LMMA establishment and formal management (Table 1; Steenbergen 2011). However, clarifying tenure sometimes clashes with objectives of enhanced community cohesiveness, leading to protracted negotiations and disputes (Carrier 1987; McDougall 2005; Macintyre and Foale 2007). Depending on the local context (e.g., different people often hold different rights within one community), and how management is established, the benefits and costs of management may be unequally distributed by gender, clan or ethnicity (Anderson and Mees 1999; Koczberski *et al.* 2006; Vunisea 2008; Cohen *et al.* 2013).

(8) Increase community organization, cohesiveness and empowerment

Many support partners seek to empower communities and strengthen local governance through participation in LMMA establishment and management (Table 1; Govan *et al.* 2008). These processes include education, awareness raising and learning for adaptation at local sites. The LMMA network prioritizes learning and information exchange at local, national and regional scales (Parks and Salafsky 2001). In Solomon Islands, national LMMA network members provided important pathways for information about resource management to reach communities, and the network provided a mechanism for representation of communities and their management efforts in higher-level decision-making (Cohen *et al.* 2012). Further, processes for establishing LMMAs frequently include bringing communities together for visioning, planning, decision-making and consensus building (Govan *et al.* 2008). These processes can enhance participation of women in decision-making about resources (Leisher *et al.* 2007; Hilly *et al.* 2011). This is a marked achievement, given cultural barriers potentially limit their role in decision-making (Vunisea 2008), despite the fact that they are fishers and distributers of fisheries benefits (Weiant and Aswani 2006; Kronen and Vunisea 2007). In the Arnavon Islands LMMA in Solomon Islands, the resource management committee better dealt with resource-use issues through a participatory forum, which also addressed "other community issues" (Leisher *et al.* 2007; Govan *et al.* 2009b).

Table 2. Perceived effectiveness of management tools in achieving objectives for Locally-Managed Marine Areas (LMMA). Effectiveness of 5 rankings based on responses from workshop participants, supplemented with evidence from reported case studies.

	Permanent closures [a]	Periodically-harvested closures [g]	Species restrictions [i]	Gear restrictions [o]	Access restrictions [r]	Alternative livelihoods strategies
(1) Increase long-term sustainable yield	Very Good [b, c]	Poor–Good [b]	Poor–Good [j]	Poor–Good [j]	Poor–Good [s]	Poor–Intermediate
(2) Increase efficiency of harvests for short-term yield	Poor [b]	Very Good [b]	Poor	Poor	Poor	n/a
(3) Maintain biodiversity & ecosystem functions	Very Good [b, d]	Poor–Good [b, d, h]	Intermediate [k]	Intermediate [d, k]	Poor–Good [s]	Poor–Intermediate
(4) Maintain biomass & breeding populations	Very Good [b]	Poor–Good [b]	Intermediate [l] –Very Good	Intermediate [j, p] –Good	Poor–Good [s, t]	Poor–Intermediate
(5) Enhance economy & livelihoods	Good [e]	Poor–Good [e]	Poor	Poor	Poor	Poor–Good [v]
(6) Maintain or reinforce customs	Good [f]	Very Good [f]	Very Poor –Good [m]	Intermediate [q]	Very Good	Intermediate [w]
(7) Assert access rights	Very Good	Very Good	Poor	Intermediate	Very Good	n/a
(8) Increase community organization, cohesiveness and empowerment	Good [f]	Very Good	Good [n]	Poor–Intermediate	Poor–Good [u]	Poor–Good

[a] *No entry areas more effective than no-take areas for most objectives.*
[b] *Effectiveness influenced by size, location, and broader management context (e.g., fishing pressure outside closure).*
[c] *Requires spillover into adjacent area open to fishing.*
[d] *Likely to be effective at maintaining habitat structure and ecosystem resilience, but outcomes might be dictated more by external factors (e.g., stress from climate change impacts or land-based runoff).*
[e] *Primarily through dive tourism and/or ecotourism-associated income; this is greater for areas that allow non-extractive activity than no-entry areas. Note, ecotourism feasibility is limited by infrastructure, access and habitat condition.*
[f] *Provided that management tool or measure aligns with community traditions/custom, and is supported by the community.*
[g] *Effectiveness varies with frequency and duration of openings and fishing effort whilst open.*
[h] *Fishing often targets important functional species disproportionately. Harvests impacting top predators could have cascading effects.*
[i] *Effectiveness influenced by species targeted; note that restrictions must be context specific (e.g., minimum mesh size is not effective for all species, size limits must tailored to species size at reproduction) and can be harder to enforce than spatial management.*
[j] *Some studies (e.g. Cohen* et al. *2013; Léopold* et al. *2013) indicate poor local compliance with many of these types of rules*
[k] *If restrictions target functionally important species, e.g., certain herbivorous fishes.*
[l] *Effectively protecting fish spawning aggregations through spatial or seasonal closures can be very effective at maintaining breeding populations; minimum size limits are less effective than slot limits.*
[m] *Can provide protection for species of cultural importance, but potentially very poor if cultural preference for consumption of large individuals or particular animals (e.g., turtles) conflicts with size or species restrictions.*
[n] *Implementation of species restrictions may increase community organization and cohesion, particularly in cases where local communities rally around a campaign to protect particular species of cultural or economic importance.*
[o] *Banning destructive gear types is critical for all objectives; effectiveness varies depending on types of gear restricted.*
[p] *Can be very effective if applied appropriately (e.g., bans on night spearfishing, spearfishing lobsters).*
[q] *Bans on monofilament nets & flashlights reinforce traditional gear use and control.*
[r] *Necessary to facilitate any other management, but requires additional restrictions.*
[s] *Effectiveness will depend on the intensity of local resource use.*
[t] *Small tenure areas will not lead to substantial self-recruitment and will not be able to maintain biomass of highly mobile species.*
[u] *Depending on the local context, the benefits and costs of management may be unequally distributed according to gender, clan or ethnicity, thus resulting in conflicts.*
[v] *Some alternative livelihoods are not related to marine management activities. A range of positive to perverse outcomes has been observed from related livelihoods, depending on the context.*
[w] *Could help maintain and reinforce customs if the alternative livelihoods revolves around a customary practice (e.g. traditional weaving for sale as handicrafts).*

This is anecdotal evidence for governance improvements, though more critical evaluations of changes in governance capacity are warranted.

MANAGEMENT ACTIONS OR 'TOOLS'

Successful adaptive co-management (i.e., of which LMMAs can be a form) relies on: broad community consultation to define objectives; clear governance arrangements and decision-making pathways; influence and support from partner agencies; and access to a portfolio of management actions (Armitage *et al.* 2009). LMMA establishment and adaptation is intended to utilize, support and strengthen these features, helping to articulate objectives such as "assert access rights" and "increase community organization, cohesiveness and empowerment".

A general process for supporting the establishment and adaptation of LMMAs was documented at a meeting of LMMA network partners in May 2012 (S. Jupiter, unpublished data): (1) agreement to the LMMA network's core value that local communities should make the management decisions and their needs come first; (2) initial community engagement to define objectives, agree on expectations, assess enabling conditions and build trust; (3) empowerment of communities through skills development and participatory action planning; (4) community-based adaptive management through a cycle of planning, implementing, monitoring, evaluating, and revising based on learning; and (5) ongoing communication and skills development, including the promotion of community champions. This process may capture management arrangements in formalized or informal plans and/or management systems, with some level of recognition by state or other institutions, depending on the country (e.g., White *et al.* 2005; Techera 2009; Clarke and Jupiter 2010). Formalization can positively impact upon effectiveness of management actions, by enhancing legitimacy, providing enforcement capacity and clarifying or asserting access rights, but may reduce flexibility for rapid adaptive management.

Here we focus on the management actions identified (by workshop participants and through literature review) as those frequently negotiated and employed for LMMAs. We discuss how well the six major categories of management actions and tools have been observed to contribute towards each of the eight LMMA objectives (Table 2).

Permanent closures

Permanent no-take marine protected areas are employed within fisheries management and marine conservation strategies worldwide to protect species and habitats within their boundaries (Lester *et al.* 2009), enhance fisheries through adult spillover (e.g., Halpern *et al.* 2010) and larval export (Harrison *et al.* 2012), and confer potential ecosystem resilience to climate change impacts through increased herbivory and associated cascading impacts (Rasher *et al.* 2012; Rasher *et al.* 2013). Yet, a range of factors influence their effectiveness for these purposes (Lester *et al.* 2009).

LMMA approaches frequently lead to the formation of small (<0.5 km^2) no-take zones, often over coral reefs (Govan 2009; Weeks *et al.* 2010). Depending on currents, other oceanographic processes, larval dispersal distances and the placement of no-take marine reserves, local fish and invertebrate abundance may increase, even for small no-take areas (Almany *et al.* 2013). Whether increases in target species lead to food security and livelihood benefits depends on the level of increase and fishers' access to these stocks. In Vanuatu, very small (<0.05 km^2) closures may not sufficiently restore breeding biomass and prevent population declines of invertebrates (Dumas *et al.* 2010). Yet, community perceptions of abundance increases within closed zones are commonly favourable (even unrealistically), and may even be catalysts for increasing interest, knowledge and awareness of resource management (World Bank 2000). Many no-take zones within LMMAs are closed indefinitely, even though communities may express the intention to open them in the future if circumstances change (Govan *et al.* 2009a). The short- to medium-term decrease in access to stocks and fishing grounds may limit use of large and/or permanent no-take closures in the Pacific (Foale and Manele 2004). Sometimes, permanent no-take areas can indirectly benefit local livelihoods, with alternative sources of income, typically related to dive tourism or ecotourism (e.g., Weeks and Jupiter 2013), however, tourism-associated benefits may be inequitably distributed (Fabinyi 2010). In contrast to periodically-harvested closures, permanent closures were not prevalent in historical management strategies in the Pacific (Johannes 1978), and there may be social barriers to their effective implementation (Foale and Manele 2004; Foale *et al.* 2011).

Periodically-harvested closures

Within LMMAs, periodically-harvested closures are a common but highly variable and flexible management tool. They fall on a spectrum between areas predominantly closed and those regularly opened to harvesting (Tiraa 2006; Cohen and Foale 2013). During closure, there may be a total ban on harvesting (Jupiter *et al.* 2012; Cohen *et al.* 2013), or restriction on certain methods (Cinner *et al.* 2005a) or species (Foale 1998). During openings, restrictions on harvesting are sometimes applied but harvests can also be unconstrained (Jupiter *et al.* 2012; Cohen *et al.* 2013). Long-term sustainability and conservation outcomes will be highly variable, reflecting the diversity of management actions, the flexible nature of opening and closure cycles, the differing use of concurrent resource-use controls and the abundance of target taxa at sites (see review in Cohen and Foale 2013). Broadly, outcomes reflect the degree of replenishment during closures, relative to the level of depletion during openings. Perceived or quantified increases in resource abundance are evident over short time-scales, within small closures with light overall harvests (e.g., Tawake *et al.* 2001; Cinner *et al.* 2005a; Bartlett *et al.* 2009b). Herbivory and ecosystem resilience may increase within periodically-harvested closures (Game *et al.* 2009; Rasher *et al.* 2012). Short-term elevated catch rates occur in some periodically-harvested areas due, in particular, to increased abundance of invertebrates (Tawake *et al.* 2001; Cohen and Alexander 2013) and increased catchability of spear-caught fish (Januchowski-Hartley *et al.* 2011). In some cases, increased abundance and enhanced catchability has been observed to spill over beyond the boundaries of the closure (Tawake *et al.* 2001; Januchowski-Hartley *et al.* 2013).

Periodically-harvested areas can be implemented with relative enthusiasm, compared with other management actions (Cohen *et al.* 2013; Léopold *et al.* 2013). In many tropical Pacific countries, periodically-harvested closures have historical origins (Johannes 1982), and their contemporary application may maintain customs by providing food and income for celebrations (Govan 2009). In several cases, advice from partners to promote long-term sustainability objectives may have contributed to community plans to keep periodically-harvested closures predominantly closed (P. Cohen, unpublished data). Yet in practice, community objectives for increased catch efficiency and short-term benefits can be more immediate, and have led to closures being harvested more frequently, intensely or even destructively, than was planned with advice from partner agencies (Jupiter *et al.* 2012, Cohen *et al.* 2013). In some areas where tourism operates, periodically-harvested closures have attracted small fees paid by tourists, visiting these sites for their cultural and aesthetic values (Tiraa 2006). Income is generated from multi-species harvests (Jupiter *et al.* 2012) or commonly, the harvesting of invertebrates (e.g., trochus) when areas are opened (Foale 1998; Cohen and Foale 2013). Yet, harvesting pressure can be intense (even destructive), with removal of substantial biomass (Jupiter *et al.* 2012; Cohen *et al.* 2013). Where harvests were light and infrequent, conservation benefits of periodically-harvested closures (species richness, live coral cover and coral diversity) did not differ significantly from areas open year-round (Cinner *et al.* 2006), but where harvests are intense, frequent and/or conducted using non-selective or destructive gears, maintenance of biodiversity and habitats is probably less achievable.

Species-specific restrictions

Species-specific regulations, including size limits, are commonly used to maintain or increase breeding stock in centralized fisheries management, particularly for less mobile species (e.g., Cancino *et al.* 2007; Cochrane and Garcia 2009). Yet, setting appropriate size limits can be complex, particularly for species with highly variable growth rates that may mature at different sizes, depending on local productivity (Prince 2003), or those where the timing of sex changes is influenced by fishing pressure (e.g., Hamilton *et al.* 2007). Species-specific size restrictions within local management have met with mixed success. For example in West Nggela, Solomon Islands, there was poor compliance with size limits for trochus (*Trochus niloticus*), regulated by the national government (Foale 1998). Similar situations have been observed for Pacific sea cucumber fisheries (Kinch *et al.* 2008). Contrastingly, in LMMAs in Vanuatu, there was good compliance for national trochus size limits and a moratorium on sea cucumber harvesting, but lower levels of compliance with community-set size limits and temporary harvest bans for other species (Léopold *et al.* 2013). Léopold *et al.* (2013) suggested that increased enforcement capacity would be necessary to better regulate additional fishing restrictions because the marine reserves and periodically-harvested closures actively employed were unlikely to assure the long-term sustainability of yields.

Species-specific catch restrictions might maintain biodiversity and ecosystem function if regulations target functionally important or vulnerable species. For example, in one location in Fiji, four species of herbivorous fish accounted for 97% of macroalgal consumption within LMMA reserves; thus, bans on harvesting these species alone could effectively maintain herbivory on reefs, contributing to reef health by reducing harmful macroalgal interactions with coral (Rasher *et al.* 2013). Spatial or temporal bans on fishing of particular species during sensitive life history phases (e.g., spawning aggregations) can maintain biomass and breeding stocks. For instance in Papua New Guinea, the camouflage grouper *Epinephelus polyphekadion* increased ten-fold in density in a reserve over a spawning aggregation site (Hamilton *et al.* 2011). In Solomon Islands, a local regulation on harvesting clams was implemented in response to observed low abundance, but the effectiveness of the measure was not determined (Cohen *et al.* 2013). Incorporating species-specific restrictions, based on totems or taboos, may reinforce customs, but little empirical evidence exists of effectiveness. The use of species-specific quotas is rare in local management initiatives, likely due to the need for data and data management systems.

Gear restrictions

Banning destructive methods (e.g., dynamite, fish poisons) and highly efficient gear (e.g., spearguns, small mesh nets) is known to be important for maintaining habitat structure, ecosystem function and breeding capacity (Fernandes *et al.* 2012). Such gear restrictions are often attempted within LMMAs (Johannes 2002; Govan *et al.* 2008). There are few assessments of their effectiveness in the Pacific (though see Carrier 1982), but elsewhere gear restrictions can increase long-term sustainable yield. For example in Kenya, fish size and catch per unit effort from permitted gears increased when beach seines were locally prohibited (McClanahan and Hicks 2011). Local enforcement and compliance with gear restrictions can be poor in Pacific LMMAs; for example Vanuatu and Solomon Islands communities initially set gear-based restrictions when they established LMMAs, but few restrictions were implemented (Cohen *et al.* 2013; Léopold *et al.* 2013). The context in which gear restrictions can be successfully implemented, and the contributions that makes towards fisheries, cultural and ecological objectives, remains an important area for future research.

Access restrictions

The ability to restrict access is a foundation of effective resource governance (Ostrom 1990), in a common input control in fisheries (Ruddle *et al.* 1992) and can support the implementation of concurrent management measures (World Bank 2000). Marine tenure can both reinforce local governance and provide the mechanism by which to limit access (Johannes 2002; Macintyre and Foale 2007). However, implementing access restrictions "will not necessarily change the volume harvested, just who harvests it" (Polunin 1984). Therefore, where local resource use is intense, access restrictions on their own may not maintain biomass or enhance sustainability. Despite the small size of marine tenure units, some species can recruit into managed areas where access has been restricted (Almany *et al.* 2013), while for others (particularly species with large home ranges or those with highly dispersing larvae), recruitment into small managed areas may be limited (White and Costello 2011). To account for this, networks of numerous small tenure-defined reserves may be more effective (Aswani and Hamilton 2004; Weeks *et al.* 2010).

Livelihood diversification strategies

Co-management partners sometimes promote livelihood diversification strategies with LMMAs to reduce fishing effort or offset perceived losses of revenue associated with management interventions (O'Garra 2007). The expectation is that diversifying income sources will lead to reduced fishing pressure on coastal ecosystems (Cinner 2014). For instance in Solomon Islands, there was increased catch per unit effort at fish aggregation devices (FADs) due to enhanced catches of pelagic fish, accompanied by a perception by fishers of decreased effort elsewhere (Prange *et al.* 2009). However, there are few documented examples that conclusively demonstrate that introduced alternative or supplemental livelihoods has led to more sustainable fisheries practice or improved resource condition (Gillett *et al.* 2008). Resource management may stall or fail if hopes for improved income do not materialize, and/or if conflict arises due to inequitable distribution of benefits (Foale 2001), as when a sewing project was introduced in Roviana Lagoon (Aswani and Weiant 2003; Niesten and Gjertsen 2010). Further, there is concern that livelihood projects may create a culture where communities demand payment for participation in management (Foale 2001), producing dependency on perpetual subsidies (Gillett *et al.* 2008). Livelihood projects may also fail to reduce fishing effort due to unforeseen outcomes or poor understanding of cultural attachments to fishing (Cinner 2014). For example, a seaweed farming project introduced in Indonesia and Philippines did not reduce fishing effort because it primarily involved women and children, rather than male fishers (Sievanen *et al.* 2005).

CONCLUSIONS

Globally, community-based and co-management approaches have gained increased recognition in practice and critical appraisal in the scientific literature. Management success depends on seven key factors: recognition of human agency; a well-defined and bounded community; perception of resource rights by community and government; functional conflict resolution mechanisms; support for community leadership; long-term commitment by co-management partners; and cohesion of community and co-management partner objectives (Ostrom 1990; Gutierrez *et al.* 2011; Cinner *et al.* 2012). We also identified that success of LMMAs has many meanings due to the multiplicity of objectives. Furthermore, progress can involve trade-offs or synergies between multiple objectives, where success towards one objective (e.g., short term increases in catch efficiency) may come at the expense of achieving others (e.g., enhancing long-term sustainability of resource-use or maintaining breeding biomass). Further, outcomes depend on the effectiveness and variable application of the many management actions applied in practice within the framework of an LMMA.

The tropical Pacific hosts some of the most ecologically and culturally diverse places in the world. The acceptance and proliferation of LMMAs in the region is substantially attributable to the non-prescriptive nature of the approach (i.e., adaptable to a range of conditions and contexts and adjusted through time). Yet, this variability in contexts, and in the resultant form LMMAs can take, challenge generating overarching recommendations to realize objectives. Our case studies demonstrated where certain objectives and management measures support, or potentially hinder, the achievement of eight overarching LMMA objectives. Yet despite hundreds to thousands of LMMAs in the tropical Pacific, most local management still proceeds with little documentation or critical evaluation. As a result, there are relatively few empirical cases that describe how objectives and management tools are negotiated, report the objectives and tools ultimately engaged, or test outcomes towards objectives. And while we appreciate that heavy data requirements are inappropriate to the approach, LMMA objectives, management measures, outcomes and limitations represent important areas for on-going research and transparent reporting, particularly given that the approach is currently heavily relied on to achieve conservation and fisheries management outcomes within the region.

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