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# Maneuvering towards adaptive co-management in a coral reef fishery

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ABSTRACT

Tropical coral reef ecosystems in the Pacific region are degrading rapidly as ocean temperatures rise and local anthropogenic stressors increase. In this context of rapid change, effective site-based management of coral reef fisheries necessitates flexible environmental governance that is closely attuned to the needs of multiple stakeholders who depend on the fishery for income, food, and cultural identity. As such, many practitioners and scholars call for adaptive co-management of coral reef fisheries where local resource users play a primary role in environmental governance with the support of flexible institutions that operate across organizational scales. This article describes the history and evaluates the current status of marine governance in Moorea, French Polynesia. Established in 2004, the management framework is under revision because it has failed to meet its ecological objectives and has generated discontent among many stakeholders. Drawing on household surveys, interviews, and archival information, the challenges to as well as the factors that may enable a more successful transition of the current governance arrangement towards co-management are detailed. It is argued that recent social mobilization, subsistence and cultural links to the fishery, the presence of geographically and socially relevant traditional governance boundaries, and the implementation of co-management in other parts of French Polynesia are positive factors. However, lack of trust between stakeholders, social heterogeneity, disruption of traditional cultural institutions and practices, minimal institutional support, and an uncertain legal framework suggest that there are significant headwinds for maneuvering towards successful co-management in Moorea.

## 1. Introduction

In the Pacific, sustainable management of small-scale coral reef fisheries is a significant issue given its role in supporting local economies and underpinning islander identities [12,22]. Yet, coral reefs represent the paradigmatic case of ecosystem decline and transformation in the Anthropocene era [26]. Although climate change-induced threats (e.g., elevated sea surface temperature, more intense cyclones, sea level rise, thermal stress, acidification) are key drivers of reef degradation worldwide, site specific management of human pressures such as fishing and marine resource use has the potential to facilitate both coral reef resilience and local livelihoods. Effective management, however, remains elusive in many Pacific Island contexts [11,18,36,6]. Some scholars continue to call for 'nature' preserves free of humans [57], but the failure of top-down, exclusive 'fences and fines' approaches to environmental management in many locations [10] has spawned numerous strategies to increase the involvement of local communities and resource users in the sustainable management of ecosystems [9]. One such strategy, known broadly as adaptive co-management, relies on a compelling rationale: that people who are affected by environmental decisions and who use local resources should be involved in resource decision-making processes [19]. As a result, there has been a proliferation of approaches ranging from near complete devolution of control to local communities to shared governance between state-level and local-level institutions [44]. Islander communities with strong customary land and sea tenure institutions, for example, have shown the capacity to regulate access to resources with minimal outside support [28].

A critical element of an effective environmental governance regime is consistent monitoring of local resource dynamics to facilitate iterative management that responds and adapts to feedbacks. Pacific Islander fishers have demonstrated monitoring capabilities in both slow and rapidly changing marine socio-ecological systems [2,32]. It is not surprising that fishers are sensitive to ecological variability considering that most coral reef social-ecological systems are highly dynamic. Fluctuating fish populations and algal coverage, bleaching events, and

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crown-of-thorns seastar outbreaks are inherent dynamics of coral reef systems [58]. Therefore, fishers can play an active role in environmental monitoring. Of course, how fishers adapt to changing conditions may not always lead to sustainable outcomes, particularly in the face of rapid social, economic or technological change. The rise of blast fishing in some areas of the Indo-Pacific region is a case in point. However, when local resource users have demonstrated cultural, subsistence, and/or economic reasons to sustainably manage resources the possibility for effective co-management increases [3].

Contexts like Hawaii, American Samoa, and New Zealand, where traditional management practices and customary tenure systems have been historically suppressed or disrupted to differing degrees, and where marine environments are under the aegis of established state agencies, represent situations where the outcomes of fisheries co-management strategies have been mixed. In Hawaii, community-based subsistence fishing area legislation was passed over 20 years ago, yet only two communities have successfully obtained subsistence fishing area designations [38,4]. In the islands of American Samoa, fisheries co-management has been successfully undertaken in multiple village communities, though not without hurdles [38]. In either case, the ecological outcomes have yet to be studied and it remains an open question how ecologically effective these managements systems will be. Positive ecological outcomes have been documented, however, at other sites such as the Solomon Islands and Papua New Guinea that are managed by local communities with little state influence [13].

Regardless of the specific approach, resource governance will inevitably have socio-ecological repercussions and unintended consequences. Creating sustainable pathways will never be error free. Resistance to protected areas and conservation efforts, for example, is common around the world [16,17]. Therefore, it is important to explore the reasons why people may resist conservation and what possibilities exist for channeling that discontent towards more positive outcomes [48]. This includes evaluating the multiple ways that local resource users engage with and understand natural resources, how decisions are made about resource use, and what regulations local resource users will support. Additionally, if fundamental political inequalities are not addressed, even well-intentioned resource management efforts can lead to the exploitation of the less powerful [14].

Here the current status and history of marine management on the island of Moorea, French Polynesia is examined. The island presents a complex entanglement of neo-colonial agitation, dynamic coral reefs, powerful hotel conglomerates, vocal fishing communities, and a resurgence of Polynesian identity and culture. The focus of this article is the *Plan de Gestion d'Espace Maritime* (PGEM), an island-wide planning scheme – implemented in 2004 by the territorial government and the local municipality – regulating all activities (i.e. recreational, tourist and fishing) taking place in Moorea's lagoon. The first of its kind in French Polynesia, it includes numerous marine protected areas where fishing practices are regulated or prohibited. The PGEM, however, has failed to meet its ecological objectives and has sowed discontent among some fishers who have actively resisted its implementation [20,52]. Acknowledging these difficulties, in 2016 Moorea's municipality, under the auspices of the French Polynesian Territorial government, began a revision of the PGEM. As of June 2018, however, most PGEM revision details have not been made public.

Below household surveys and interviews with community members and other stakeholders are drawn on to assess the current status of the PGEM. Then the challenges and the enabling factors that could potentially lead to a more effective management regime are described. Our analysis is guided by scholarship that has identified the characteristics and conditions that support successful adaptive co-management arrangements (Table 1).

## 2. Research site and methods

Moorea is a 134 $km^2$ high volcanic island located 25 km west of Tahiti in the Society Islands Archipelago of French Polynesia. Its barrier reefs emerge roughly one kilometer from the shore, resulting in 29 $km^2$ of coral reef-lagoon ecosystem (Fig. 1). Moorea and the rest of the Society Islands were declared a French Protectorate in 1842 and the islands continue to be under French rule, although today the French Polynesia government has considerable autonomy from France with its designation as a *collectivité d'outre-mer* (overseas collective).

Moorea underwent tremendous economic development and social change associated with the French government's decision in 1962 to move their nuclear testing program from Algeria to the Tuamotus Archipelago of French Polynesia. The budgetary allocations associated with the nuclear program spurred large-scale economic and infrastructure development on Tahiti, causing a major shift in lifeways for much of the country. Papeete, Tahiti became the economic and political capital as the construction of an international airport and deep-water harbor led to an influx of French Polynesians from the outer islands seeking wage-employment. The airport in particular opened up a new opportunity for international tourism, which quickly developed into a major income earner for the country. Moorea is now one of the most visited islands in French Polynesia with nearly 75,000 annual tourists that stay in 11 major hotels and 50 smaller "*pensions de famille*" [50].

Currently, Moorea's reefs provide two primary economic opportunities to island residents: fishing and tourism [43]. Although fishing does not generate nearly as much economic activity and income as the tourism industry, its benefits are more broadly shared than the jobs and profits associated with tourism [35]. The reef fishery is dominated by non-economic and recreational motivations, with the majority of catch serving as a supplement to local diets and household incomes rather than as a necessity for food security or economic survival. The importance of Moorea's fishery to cultural heritage and pride is fundamental; the consumption of marine species perhaps being as important as the Tahitian language to Polynesian residents [34]. Fish, invertebrates, and crustaceans are consumed at church gatherings, birthdays, Sunday feasts, and other important events and play a dominant role in local diets. When fishing practices and the significance of fish consumption are considered in conjunction with the varied usages and pressures that tourism[1] exert on the lagoon, management becomes increasingly complex.

Between 2014 and 2015, our team conducted 351 household surveys in three of Moorea's five districts, known in French as *communes associées*: Afareaitu (n = 121), Papetoai (n = 116), and southern Haapiti (n = 114). Afareaitu forms the municipal seat of the Moorea-Maiao municipality, Papetoai has more of its lagoon space under management than the other two districts studied and has more intense tourism activity, while southern Haapiti is more remote with little tourism development. These three districts were selected for the survey due to their differing social, economic, and marine regulatory contexts.

Survey topics covered demographics, fishing practices, perceptions of environmental health, and perceptions of fishery change through time. A section of the survey questionnaire was devoted to resource governance and the questions were developed based on the academic literature that identifies characteristics and conditions of successful adaptive co-management. All survey research employed both convenience and reputational sampling methods with the goal of achieving an even distribution across each district's designated survey area. Fourteen key informant interviews were also conducted with highly regarded fishers in the three districts (Afareaitu n = 8; Haapiti n = 2; Papetoai n = 4), a *Service de la P ê che* official was interviewed, and the first island-wide public consultation meeting for the PGEM was observed in June 2016. All researchers received IRB ethics training.

[1] Including local Polynesian "tourists" who visit from nearby islands to fish in the waters surrounding Moorea.

**Table 1**
Select enabling conditions of successful co-management.

| Description of condition | Supporting references |
|---|---|
| Community self-organization spurred by conflict over resources | [4,48] |
| Social, cultural, spiritual and/or economic connections to places and resources | [3,51] |
| Spatial planning corresponds to appropriate ecological and socio-political scales | [15,23] |
| Supportive and well-defined legislation, policies, and rights that partners understand and agree upon | [7,27] |
| Socio-economic similarities in terms of norms, trust, communication, demographics, or fishing practices | [23,45] |
| Scientific knowledge combined with local knowledge supports co-learning | [6,7,14,29] |
| Accessible and clear goals and conflict resolution mechanisms | [15,45] |

## 3. Establishment of the Plan de Gestion d'Espace Maritime

The creation of marine protected areas (MPAs) in French Polynesia was closely associated with the tourism economy. Tourism was widely understood by policy makers as an environmentally friendly source of economic revenue that could sustain both the economy of French Polynesia and its marine biodiversity [43]. French legislation, *Le Pacte de Progrès* (The Progress Pact), enacted in 1993 paved the way for the creation of MPAs on the island. *Le Pacte* was developed to fill the economic void that would result from halting French subsidies of the nuclear testing program [56]. Just prior to its implementation, several severe cyclones struck Moorea that damaged the coral reefs. A fear that overfishing would prevent the reef and fish from recovering added urgency to the management initiative [39]. As a result, in 1995 the French Polynesian government began the planning process to implement MPAs. Nine years later, in October 2004, the newly autonomous government of French Polynesia enacted, in Moorea, the first marine spatial planning endeavor of the country, *Le Plan de Gestion d'Espace Maritime* (PGEM). The PGEM is a marine spatial planning framework which devolves the management of the lagoon (from shore to the outer slope of the reef crest) to the municipality. The PGEM parallels the municipality's land planning framework, the *Plan Général d'Aménagement* (PGA). Both the PGEM and PGA permit, regulate, or prohibit specific activities in designated zones.

The present PGEM management plan includes two managed fishing areas that impose size/species restrictions and eight no-take MPAs. Five of the eight MPAs and both managed fishing areas are located on the northern coast, a region dominated by tourism and large-scale resorts. Fishing regulations defined by the PGEM are in addition to national-level marine use regulations enforced by the *Direction des Resources Marines et Minières* (DRMM). The DRMM is the territorial department of fisheries and is often locally referred to as the *Service de la Pêche*. Some of the PGEM regulations – such as minimal mesh size of nets – are more restrictive than those of the DRMM, creating some confusion among fishers as to which regulations to follow.

**Table 2**
Characteristics of Moorea that may enable successful co-management regimes on the island or pose challenges.

| Enabling conditions as highlighted in the literature | Characteristics of Moorea | |
|---|---|---|
| | Enablers | Challenges |
| Community self-organization spurred by conflict over resources | - Fishers have self-organized into an association that is requesting the devolution of management to district-level committees | - Traditional community organizing systems have been disrupted by colonialism and globalization.<br>- History of conflicts could hinder collaboration between stakeholders |
| Social, cultural, spiritual and/or economic connections to places and resources | - Many stakeholder groups support management efforts to preserve and protect marine species<br>- Commitment to management due to high reliance on marine resources for economic, cultural, and subsistence purposes | - Interests vary by stakeholder group (fishers, tourist operators, hoteliers, scientists, managers, etc.) and need to be accounted for under marine spatial planning efforts. |
| Spatial planning corresponds to appropriate ecological and socio-political scales | - Suitable ecological and governance boundaries already in place to delineate management areas on a district level<br>- Multi-scale management framework proposed | - PGEM established at island-scale will need to be reworked<br>- Marine resource governance at the district-level is nascent<br>- National-level imposed marine use regulations create confusion and complexity |
| Supportive and well-defined legislation, policies, and rights that partners understand and agree upon | - The environment is under the jurisdiction of the French Polynesia government<br>- Models of co-management available in other parts of French Polynesia<br>- ZPR legislative framework decided upon during PGEM revision process. | - PGEM legislative framework under the Code de l'Urbanisme is not conducive to co-management efforts<br>- Lack of enabling legislation for co-management specific to Moorea<br>- Lack of funding sources for co-management. |
| Socio-economic similarities in terms of norms, trust, communication, demographics, or fishing practices | - Cultural significance of fishery throughout island<br>- High levels of reef fish consumption among populace<br>- Predominately Tahitian or other Polynesian ancestry | - Social heterogeneity, in part due to inter- and intra-island migration.<br>- Livelihood heterogeneity<br>- Influence of the tourism industry is variable around the island<br>- Powerful external interests associated with the tourism industry |
| Scientific knowledge combined with local knowledge supports co-learning | - Established scientific research institutions on the island that have in-depth, long-term datasets on reef conditions<br>- Ongoing marine ecological monitoring | - Distrust between some fishers and some scientists undermines collaboration.<br>- Current marine ecological monitoring not focused marine management |
| Accessible and clear goals and conflict resolution mechanisms | - *Rahui* inspired management principles have been outlined. | - No specified sanctions for violating regulations under proposed *rahui* management.<br>- Specifics of co-management rules and strategies are vague.<br>- Lack of conflict management strategies. |

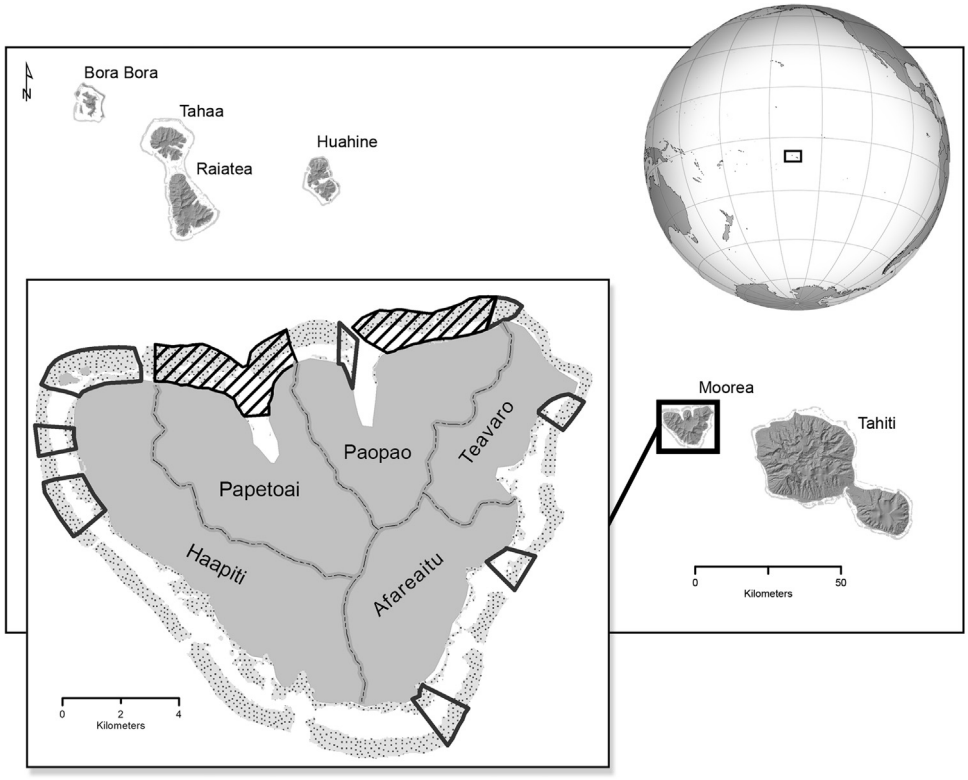


**Fig. 1.** Moorea's eight marine protected areas (black polygons), two managed marine spaces (hatched polygons), and five administrative districts.

## 4. Results and discussion: enabling characteristics and challenges to co-management in Moorea

### *4.1. Community self-organization spurred by conflict over resources*

The PGEM has led to discontent among some fishers who contend that the spatial zoning and regulations of MPAs and managed fishing areas prioritize tourism operators' and hoteliers' interests over those of other stakeholders [55]. Planners attempted to incorporate stakeholder input during the original PGEM planning process, particularly regarding the placement of the MPAs. These efforts were met with resistance. Many of Moorea's residents refused to attend PGEM planning meetings. More overt acts of resistance also occurred, including the burning of the boat and nets of an individual who was perceived to be assisting too much in the MPA planning process. These actions, although not necessarily conducive to collaboration, are forms of social mobilization, self-organization, and political will, characteristics that can lead to successful co-management initiatives [4].

Discontent with the PGEM has led to widespread disregard of PGEM regulations, including continued fishing within MPAs and managed fishing areas. Fish surveys conducted in 2000, four years prior to the establishment of the PGEM, and in 2008, showed that the closures had no effect on relative fish densities [52]. These acknowledged problems have compelled the territorial government and municipality to undertake a community-based consultation process to revise the PGEM. The first island-wide meeting for the revision process was held in June 2016. During the meeting, PGEM representatives stated that the restructuring was largely to redress the 'sense of injustice' caused by the PGEM. The revision process followed standard legal procedure where a newly composed committee, the *Commission Locale de l'Espace Maritime* (CLEM), led the consultation process. The committee's composition was designated by the municipality and approved by the territorial government. The new committee included five (out of 33) representatives from fishing communities, however, fishers did not choose their representatives. The meeting gave the perception that the territorial government and municipality had already developed a framework to revise the PGEM without thoroughly consulting fishers. Gathering amongst themselves during the lunch break of the meeting, fishers discussed how to move forward in the consultation process. Some people decided to demand *rahui*.

Traditionally, *rahui* was a flexible system of resource management where chiefs who presided over local kin-groups regulated access to resources [5]. These kinds of management regimes were found throughout the pre-European Pacific and usually involved pie-shaped, ridgetop to reef crest ecosystem units where land and sea areas were managed as a cohesive whole [49]. Marine resource use areas (e.g., known fishing grounds) were typically subject to temporary, one to three year, spatial closures that were lifted prior to important social events, such as a chief's wedding, where large amounts of fish and invertebrates would be needed. The closure of marine resource use areas enabled stocks to replenish and would help insure a large harvest when the moratorium was lifted. In others words, the objective of marine space closures was to maintain social relationships, such as ensuring adequate resources for cultural celebrations and significant social events, rather than for strictly ecological outcomes such as the maintenance of biodiversity.

*Rahui* in this traditional form is no longer practiced in Moorea. It was not only prohibited under colonial rule but also was quite effectively undermined when land ownership was formalized in the early 1900s, removing the communal property model upon which *rahui* was based. Today, however, while *rahui* is linked to environmental management strategies, it is being revived and asserted by traditional authorities to contest state control over environmental resources. In fact, some other islands in French Polynesia islands including Tahiti, Rapa iti (Austral Archipelago), and Fakarava (Tuamotus Archipelago) have co-management regimes that are called *rahui*. On Moorea, some Mooreans have formed a grassroots organization, known as the *Association Rahui de Moorea*. The group is proposing that the PGEM be converted to *rahui* and that some marine management decision-making authority be devolved to commune-level committees comprised of traditional

authorities and elders [46].

These examples of overt political expression on Moorea, both in the past and presently, have been viewed by some policy makers, PGEM managers, and scientists as problematic due to the intermixing of political and environmental matters. Yet conflict and political positioning has been shown to be a key motivating condition for self-organization and the emergence of co-management [4]. Indeed, the adaptive co-management framework is grounded in the assumption that political contestation and resource management are inevitably intertwined. When management regimes are established, its effects are felt beyond the environmental resources as they constrain or enable the behavior of fishers and other stakeholders. Therefore, conflicts are an expected and inevitable outcome of environmental management [42]. The challenges include channeling political activism towards a constructive and inclusive pathway of power-sharing and mitigating placing an overwhelming burden on those who are structurally disadvantaged or disempowered.

### 4.2. Social, cultural, spiritual and/or economic connections to places and resources

Moorea's population demonstrates a vested interest in the fishery through their extensive cultural ties and uses of the marine environment. Amongst our survey population, over 75% of the households surveyed had at least one person who currently fishes, and 83% of all households desired that their children fish. Previous work shows that Mooreans consume significant amounts of seafood [59]. Of the households surveyed, 98% ate fresh fish at least one time or more per week, with 35% of respondents consuming fish 6–7 times a week, 32% consuming fish 3–5 times a week, and 31% of households eating fish at least 1–2 times a week.

A vast majority (96.5%) of surveyed households said that fishing was important because it enabled them to consume fresh fish (as opposed to canned or frozen). Many respondents also stated that fishing was important for sharing with family/friends or for enjoyment/fun, and, to a lesser degree to sell the catch or because there is no other work available (Table 3). In Haapiti, however, the importance of fishing due to a lack of work was a more frequent response compared to other districts ($\chi 2 = 6.6784$, 2 d.f., $p = 0.03547$). While in Afareaitu the importance of giving fish to family/friends was a statistically significant more frequent response ($\chi 2 = 4.756$, 2 d.f., $p = 0.0006249$).

Mooreans talk about the lagoon environment as their “refrigerator”. Through fishing, people are able to feed themselves and their families, while also earning spare cash by selling fish. Thus, fishing meets multiple economic and subsistence purposes and is a vital fallback option for those who cannot access other work. For many Pacific Islanders, fresh fish represent a non-substitutable source of protein [33].

### 4.3. Spatial planning and appropriate ecological and socio-political scales

The spatial scale of successful co-management regimes tends to be large enough to provide ecological diversity, but small enough to be politically and socially tractable [15,23,54]. User participation is most effective when carried out at the lowest level of social or political organization possible (i.e. a small village rather than an entire island), an idea known as the subsidiary principle [31]. Yet the management of the initial PGEM was at the scale of the entire island and fishers generally fish within their district, are best acquainted with the lagoon conditions in those relatively limited geographic areas, and have varying income generating opportunities that push or pull them into the fishery. For example, 57% of households in Haapiti said that fishing is very important because there is no other work opportunities, while only 5% from Afareaitu stated this and 20% in Papetoai. Afareaitu is the seat of the municipal government and Papetoai has several large hotels, which provide more income earning opportunities than what are available in Haapiti.

Moorea's coral reef ecology also has notable intra-island variation. There is considerable variation in reef habitats and associated fishes along an inshore to offshore transect that includes fringing reefs closest to shore, shallow mid-lagoon and back reef habitats and the steeply sloping deep fore reef seaward of the reef crest [24]. In addition, patterns of disturbance and post-disturbance speed of recovery of the coral reef community vary among the coasts of the triangular-shaped island [25]. For this reason, fishers are continually affected by perturbations that have high levels of spatial heterogeneity.

Considering the heterogeneity on the island, the proposal made by the *Association Rahui de Moorea* to devolve some management control to the district-level has both ecological and social justifications. This devolution could build on the current political structures since the districts are already established political units. Moreover, devolving aspects of management authority to the districts could provide a more ecologically effective and socially feasible alternative to the current island-wide approach implemented through the PGEM, since it would facilitate the incorporation of place-based knowledge and monitoring into management decision-making.

### 4.4. Supportive and well-defined legislation, policies, and rights

Across the households surveyed, there were varying levels of support for current PGEM regulations. Fifty-six percent of respondents stated that they supported the PGEM regulations, and an additional 14% said that they ‘sometimes’ supported regulations. Residents of Papetoai stated lower levels of support for regulations than residents of Afareaitu and Haapiti, who have less direct interaction with MPAs (Table 4). In fact, roughly 75% of Papetoai's marine space is regulated under the PGEM (see Fig. 1).

Household survey respondents said that they supported the PGEM because: ‘it preserves/protects marine resources’; ‘it allows species to reproduce and mature,’ and ‘people should not fish for small fish’. The most common responses for not supporting the PGEM were: ‘the PGEM blocks access to food/income’; ‘there are too many regulations and regulations that do not make sense’; ‘MPAs should be more like *Rahui*/MPAs are not real *Rahui*’; and because ‘the PGEM is for tourists’. The fact that most Mooreans support marine management regulations suggests that the populace is receptive to marine resource governance. The negative perceptions of the PGEM seem to largely be due to how the

**Table 3**
Average scores for responses to the question “What makes fishing important?” (0 = Not Important, 1 = Somewhat Important, 2 = Very Important). (n = 231).

| | Afareaitu | S. Haapiti | Papetoai |
|---|---|---|---|
| For eating fish | 1.96 | 1.99 | 1.93 |
| To give fish to family/friends | 1.91* | 1.56 | 1.39* |
| For enjoyment/fun | 1.78 | 1.56 | 1.46 |
| To sell the catch | 0.82 | 0.79 | 0.66 |
| Because there is no other work available | 0.20* | 1.22* | 0.48 |

* Significant difference ($P < 0.05$) in responses between districts shown by Kruskal-Wallis tests. Post-hoc Dunn tests identified the districts where these differences were present.

**Table 4**
Frequency of responses to the question “Do you support these [respondent stated] PGEM regulations?” (n = 382).

| | Afareaitu | S. Haapiti | Papetoai |
|---|---|---|---|
| Support regulations | 54% | 51% | 37% |
| Sometimes support regulations | 26% | 4% | 12% |
| Do not support regulations | 19% | 26% | 34% |
| Unsure | 1% | 18% | 16% |

PGEM was implemented: as a top-down mechanism with permanent closures and no-take zones that disproportionately affect some districts and stakeholders and that appear to have been designed around the interests of hoteliers and tourist operators.

Although there is local support for marine resource governance, especially if envisioned as *rahui*, legislative mechanisms are necessary to devolve control to traditional authorities. This begs the question: is *rahui* legislatively possible in Moorea[2]? Moorea's PGEM was instituted under legislation that requires national-level approval of any adaptations to the management plan. Moreover, the local municipal governments have formal authority and control over the PGEM. However, a more flexible legal framework, known as the Zone de Pêches Réglementées (Regulated Fishing Zones) (ZPR) has been developed by the DRMM (Department of Fisheries and Mines). The ZPR enables local managers, in collaboration with DRMM staff, to open, regulate or close marine use areas. These decisions can take effect immediately through an arrêté (decree) signed by the Conseil des Ministres (a government board which meets every week). As a result, ZPRs provide a much more malleable and adaptive legal framework than the one leading to the creation of a PGEM. Indeed the latter can only be modified by a lengthy and centralized process of revision that can last several years (as is the current case in Moorea). The ZPR may also devolve decision making authority to rahui management committees rather than formal political authorities (e.g., municipalities and mayors).

Within this new legal and policy framework, there is precedent for adaptive co-management where district-level committees manage their lagoon marine spaces. Several co-management regimes have been developed including one on Fakarava in the Tuamotus Archipelago and another on the island of Tahiti [5]. The Tahiti management area is located in Teahupoo, a district at the far south-eastern end of Tahiti Nui (the smaller half of the island of Tahiti). The Teahupoo managed area extends from ridgetop to reef and adheres to a traditionally managed area, delineated by a *marae* (pre-Christian communal religious spaces dedicated to specific deities). The governance regime was initiated in June 2014 and it includes a permanent, no-take zone, whose location was decided upon by district members, and, notably, traditional experts on fishing. The explicit objectives of the Teahupoo managed area intermix social and ecological goals. They include preserving marine species and marine biodiversity; rebuilding marine resource stocks in order to perpetuate the traditional cultural activity of fishing in the protected area; and promoting sustainable resource management, notably traditional management. Resource decisions are made through active participation.

One outcome of the current PGEM revision process is that the municipality will maintain jurisdiction over the lagoon's no-take zones, though it will no longer control fishing regulations outside of no-take areas. Areas outside of the no-take zones will be converted to a ZPR framework and marine resource management will be devolved to newly formed, district-level fishing committees. These revisions to the PGEM constitute a significant step towards adaptive co-management, although, some fishers, most notably from the *Association Rahui de Moorea*, argue that the district-level fishing committees should be granted more control over fishing within the no-take zones.

### 4.5. Socio-economic similarities and differences

Shared cultural values, whether in terms of kinship, ethnicity, language, religion, or fishing techniques, have been discussed as an enabling factor for co-management [45]. Moorean residents share many common cultural values and practices such as the widespread consumption of fresh reef fish, as well as a common ethnic heritage (87.5% of the island's population are French Polynesian).

Despite these shared cultural aspects, there remain many social differences across the island, particularly relating to livelihood opportunities and migration rates, which may present challenges to the implementation of co-management. In Afareaitu, for example, 70% of household respondents were originally from the village in which we interviewed them, whereas in both Papetoai and Haapiti, only 45% of households were from the village where they were interviewed. In-migration increases social heterogeneity, although it should be noted that the majority of new residents migrated from other Moorean communities or from Tahiti. Livelihoods are also quite varied with 22% of households indicating that tourism is their primary source of income, followed by retirement pensions (15%), agriculture (9%), construction (7%), and small business (6%). The largest occupational category was 'other,' with 33% of households responding that they were engaged in multiple kinds of work. There were also marked district-level differences in livelihoods with 37% of respondents in Afareaitu working in the tourism industry while only 12% in Haapiti indicated that this was their current occupation. Notably, fishing was mentioned by only 1% of households as the primary occupation. Differing perceptions of illegal fishing were also evident in the household survey, which is related to the unequal distribution of MPAs around the island. In Papetoai, where much of the marine space is regulated under PGEM, a higher percentage of households perceived illegal fishing as a big problem (59%) followed by Afareaitu (41%), and Haapiti (29%), where fewer MPAs are located.

Differing rates of reliance on, and exposure to, tourism may also present a challenge to successful co-management. Papetoai, in particular, represents a center for tourism in Moorea, experiencing much more tourism than the other districts surveyed. Two large hotels are located there and it contains Opunohu Bay, a popular overnight stopping point for cruise ships. In some cases, tourism has been shown to complicate co-management efforts through marginalizing residents and impacting their connection to place [53], although in others it has provided positive potential if tourist resources are channeled to local communities (as in Teahupoo). If marine governance disproportionately favors one type of stakeholder, especially outsider interests such as hoteliers, and does not contribute more broadly to diverse stakeholders' livelihoods, it has been shown to be less successful [37].

### 4.6. Scientific knowledge and local knowledge

Adaptive co-management is based on the principle that multiple sources of knowledge and information should inform decision-making processes. In this regard, Moorea has great potential for collaboration between fishers from around the island and researchers from two Moorea-based research stations. Moorea is home to the French *Center de Recherches Insulaires et Observatoire de l'Environnement* (CRIOBE) and the American U.C. Berkeley Richard B. Gump Station (from here forward, Gump). CRIOBE was established on Moorea in 1971 and Gump in 1985. Together, the two stations host numerous faculty and research associates who have extensively studied Moorea's coral reefs over many decades. The island is now recognized as one of the world's centers of coral reef research.

If the researchers working in these stations join fishers and other stakeholders to co-generate knowledge about the coral reefs of Moorea, such ventures could contribute to the advancement of socially equitable and ecologically effective adaptive co-management solutions [29,8]. In Micronesia, for example, scientific monitoring and adaptive management have been tightly coupled [41]. Monitoring produced new knowledge about changing marine ecological conditions in Micronesia, which was effectively communicated to the stakeholders and conservation managers and led to adaptive shifts in the management regime. On Moorea, however, researchers have rarely engaged with

[2] Very recently, in October 2017, the updated *Code de l'Environnement* (Legal code regulating environmental issues) recognizes *rahui* as an oral, cultural, and traditional value that may operate in natural resources management. However, it states that *rahui*-based management practices must abide to all pre-existing written legislation. (Loi du Pays no. 2017–25 du 05/10/2017 – page 6415).

fishers or provided the PGEM staff with systematic monitoring data. With limited knowledge about the research activities conducted by the centers, fishers frequently suggest that CRIOBE, and to lesser extent Gump, are conduits of neo-colonial power and control. Moreover, some researchers in the research stations assume that the fishers are not capable of effective management and that if decision-making authority is weighted too heavily towards fishers, they will overfish and undermine Moorea's coral reef biodiversity. When asked about their views, researchers would cite the industrial-scale fisheries of North America and Europe, several of which, in the past, have collapsed as a result of unsustainable fishing under minimal regulation.

### 4.7. Accessible and clear goals and conflict resolution mechanisms

Clear goals and outcomes are important elements of successful co-management [27,40]. On Moorea this process has been initiated by the *Association Rahui de Moorea* which has organized *rahui* committees in Haapiti, Afareaitu, and Papetoai with between 10 and 50 representatives from each district.

The association has proposed the following broad management principles: a) to guarantee important fishing and environmental knowledge be transmitted to younger generations in order to protect and preserve natural and cultural sites; b) to allow traditional management practices that are based on respect but which are adapted to contemporary circumstances; and c) to strengthen fisher's participation in decision-making [47]. We make special note that the second principle indicates how *rahui* is envisioned not as a relic from the past to be re-imposed, but as a more dynamic hybrid of old and new. *Rahui* in this context, is both a political act asserting Tahitian identity, as well as a framework for community-guided management efforts. However, more details about the specific restrictions and management strategies need to be developed.

While the *Association Rahui de Moorea* has proposed to devolve management to district-level committees, it has also proposed that management decisions be administered through a *Toohitu* council, an island-wide group that would approve and advise on management decisions. This structure, to some extent, mirrors traditional Tahitian political structures, which were hierarchical with high levels of specialization. It also parallels similar systems of natural resource management emerging in other Pacific islands that are being incorporated into contemporary co-management arrangements, including fisheries co-management in Samoa [30], and the *Aha Moku* council system in Hawaii [1].

The community leaders of the Association explicitly voice their opposition to the PGEM because they perceive it as a neo-colonial tool for disempowering local fishers from lagoon management. While their demand for transferring lagoon management from the municipality to local community/*rahui* committees appears to not have been met in the PGEM revision, the formal management plan proposed by the Association forced CLEM to include more fisher representatives in the PGEM. This includes the creation of local fishing committees in each district that will manage their respective lagoon areas outside of the no-take zones.

## 5. Conclusion

Maneuvering Moorea's PGEM towards adaptive co-management involves overcoming multiple challenges and building on the enabling conditions presented in the previous section and which are summarized in Table 2. The fact that some Moorean residents are seeking devolved resource management approaches demonstrates self-organization and leadership and increases the likelihood that devolution of management responsibilities will be seen as an act of empowerment rather than a burden to the communities. Importantly, the devolution of some power and decision-making authority to the districts seems to be at a more appropriate social and ecological scale for co-management of Moorea's lagoon seascapes and the PGEM revision appears to have taken a step in this direction.

However, there is nothing inevitable about the outcomes of fisheries co-management, and support is needed at multiple scales. At this point in time, Moorea lacks the institutional and legal structures necessary for enduring co-management arrangements, and, as illustrated in other locations that have transitioned to fisheries co-management, these institutions, and the necessary relationships and trust between fishers, government officials, and researchers, can take decades to solidify [21].

Despite challenges, the *rahui*-oriented management system envisioned by some local activist groups has the potential to improve marine management in Moorea by blending the long-term scientific monitoring taking place on the island with fishers' knowledge and community resource monitoring. This would not be a reversion to or resuscitation of a traditional, pre-European practice, but rather a contemporary *rahui* that is both cutting-edge and ancient. The overarching challenge is to gather all actors, including those who feel they have been left out of the PGEM, into a continual process of ongoing dialogue and action, where paths of tradition and innovation intertwine to adaptively manage the coral reefs of Moorea. With climate induced changes such as rising ocean temperatures expected to intensify in the coming decades, the urgency for a more collaborative and potentially effective management arrangement cannot be overstated.

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## References

[1] N. Abercrombie, Hawaiian Legislature, Act 288 - Relating to Native Hawaiians HB2806 HD2 SD2 CD1, 2012.
[2] S. Aswani, M. Lauer, Indigenous people's detection of rapid ecological change, Conserv. Biol. 28 (3) (2014) 820–828.
[3] A. Ayers, J. Kittinger, M. Imperial, M. Vaughan, Making the transition to co-can-agement governance arrangements in Hawai'i: a framework for understanding transaction and transformation costs, Int. J. Commons 11 (1) (2017) 388–421.
[4] A.L. Ayers, J.N. Kittinger, Emergence of co-management governance for Hawai'i coral reef fisheries, Glob. Environ. Change 28 (2014) 251–262.
[5] T. Bambridge (Ed.), The Rahui: Legal Pluralism in Polynesian Traditional Management of Resources and Territories, Australia ANU Press, Acton, 2016.
[6] C. Bartlett, K. Pakoa, C. Manua, Marine reserve phenomenon in the Pacific islands, Mar. Policy 33 (4) (2009) 673–678.
[7] F Berkes, Evolution of co-management: Role of knowledge generation, bridging organizations and social learning, J. Environ. Manag. 90 (2009) 1692–1702, https://doi.org/10.1016/j.jenvman.2008.12.001.
8] F. Berkes, Community-based conservation in a globalized world, PNAS 104 (39) (2007) 15188–15193.
[9] F. Berkes, Devolution of environment and resources governance: trends and future, Environ. Conserv. 37 (04) (2010) 489–500.
[10] D. Brockington, R. Duffy, J. Igoe, Nature Unbound: Conservation, Capitalism and the Future of Protected Areas, Earthscan, London, 2008.
[11] J.S. Brooks, K.A. Waylen, M.B. Mulder, How national context, project design, and local community characteristics influence success in community-based conservation projects, Proc. Natl. Acad. Sci. 109 (52) (2012) 21265–21270.
[12] J. Cinner, Coral reef livelihoods, Curr. Opin. Environ. Sustain. 7 (2014) 65–71.
[13] J.E. Cinner, C. Huchery, M.A. MacNeil, N.A.J. Graham, T.R. McClanahan, J. Maina, E. Maire, J.N. Kittinger, C.C. Hicks, C. Mora, E.H. Allison, S. D'Agata, A. Hoey, D.A. Feary, L. Crowder, I.D. Williams, M. Kulbicki, L. Vigliola, L. Wantiez, G. Edgar, R.D. Stuart-Smith, S.A. Sandin, A.L. Green, M.J. Hardt, M. Beger, A. Friedlander, S.J. Campbell, K.E. Holmes, S.K. Wilson, E. Brokovich, A.J. Brooks, J.J. Cruz-Motta, D.J. Booth, P. Chabanet, C. Gough, M. Tupper, S.C.A. Ferse, U.R. Sumaila, D. Mouillot, Bright spots among the world's coral reefs, Nature 535 (7612) (2016) 416–419.
[14] J.E. Cinner, T.R. McClanahan, M.A. MacNeil, N.A.J. Graham, T.M. Daw, A. Mukminin, D.A. Feary, A.L. Rabearisoa, A. Wamukota, N. Jiddawi,

Comanagement of coral reef social-ecological systems, Proc. Natl. Acad. Sci. 109 (14) (2012) 5219–5222.
[15] J.E. Cinner, A. Wamukota, H. Randriamahazo, A. Rabearisoa, Toward institutions for community-based management of inshore marine resources in the Western Indian Ocean, Mar. Policy 33 (3) (2009) 489–496.
[16] A. Davis, K. Ruddle, Massaging the misery: recent approaches to fisheries governance and the betrayal of small-scale fisheries, Hum. Organ. 71 (3) (2012) 244–254.
[17] W. Dressler, B. Büscher, M. Schoon, D.A.N. Brockington, T. Hayes, C.A. Kull, J. McCarthy, K. Shrestha, From hope to crisis and back again? A critical history of the global CBNRM narrative, Environ. Conserv. 37 (1) (2010) 5–15.
[18] L. Evans, N. Cherrett, D. Pemsl, Assessing the impact of fisheries co-management interventions in developing countries: a meta-analysis, J. Environ. Manag. 92 (8) (2011) 1938–1949.
[19] C. Folke, T. Hahn, P. Olsson, J. Norberg, Adaptive governance of social-ecological systems, Annu. Rev. Environ. Resour. 30 (1) (2005) 441–473.
[20] C. Gaspar, T. Bambridge, Territorialités et aires marines protégées à Moorea (Polynésie française), Le. J. Soc. Océanistes 126–127 (1/2) (2008) 231–245.
[21] S. Gelcich, T.P. Hughes, P. Olsson, C. Folke, O. Defeo, M. Fernández, S. Foale, L.H. Gunderson, C. Rodríguez-Sickert, M. Scheffer, Navigating transformations in governance of Chilean marine coastal resources, Proc. Natl. Acad. Sci. 107 (39) (2010) 16794–16799.
[22] R. Gillett, Fisheries in the Economies of the Pacific Island Countries and Territories, The Pacific Communities, Noumea, New Caledonia, 2016.
[23] N.L. Gutiérrez, R. Hilborn, O. Defeo, Leadership, social capital and incentives promote successful fisheries, Nature 470 (7334) (2011) 386–389.
[24] X. Han, T.C. Adam, R.J. Schmitt, A.J. Brooks, S.J. Holbrook, Response of herbivore functional groups to sequential perturbations in Moorea, French Polynesia, Coral Reefs 35 (3) (2016) 999–1009.
[25] S.J. Holbrook, T.C. Adam, P.J. Edmunds, R.J. Schmitt, R.C. Carpenter, A.J. Brooks, H.S. Lenihan, C.J. Briggs, Recruitment drives spatial variation in recovery rates of resilient coral reef, Sci. Rep. 8 (1) (2018) 7338.
[26] T.P. Hughes, M.L. Barnes, D.R. Bellwood, J.E. Cinner, G.S. Cumming, J.B.C. Jackson, J. Kleypas, I.A. van de Leemput, J.M. Lough, T.H. Morrison, S.R. Palumbi, E.H. van Nes, M. Scheffer, Coral reefs in the Anthropocene, Nature 546 (7656) (2017) 82–90.
[27] S. Jentoft, R. Chuenpagdee, J.J. Pascual-Fernandez, What are MPAs for? On goal formation and displacement, Ocean Coast. Manag. 54 (1) (2011) 75–83.
[28] S.D. Jupiter, P.J. Cohen, R. Weeks, A. Tawake, H. Govan, Locally-managed marine areas: multiple objectives and diverse strategies, Pac. Conserv. Biol. 20 (2) (2014) 165–179.
[29] K.A. Karr, R. Fujita, R. Carcamo, L. Epstein, J.R. Foley, J.A. Fraire-Cervantes, M. Gongora, O.T. Gonzalez-Cuellar, P. Granados-Dieseldorff, J. Guirjen, A.H. Weaver, H. Licón-González, E. Litsinger, J. Maaz, R. Mancao, V. Miller, R. Ortiz-Rodriguez, T. Plomozo-Lugo, L.F. Rodriguez-Harker, S. Rodríguez-Van Dyck, A. Stavrinaky, C. Villanueva-Aznar, B. Wade, D. Whittle, J.P. Kritzer, Integrating science-based co-management, partnerships, participatory processes and stewardship incentives to improve the performance of small-scale fisheries, Front. Mar. Sci. 4 (345) (2017).
[30] M. King, U. Faasili, Community-based management of subsistence fisheries in Samoa, Fish. Manag. Ecol. 6 (2) (1999) 133–144.
[31] J. Kooiman, Governing as Governance, Sage, London, 2003.
[32] M. Lauer, S. Aswani, Indigenous knowledge and long-term ecological change: detection, interpretation, and responses to changing ecological conditions in Pacific Island communities, Environ. Manag. 45 (5) (2010) 985–997.
[33] Y. Laurans, N. Pascal, T. Binet, L. Brander, E. Clua, G. David, D. Rojat, A. Seidl, Economic valuation of ecosystem services from coral reefs in the South Pacific: taking stock of recent experience, J. Environ. Manag. 116 (2013) 135–144.
[34] P. Leenhardt, M. Lauer, R. Madi Moussa, S.J. Holbrook, A. Rassweiler, R.J. Schmitt, J. Claudet, Complexities and uncertainties in transitioning small-scale coral reef fisheries, Front. Mar. Sci. 3 (70) (2016) 1–9.
[35] P. Leenhardt, R.M. Moussa, R. Galzin, Reef and lagoon fisheries yields in Moorea: A summary of data collected. SPC Fisheries Newsletter #137 January/April 2012, 2012.
[36] M. Leopold, J. Beckensteiner, J. Kaltavara, J. Raubani, S. Caillon, Community-based management of near-shore fisheries in Vanuatu: what works? Mar. Policy 42 (2013) 167–176.
[37] A. Levine, Staying afloat: state agencies, local communities, and international involvement in marine protected area management in Zanzibar, Tanzania, Conserv. Soc. 5 (4) (2007) 562.
[38] A.S. Levine, L.S. Richmond, Examining enabling conditions for community-based fisheries comanagement: Comparing efforts in Hawai'i and American Samoa, Ecol. Soc. 19 (2014) (1 C7 - C24).
[39] T.L. Lison de Loma, C.W. Osenberg, J.S. Shima, Y. Chancerelle, N. Davies, A.J. Brooks, R. Galzin, A framework for assessing impacts of Marine Protected Areas in Moorea (French Polynesia), Pac. Sci. 62 (3) (2008) 431–441.
[40] G. McDonald, B. Harford, A. Arrivillaga, E.A. Babcock, R. Carcamo, J. Foley, R. Fujita, T. Gedamke, J. Gibson, K. Karr, J. Robinson, J. Wilson, An indicator-based adaptive management framework and its development for data-limited fisheries in Belize, Mar. Policy 76 (2017) 28–37.
[41] J.R. Montambault, S. Wongbusarakum, T. Leberer, E. Joseph, W. Andrew, F. Castro, B. Nevitt, Y. Golbuu, N.W. Oldiais, C.R. Groves, Use of monitoring data to support conservation management and policy decisions in Micronesia, Conserv. Biol. 29 (5) (2015) 1279–1289.
[42] R. Plummer, D.R. Armitage, R.C. De Loë, Adaptive comanagement and its relationship to environmental governance, Ecol. Soc. 18 (1) (2013).
[43] B. Poirine, The economy of French Polynesia: past, present, and future, Pac. Econ. Bull. 25 (1) (2010) 24–34.
[44] R.S. Pomeroy, F. Berkes, Two to tango: the role of government in fisheries co-management, Mar. Policy 21 (5) (1997) 465–480.
[45] R.S. Pomeroy, B.M. Katon, I. Harkes, Conditions affecting the success of fisheries co-management: lessons from Asia, Mar. Policy 25 (3) (2001) 197–208.
[46] J. Rey Moorea - Moorea Rahui Souhaite Imposer Le Principe D'une Gestion Lagonaire Communautaire. *La Depeche de Tahiti*. Sept 12th.
[47] J. Rey, PGEM de Moorea: Les Pêcheurs Ont Fait Entendre Leur Voix. *La Depeche de Tahiti* Feb. 27th, 2017.
[48] P. Robbins, K. McSweeney, T. Waite, J. Rice, Even conservation rules are made to be broken: implications for biodiversity, Environ. Manag. 37 (2) (2006) 162–169.
[49] K. Ruddle, Social principles underlying traditional inshore fishery management systems in the Pacific Basin, Mar. Resour. Econ. 5 (4) (1988) 351–363.
[50] SDT, Les séries statistiques du tourisme en Polynésie française Ministère du Tourisme, Papeete, French Polynesia: Service du Tourisme (SDT), 2013.
[51] The Nature Conservancy, 2017. Capturing and Sharing Knowledge for Community-Based Marine Conservation: The Pacific Way. The Nature Conservancy.
[52] L. Thiault, Ecological evaluation of a Marine Protected Area (MPA) network: A pplication to the marine spatial planning of Moorea island, French Polynesia (master thesis in French). Papeete: Centre de Recherches Insulaires et Observatoire de l'Environnement, French National Centre for Scientific Research, 2014.
[53] M.B. Vaughan, N.M. Ardoin, The implications of differing tourist/resident perceptions for community-based resource management: a Hawaiian coastal resource area study, J. Sustain. Tour. 22 (1) (2014) 50–68.
[54] M.B. Vaughan, B. Thompson, A.L. Ayers, Pāwehe Ke Kai a'o Hā'ena: creating state law based on customary indigenous norms of coastal management, Soc. Nat. Resour. 30 (1) (2017) 31–46.
[55] B.L.E. Walker Mapping Moorea's lagoons: Conflicts over marine protected areas in French Polynesia. Proceedings of the Inaugural Pacific Regional Meeting of the International Association for the Study of Common Property, Brisbane, Australia, pp. 2–24.
[56] B.L.E. Walker, M.A. Robinson, Economic development, marine protected areas and gendered access to fishing resources in a Polynesian lagoon, Gend. Place Cult. 16 (4) (2009) 467–484.
[57] E.O. Wilson, Half-Earth: Our Planet's Fight for Life, WW Norton & Company, New York, 2016.
[58] S.K. Wilson, M. Adjeroud, D.R. Bellwood, M.L. Berumen, D. Booth, Y.-M. Bozec, P. Chabanet, A. Cheal, J. Cinner, M. Depczynski, D.A. Feary, M. Gagliano, N.A.J. Graham, A.R. Halford, B.S. Halpern, A.R. Harborne, A.S. Hoey, S.J. Holbrook, G.P. Jones, M. Kulbiki, Y. Letourneur, T.L. De Loma, T. McClanahan, M.I. McCormick, M.G. Meekan, P.J. Mumby, P.L. Munday, M.C. Öhman, M.S. Pratchett, B. Riegl, M. Sano, R.J. Schmitt, C. Syms, Crucial knowledge gaps in current understanding of climate change impacts on coral reef fishes, J. Exp. Biol. 213 (6) (2010) 894–900.
[59] M. Yonger, Approche de la pêcherie récifo-lagonaire de Moorea (Polynésie française): evaluation de la production halieutique et de la population de pêcheurs. Mémoire de D.A.A. ENSA, Rennes, 2002.