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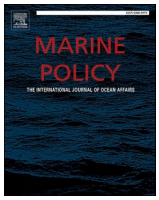

Full length article

Fisheries science and marine education catalyze the renaissance of traditional management *(rahui)* to improve an artisanal fishery in French Polynesia

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ABSTRACT

Coral reef fisheries provide important ecosystem services to coastal communities, yet in the Pacific Islands, many of these contemporary fisheries are threatened by overexploitation. Historically, Pacific Island societies successfully utilized community-based management and spatial temporal closures to regulate the harvest of marine resources. In recognition of their past success these actions are currently being reemployed throughout the region. However, in many communities, innovative approaches may be needed to revitalize such practices and adapt traditional management to contemporary societal needs and expectations. This study presents the case of Anaa Atoll, a remote Pacific Island in the Tuamotu Archipelago of French Polynesia, and the community's efforts to conserve a culturally important but overexploited bonefish (*Albula glossodonta*) fishery. Ultimately, fisheries research, education, and the creation of Aire Marine Educative (a marine area that is managed by a local primary school) were successful in building social cohesion and supporting the renaissance of *rahui* (a traditional form of restricting access to resources and or territories) to manage this fishery. On March 1st, 2019, the community of Anaa reinitiated this tradition for the first time in centuries. Based on these experiences, and an ensuing increase in the Spawning Potential Ratio of the bonefish stock, it is proposed that nationally recognized local management systems that incorporate fisheries research, youth education, and the cultural practices of communities should be supported in the marine policies of the Pacific Islands and beyond.

1. Introduction

Throughout history, artisanal coral reef fisheries have supported coastal communities across the developing world and remain indispensable for food security and small-scale economic enterprise for over 6 million people [1–3]. However, the overexploitation of contemporary coral reef fisheries is widespread, and declining yields place these ecosystem services in jeopardy [4–7]. Population growth, advances in technology, and ineffective resource management regimes contribute to declines in fisheries resources [8–11]. Yet, these universal challenges are compounded in coral reef fisheries as fishers target multiple species with diverse life histories and utilize numerous gear types, at decentralized landing sites [12,13]. Consequently, most societies in which coral reef fisheries operate lack data on the species assemblages that comprise

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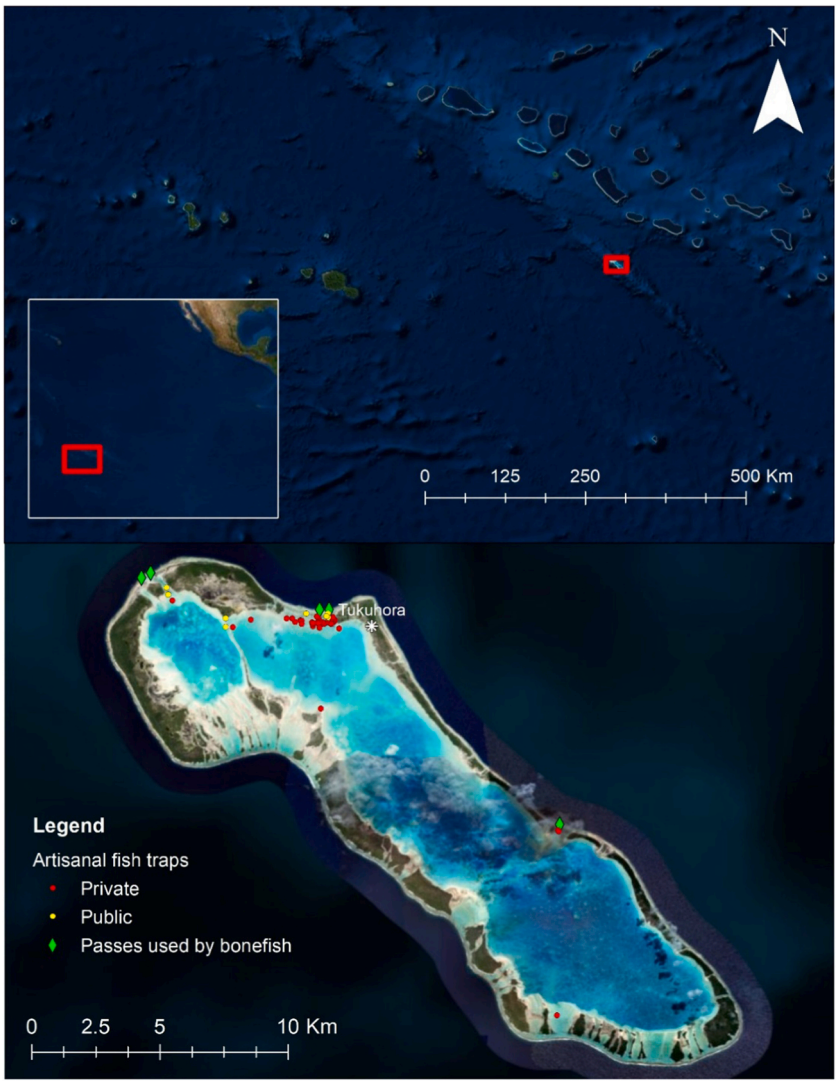

Fig. 1. The location of Anaa Atoll in the Tuamotu Archipelago of French Polynesia and Tukuhora Village (green triangles indicate the migratory passes utilized by bonefish, red dots indicate the location of private traps, yellow dots indicate the location of public traps).

their resource, and thus have limited capacity to quantitatively evaluate the conservation status of their fisheries [2,10,14–17].

In the Pacific Islands, many communities depend on the yields from coral reefs for food security, and with these yields diminishing, it is estimated that 70% of Pacific Island territories and countries will be unable to meet their demand with locally produced marine products by the year 2030 [18,19]. Furthermore, localized threats from over-exploitation are expected to be exacerbated by climate change [20–22]. Considering the growing humanitarian and environmental challenges faced by coastal indigenous communities in the Pacific Islands and beyond, the United Nations has set a goal to increase economic benefits to small island developing states by promoting the sustainable use of marine resources through the management of fisheries, aquaculture, and tourism by 2030 [23]. These are ambitious goals, but ultimately it is clear that livelihoods in these communities depend on identifying innovative approaches to maintaining healthy fisheries [18,19,24].

Given the importance of marine resources to this region, the limited capacity for top-down fisheries management, and declining fisheries yields, many Pacific Island communities have returned to their cultural roots by implementing traditional management practices [25–29]. Traditional community-based management initiatives are locally driven efforts that rely on inhabitants to collectively agree upon equitable resource use and develop harvest restrictions that are specific to their fisheries conservation objectives [30]. Historically, these methods included customary marine tenure, closed areas or seasons, and other catch and effort limitations [25,26,29–32]. Working within communities to support these bottom-up conservation efforts has proven to be a socially acceptable and biologically effective approach to management of artisanal coral reef fisheries [33–37]. However, traditional management has not been universally implemented, and although many communities have historic roots in self-governance and marine conservation, decades have passed for many cultures since these mechanisms were applied to the social-ecological system [27]. Consequently, integrated approaches are needed to adapt traditional management to contemporary society [38,39]. To this end, providing communities with scientific data on the status of their fisheries, education, and new co-management platforms may present a successful model for the revitalization of these practices and progress toward sustainable fisheries [35,40–43].

This paper presents the case study of Anaa Atoll, a remote Pacific Island in the Tuamotu Archipelago of French Polynesia. The community of Anaa is a traditional Polynesian society that has encountered a shifting sociopolitical landscape and epitomizes the socioeconomic and environmental challenges faced by many societies in the Pacific Islands, which this paper contends can be addressed with the recognition of community-based action and revival of traditional management

initiatives. The focus of this paper reviews the efforts made by the community to conserve a culturally important fishery for bonefish (*Albula glossondonta*) that was overexploited and in need of management. Ultimately, research, education, and a hybrid system of nationally recognized local management, was successful in building social cohesion to support the renaissance of *rahui* (a traditional form of restricting access to resources and or territories) to manage this fisheries resource [44].

2. Anaa Atoll

Anaa is the westernmost atoll in the Tuamotu Archipelago of French Polynesia, with one village, Tukuhora, that is inhabited by approximately 500 residents (Fig. 1). The local economy is largely based on copra (dried coconut; the principle export of the archipelago), which is government-subsidized to retain the industry's viability in the rural outer islands and avoid the social problems associated with emigration and urban overcrowding in Tahiti [45,46]. Nevertheless, as the finite amount of cultivatable land is divided amongst generations, the income derived from copra is marginalized, and there is an increasing reliance on the harvest of coral reef fisheries to fill the growing void in economic opportunity. Bonefish, locally known as *kiokio*, is a species that provides food to local inhabitants, income through commercial sale, and new economic opportunities in the form of recreational fly-fishing tourism. However, at the time of this study, local ecological knowledge suggested that this fishery had declined significantly from its historical abundance, and there was concern it was overexploited and in need of management.

2.1. History of resource management and rahui on Anaa

Prior to western contact, the marine resources of Anaa Atoll provided food security to as many as 5000 inhabitants with little to no imports [47,48]. Marine resources were harvested communally and shared to meet daily nutrient requirements. When a resource was acknowledged to be in decline, management was achieved through a combination of both ritual and social controls known as *rahui*, in which the harvest of overexploited resources could be temporally prohibited [44,47]. Furthermore, to prevent overexploitation, the time of year when a species could be fished adhered to a seasonal and lunar calendar [47]. Ceremonies known as *tiorega* were held at the opening of a season for a particular species, during which a portion of the first fish harvested was offered to the gods on a sacred stone alter known as, *marae tiorehaga katiga,* after which the remains were offered to high-ranking community members and the restriction on harvest would be subsequently lifted [47]. However, like many societies in the Pacific Islands during the 19th and 20th centuries, these traditional management systems were lost with westernization and the introduction of a currency-based economy [27]. The ensuing changes in the social structure of the community coupled with the advent of new technologies such as commercially made fishing equipment, refrigeration, and rapid intra- and inter-island transport increased the capacity of the community to harvest marine resources.

2.2. The past and present fishery for bonefish (Albula glossodonta) at Anaa Atoll

Bonefish are harvested on Anaa Atoll as they transit between the lagoon and the outer reef during their spawning migrations to the open ocean with traps made of coral rock, known as *kaua* that are permanently constructed inside of the *hoa* (i.e., passageways between islets) in the northeast of the atoll [47,49,50]. Little information exists regarding proprietorship of the atoll's artisanal fish traps prior to western contact. There is evidence that a limited number of small traps were held by families [47] and anecdotal information from local residents suggests that the larger traps associated with the villages of Tukuhora and Temarie in the northeast of the atoll are the oldest and were historically communally owned. However, after a series of cyclones devastated the atoll in the 1980 s, there was a proliferation in the construction of private fish traps, which now saturate these migratory corridors and overcapitalized the fishery. This, coupled with the introduction of chicken wire to private traps, increased their efficiency in capturing and holding large numbers of fish during periods of high water and left few openings through which bonefish schools could migrate to spawn [50]. In the year 2015, aerial surveys identified 13 public and approximately

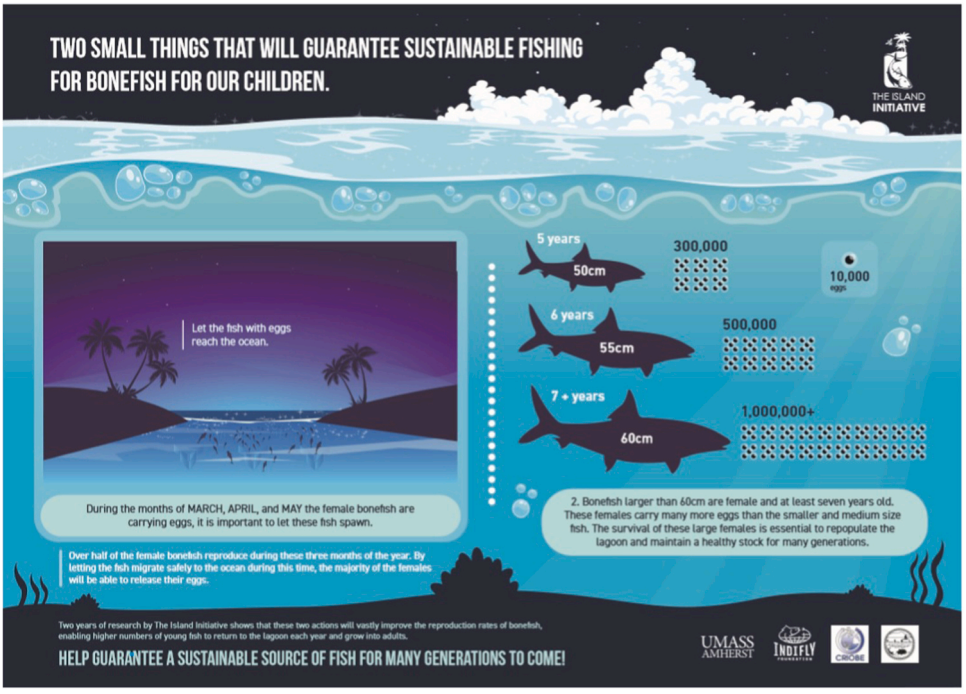

Fig. 2. Info-graphic summarizing the key findings of the collaborative research and implications for bonefish conservation (a closed season during the months of March, April, and May, and the protection of mega-spawners (French and Paumotu versions were distributed throughout the community).

Fig. 3. Students at the Tavahiroa Elementary School learning about the biology of bonefish, presenting bonefish conservation recommendations at the community meeting, and evaluating bonefish abundance with drone photography in the marine educational program.

36 private fish traps that were constructed at a certain point in time. Although there are no records of how many fish traps historically operated concurrently, at the time of the survey, 47% of the private fish traps were in a state of disrepair. Conversations with the residents of Anaa Atoll, suggested that these inactive traps had remained unused for years, however, the corals they are constructed from continue to grow and have closed off significant sections of this passageway. Although these dormant traps do not actively fish, they restrict bonefish movement and increase the efficacy of the active traps by creating a barrier in their migratory corridor [50]. In the year 2013, the Direction Des Resources Marines (DRM) introduced a permitting system whereby individuals were required to apply for a concession to operate private traps and over the course of our initial stock assessment (i.e., 2016–2018), eight to 12 private traps operated along with the atoll's public traps.

2.3. Fisheries research to assess the status of the bonefish fishery

Fisheries research highlighted the overexploited status of this species and a need for the revitalization of community-based management. A survey of artisanal fishers indicated that bonefish accounted for 25% of the catch and were the dominant species in the atoll's multispecies coral reef fishery [50]. Conventional and acoustic tagging revealed that throughout the Austral fall and winter (i.e., March to September), the atoll's bonefish stock spatially and temporally synchronize their spawning movements and traverse the migratory corridors in the northeast of the atoll where they are exploited by the trap fishery [51–53]. This work demonstrated that these migrations occur during the waning gibbous moon and the sex ratio of the catch was female-dominated during the first three months of the spawning season (i.e., March, April, and May), but yielded to a male dominated sex ratio from June to September [52,54]. Furthermore, the passageway adjacent to Tukuhora Village was the most important spawning corridor, with 92% of recaptures occurring in this region [52]. A length-based stock assessment revealed that the Spawning Potential Ratio (SPR) was between 7% and 11%, and mega-spawners constituted 2–5% of the stock over the three-year study period [54]. To put these results into context, an SPR between 20% and 40% is the minimum reproductive output required to maintain fish stocks, while an SPR of less than 20% is symptomatic of overexploitation [54,55].

This body of research corroborated the traditional ecological knowledge of the atoll's elders (which cited significant declines from their historic abundance) and provided strong evidence that the bonefish stock was exploited to a level that threatened the foundation of the community's food security, commercial fisheries, and the opportunity for development of alternative livelihoods in fly-fishing ecotourism [50–52,54]. To communicate these findings with the broader community, infographics were produced in both French and Paumotu (the language of the Tuamotu Archipelago) that summarized the key aspects of bonefish biology and recommendations for sustainable harvest, which included a temporary closed season during the months of March, April, and May, and the preservation of mega-spawners to protect a proportion of female spawning stock (Fig. 2).

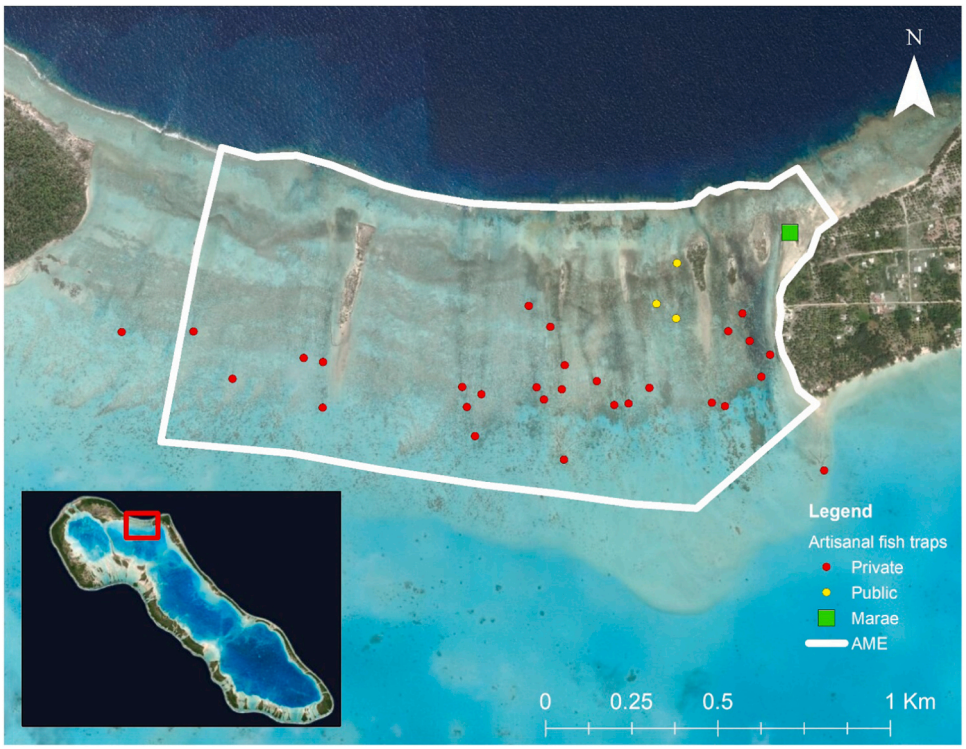

Fig. 4. The location of the Aire Marine Educative (AME) "*Te Kura Moana No Tagihia*" where the *rahui* was implemented (red dots indicate the location of private traps, yellow dots indicate the location of public traps, green square indicates the location of the *marae* (stone altar) and white polygon indicates the AME superimposed on the bonefish migratory corridor).

2.4. Youth education, the Aire Marine Educative (AME) initiative and rahui for fisheries management

The results of this research program suggested an ongoing decline of the bonefish population, yet the paradigm of shifting baselines in resource abundance was pervasive among the younger generations [56]. Consequently, a partnership was formed with the Tavahiroa Elementary School to help educate the atoll's youth (age 9–11) on the importance of sustainable fisheries and the marine environment to their long-term food security. During this time, classes were taught that focused on bonefish biology and the principles of sustainable fisheries management through a series of laboratory sessions and field trips (Fig. 3). These initial courses were successful in educating and inspiring the island's youth; however, there was no official structure by which local management could be implemented until the French Biodiversity Agency (Agence française pour la biodiversité) presented the opportunity to establish an Aire Marine Educative (AME). An AME is a nationally recognized small coastal area that is managed by a local primary school with the intent to help young people understand and protect the marine environment, through collaboration with the local municipality and resource user associations (http://www.aires-marines.com/content/view/full/16746). Given the state of the atoll's bonefish resource and the significance to the community, the migratory corridor adjacent to Tukuhora Village, where the bonefish population is heavily exploited was selected for the location of the AME (named "*Te Kura Moana No Tagihia*" and instituted on June 6th, 2018; Fig. 4). The AME spatial zoning provided national recognition to the local education and management efforts that were underway on Anaa Atoll and a platform for the school to work within their community to establish conservation policies within the borders of the AME.

A principal tenant in the AME program is to engage students in the marine management process and to teach leadership by transmitting knowledge of the marine environment within their community. To this end, after the approval of the AME, the students at the Tavahiroa Elementary School took the initiative to share the status of the bonefish resource and seek management solutions within their community. This process involved several stages, including meetings with the fishers of the atoll who held the concessions to private traps within the AME, and a community-wide event where the children presented to their parents, followed by questions and answers with the project scientists (Fig. 3). These meetings were collaborative and encouraged each community member to comment and contribute ideas. It was clear that new solutions were not needed; community members suggested a return to the traditional practice of *rahui* (a temporary restriction on the harvest of resources), which had been historically instituted to address overexploitation and promote recovery of fish stocks. Following a unanimous vote by the community members present at the meeting in favor of temporarily deactivating the traps in the AME during the months of March, April, and May, the school moved forward with a door-to-door petition that would ultimately be approved by 87% of the population (Fig. 5). Upon the ratification of the petition, a *rahui* during these months of the year was approved for a five year period by the atoll's municipal council, and the AME was inaugurated by local and national government on August 9th, 2018 (https://www.radio1.pf/anaa-a-son-aire-marine-educative/).

On March 1st, 2019, the community of Anaa reinitiated the tradition of *rahui* for the first time in centuries. All public and private traps located in the AME (i.e., the bonefish migratory corridor adjacent to Tukuhora Village) were deactivated by lowering the rocks or removing the chicken wire enclosures at the cod end of the traps. Following deactivation of the trap fishery, a *marae* (stone alter as described above) was constructed on a *motu* (small Islet) inside of the migratory corridor. The *marae* consisted of a raised rectangular platform oriented in the direction of the sun's rotation with six stones placed in a semi-circle representing the six historic villages of Anaa Atoll (Fig. 6). During the inauguration of the *rahui*, a ceremony was held in which a sacrificial male and female bonefish were oriented head to tail in the direction of the lagoon and ocean, symbolizing the reproductive migration between the two habitats

Fig. 5. The Aire Marine Educative (AME) a community supported marine educational area, the public fish traps that are managed during the *rahui*, and a group of pre-spawning bonefish inside the AME's borders.

that is protected by the *rahui* (Fig. 6). The fish were placed inside the tomb of the *marae*, which was covered, and a large white sacred stone was positioned vertically in the center of the *marae* to signify that the harvest of bonefish in this corridor was *tapu* (restricted) for the next three months. This center stone was removed on June 1st, 2019 to signify the end of the *rahui* period and the traps were reconstructed to reopen the fishery until March 1st of the following year. This renaissance of traditional spatiotemporal management was continued in 2020, and conversations with residents of Anaa Atoll indicate that the *rahui* was both respected and supported by the population during this time.

2.5. Preliminary data on the efficacy of the rahui at Anaa Atoll

A post-*rahui* monitoring program was developed to evaluate the SPR of the bonefish stock and determine if there was a biologic response to the reduced fishing effort achieved by the *rahui*. During the season open to fishing in the AME (i.e., June-February of 2019 and 2020), a local resident recorded the fork length (cm) and sex of bonefish that were harvested in the artisanal trap fishery. This preliminary post-*rahui* data was combined with the data collected from 2016 to 2018 (i.e., years prior to the *rahui*) to evaluate the annual length frequency distributions of female bonefish from 2016 to 2020 (Table 1). These data were used to model the SPR of the stock with the age-structured methods outlined in Filous et al. [54] and the life history parameters $L_{50} = 48$, $L_{95} = 51$, $L_{\infty} = 78$ cm FL and the M/K ratio = 1.0 [51,54]. These results suggest that the SPR of the stock increased from the pre-*rahui* low of 7% in 2017 to a post-*rahui* high of 17% in 2020 (Table 1). While there was likely a decrease in total trapping effort in the decades prior to our study, as noted above, dormant fish traps are a permanent feature of this passageway, that restrict the movements of bonefish during their spawning migrations and increase the efficacy of the remaining active traps. Although preliminary, the increase in SPR to 17% in the wake of the *rahui*, suggests that fishing mortality has been reduced, a segment of the stock can now reach its spawning grounds during the closed season, and the stock is being exploited at a more sustainable level.

3. Synthesis

Pacific Island societies have a rich history of managing limited marine resources that is rooted in the maintenance of the collective well-being [26,30,41,57]. These traditions and their revival in the 21st Century has made the Pacific Island region a world leader in the development of Locally Managed Marine Areas for the management of coral reef fisheries [29,32,58]. The actions taken by the community of Anaa Atoll provide yet another example of this renaissance of traditional management and its utility in contemporary society. This case study suggests that fisheries science, marine education, and the integration of local management measures with the cultural heritage of a people are essential to the success of this local marine conservation effort and holds promise for other remote Pacific Island communities.

Traditional ecological knowledge is an important source of information in indigenous communities that must be considered in research and management [38,59–63]. However, the marine environment is changing rapidly, baselines are shifting, and empowering local

Fig. 6. The *rahui* ceremony and *marae (*stone alter) that was constructed in the bonefish migratory corridor adjacent to Tukuhora Village to signify the closure of the fishery for the months of March, April, and May.

Table 1
The Spawning Potential Ratio (SPR) and ratio of fishing mortality to natural mortality (FM) for female bonefish harvested at Anaa Atoll, from 2016 to 2020 (note, 2019 was the first year of the *rahui*).

Year	Number of males	Number of females	FM	SPR
2016	126	144	4.28	11
2017	893	631	9.46	7
2018	735	891	6.16	8
2019	261	52	3.40	14
2020	466	477	4.59	17

communities to revive traditional forms of management should include quantitative scientific data on the status of fish stocks and identify what can be done to specifically address underlining resource management issues [59,60,64–66]. In the case of Anaa Atoll, fisheries research played an important role in complementing the traditional ecological knowledge of this community by describing the specifics of spawning patterns and movements and highlighting the vulnerability of the bonefish population in the migratory passage adjacent to Tukuhora Village where the AME is now established. Furthermore, by utilizing data limited length-based fisheries methods such as SPR, the community of Anaa was provided with an assessment of their fishery in reference to its potential productivity as an unfinished stock. This body of work highlighted the overexploited status of this resource and demonstrated that a significant portion of the population's female spawning stock is lost during the initial three months of the reproductive season. This information built the community's capacity to support traditional management by highlighting the severity of their observed decline in bonefish abundance and providing an understanding of how a *rahui* in the AME (i.e., seasonal closure during this time period) would be an enforceable management solution that protects the essential components of the populations spawning stock, while at the same time allowing fishers to continue to harvest this resource for the remainder of the year [67–69]. Ultimately, the preliminary data on the population's SPR during the post-*rahui* years suggest that the reproductive potential of the bonefish stock is improving in response to the *rahui* and the stock may be on its way to recovery due to reduced fishing mortality during the closed season.

In this case study, marine education played a vital role in supporting the management of this fishery, as it improved the social capital of the conservation movement [70], combated shifting baselines among the atoll's youth, and promoted a greater understanding of the need for change in the status quo through intergenerational learning [71,72]. Shifting baselines in resource abundance pose a major challenge to marine conservation [56,73–75]. Yet, marine education can halt the shifting baseline by making new generations aware of the historic changes that have occurred in the environment [76,77]. The youth education program on Anaa Atoll, supplemented their traditional knowledge by focusing on teaching bonefish biology, the significance of their movements in the AME and why the abundance of this species had declined. Furthermore, by having the youth present science-based management recommendations to their parents at community meetings, along with their request and reasoning behind the resurgence of *rahui*, they were able to transmit their knowledge and promote a greater

understanding of this conservation issue, which was able to permeate in this society thorough intergenerational learning [71,72,76]. With the successful initiation of *rahui* on Anaa Atoll, the involved youth were empowered to make change for their own marine resources, and in recognition for their efforts, the school children at the Tavahiroa Elementary School were granted the 2020 Local Hero Award by the Blue Marine Foundation (https://www.bluemarinefoundation.com/2020/05/04/ocean-awards-2020-winners/).

Community involvement in resource management and social cohesion is a critical factor to successfully bring societies together to manage limited resources [39,78]. However, many communities lack the institutional capacity to undertake collective management actions [79–81]. The AME program is an innovative approach to education and management that gave the local school system the opportunity to influence the management of common property and provided an institutional framework from which local resource management could be addressed. In this instance, the AME program served as a platform to build social cohesion in that it removed the individualism commonly encountered between resources users in the management of common properties [82], and focused resource use on educational opportunities and food security for future generations. Furthermore, the integration of management with the cultural heritage of the community through the establishment of *rahui*, construction of a *marae*, and revival of a traditional ceremony were important actions in facilitating the acceptance of a fisheries closure. The restoration of this traditional ceremony removed the stigma associated with temporarily restricting access to the bonefish resource and instituted a sense of pride in bringing back past traditions.

The case study of Anaa Atoll presents the challenges faced by many isolated communities of the Pacific Islands and demonstrates how a solution was achieved through a hybrid system of modern and traditional management. This model can be adapted to empower local communities to create a path toward resource management by: (1) providing data on the status of important fisheries resources, (2) promoting education of younger generations to support resource management, (3) developing co-management actions that are in line with the cultural identity of a community, and (4) providing communities with opportunities develop to nationally recognized local management initiatives. Given the success of these efforts on Anaa Atoll, the marine policies of national governments and non-governmental conservation organizations should support research and marine education as a catalyst for bottom up fisheries management.

CRediT authorship contribution statement

Alexander Filous: Project administration, Formal analysis, Writing - original draft, Methodology, Conceptualization. **Robert J. Lennox:** Formal analysis, Writing - original draft, Methodology, Conceptualization. **Jean Pierre Beaury:** Methodology, Conceptualization, Supervision. **Hinano Bagnis:** Methodology, Conceptualization, Supervision, Funding acquisition. **Mathew Mchugh:** Conceptualization, Funding acquisition. **Alan M. Friedlander:** Conceptualization, Writing - review & editing. **Eric E. G. Clua:** Conceptualization, Writing - review & editing. **Steven J. Cooke:** Conceptualization, resources, Writing - review & editing. **Todd K. Fuller**: Conceptualization, Writing - review & editing. **Andy J. Danylchuk**: Methodology, Conceptualization, Funding acquisition, Resources, Supervision, Writing - review & editing.

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References

[1] A.E. Johnson, J.E. Cinner, M.J. Hardt, J. Jacquet, T.R. Mcclanahan, J. N. Sanchirico, Trends, current understanding and future research priorities for artisanal coral reef fisheries research, Fish Fish. 14 (2013) 281–292, https://doi.org/10.1111/j.1467-2979.2012.00468.x.

[2] A.L. Neil, C. Bene, S.J. Hall, E.H. Allison, S. Heck, B.D. Ratner, Diagnosis and management of small-scale fisheries in developing countries, Fish Fish. 8 (2007) 227–240, https://doi.org/10.1111/j.1467-2679.2007.00252.x.

[3] L.S.L. Teh, L.C.L. Teh, U.R. Sumaila, A global estimate of the number of coral reef fishers, PLoS One (2013), https://doi.org/10.1371/journal.pone.0065397.

[4] E.S. Darling, S. D'agata, Coral reefs: fishing for sustainability, Curr. Biol. 27 (2017) R65–R68, https://doi.org/10.1016/j.cub.2016.12.005.

[5] J.R. McGoodwin, Crisis in the world's fisheries: people, problems, and policies, Stanford University Press, 1995.

[6] K. Newton, I.M. Côté, G.M. Pilling, S. Jennings, N.K. Dulvy, Current and future sustainability of island coral reef fisheries, Curr. Biol. 17 (2007) 655–658, https://doi.org/10.1016/j.cub.2007.02.054.

[7] G. Paredes, R.R. Warner, J.B.C. Jackson, J.M. Pandolfi, R.H. Bradbury, E. Sala, T. P. Hughes, K.A. Bjorndal, R.G. Cooke, D. McArdle, L. McClenachan, M.J. H. Newman, Global trajectories of the long-term decline of coral reef ecosystems, Science 301 (2003) 955–958, https://doi.org/10.1126/science.1085706.

[8] E.M. Finkbeiner, N.J. Bennett, T.H. Frawley, J.G. Mason, D.K. Briscoe, C.M. Brooks, C.A. Ng, R. Ourens, K. Seto, S. Switzer Swanson, J. Urteaga, L.B. Crowder, Reconstructing overfishing: moving beyond Malthus for effective and equitable solutions, Fish Fish. 18 (2017) 1180–1191, https://doi.org/10.1111/faf.12245.

[9] D. Pauly, From growth to Malthusian overfishing: stages of fisheries resources misuse, Tradit. Mar. Resour. Manag Knowl. Inf. Bull. SPC 3 (1994) 7–14.

[10] D. Pauly, Small-scale fisheries in the tropics: marginality, marginalization, and some implications for fisheries management, Glob. Trends Fish. Manag. 20 (1997) 40–49.

[11] R.S. Pomeroy, Managing overcapacity in small-scale fisheries in Southeast Asia, Mar. Policy 36 (2012) 520–527, https://doi.org/10.1016/j.marpol.2011.10.002.

[12] S. Jennings, N.V.C. Polunin, Impacts-of-fishing-on-tropical-reef-ecosystems, Ambio 25 (1996) 44–49.

[13] T.R. McClanahan, S.C. Mangi, Gear-based management of a tropical artisanal fishery based on species selectivity and capture size, Fish. Manag Ecol. (2015), https://doi.org/10.1111/j.1365-2400.2004.00358.x.

[14] D. Fenner, Challenges for managing fisheries on diverse coral reefs, Diversity 4 (2012) 105–160, https://doi.org/10.3390/d4010105.

[15] T.P. Hughes, N.A.J. Graham, J.B.C. Jackson, P.J. Mumby, R.S. Steneck, Rising to the challenge of sustaining coral reef resilience, Trends Ecol. Evol. 25 (2010) 633–642, https://doi.org/10.1016/j.tree.2010.07.011.

[16] I.B.M. Kosamu, Conditions for sustainability of small-scale fisheries in developing countries, Fish. Res. 161 (2015) 365–373, https://doi.org/10.1016/j.fishres.2014.09.002.

[17] M.A. MacNeil, N.A.J. Graham, J.E. Cinner, S.K. Wilson, I.D. Williams, J. Maina, S. Newman, A.M. Friedlander, S. Jupiter, N.V.C. Polunin, T.R. McClanahan, Recovery potential of the world's coral reef fishes, Nature 520 (2015) 341–344, https://doi.org/10.1038/nature14358.

[18] J.D. Bell, M. Kronen, A. Vunisea, W. Nash, G. Keeble, A. Demmke, S. Pontifex, S. Andrefouet, Planning the use of fish for food security in the Pacific, Mar. Policy 33 (2009) 64–76, https://doi.org/10.1016/j.marpol.2008.04.002.

[19] J.D. Bell, V. Allain, E.H. Allison, S. Andréfouët, N.L. Andrew, M.J. Batty, M. Blanc, J.M. Dambacher, J. Hampton, Q. Hanich, S. Harley, A. Lorrain, M. McCoy,

N. McTurk, S. Nicol, G. Pilling, D. Point, M.K. Sharp, P. Vivili, P. Williams, Diversifying the use of tuna to improve food security and public health in Pacific Island countries and territories, Mar. Policy 51 (2015) 584–591, https://doi.org/10.1016/j.marpol.2014.10.005.
[20] E.H. Allison, A.L. Perry, M.C. Badjeck, W. Neil Adger, K. Brown, D. Conway, A. S. Halls, G.M. Pilling, J.D. Reynolds, N.L. Andrew, N.K. Dulvy, Vulnerability of national economies to the impacts of climate change on fisheries, Fish Fish. 10 (2009) 173–196, https://doi.org/10.1111/j.1467-2979.2008.00310.x.
[21] Q. Hanich, C.C. Wabnitz, Y. Ota, M. Amos, C. Donato-Hunt, A. Hunt, Small-scale fisheries under climate change in the Pacific Islands region, Mar. Policy 88 (2018) 279–284, https://doi.org/10.1016/j.marpol.2017.11.011.
[22] R. Valmonte-Santos, M.W. Rosegrant, M.M. Dey, Fisheries sector under climate change in the coral triangle countries of Pacific Islands: Current status and policy issues, Mar. Policy 67 (2016) 148–155, https://doi.org/10.1016/j.marpol.2015.12.022.
[23] UN General Assembly (2015) Transforminng our world: the 2030 Agenda for Sustainable Development, A/RES/70/1.
[24] A.M. Cisneros-Montemayor, D. Pauly, L.V. Weatherdon, Y. Ota, A global estimate of seafood consumption by coastal indigenous peoples, PLoS One 11 (2016) 1–16, https://doi.org/10.1371/journal.pone.0166681.
[25] S. Aswani, S. Albert, A. Sabetian, T. Furusawa, Customary management as precautionary and adaptive principles for protecting coral reefs in Oceania, Coral Reefs 26 (2007) 1009–1021, https://doi.org/10.1007/s00338-007-0277-z.
[26] A.M. Friedlander, Marine conservation in Oceania: past, present, and future, Mar. Pollut. Bull. 135 (2018) 139–149, https://doi.org/10.1016/j.marpolbul.2018.05.064.
[27] R.E. Johannes, Traditional marine conservation methods in oceania and their demise, Ann. Rev. Ecol. Syst. 9 (1978) 349–364.
[28] R.E. Johannes, The case for data less marine resource management: examples from tropical nearshore finfisheries, Trends Ecol. Evol. 13 (1998) 243–246, https://doi.org/10.1016/S0169-5347(98)01384-6.
[29] R.E. Johannes, The renaissance of community-based marine resource management in Oceania, Annu Rev. Ecol. Syst. 33 (2002) 317–340, https://doi.org/10.1146/annurev.ecolsys.33.010802.150524.
[30] R.E. Johannes, Traditional conservation methods and protected marine areas in Oceania, Ambio 11 (1982) 258–261.
[31] T. Adams, The interface between traditional and modern methods of fishery management in the Pacific Islands, Ocean Coast. Manag. 40 (1998) 127–142, https://doi.org/10.1016/S0964-5691(98)00041-6.
[32] S.D. Jupiter, P.J. Cohen, R.T. Weeks, G.H. Alifereti, Locally-managed marine areas: multiple objectives and diverse strategies, Pac. Conserv. Biol. 20 (2014) 165–179.
[33] J. Cinner, J.M. Michael, R.T. Mcclanahan, R.G. Almany, Periodic closures as adaptive coral reef management in the Indo-Pacific, Ecol. Soc. (2006), https://doi.org/10.5751/ES-01618-110131.
[34] R.J. Hamilton, T. Potuku, J.R. Montambault, Community-based conservation results in the recovery of reef fish spawning aggregations in the Coral Triangle, Biol. Conserv. 144 (2011) 1850–1858, https://doi.org/10.1016/j.biocon.2011.03.024.
[35] R.E. Johannes, Working with fisherman to improve tropical coastal fisheries and resource management, Bull. Mar. Sci. 31 (1981) 673–680, https://doi.org/10.1093/phe/phr030.
[36] M. Léopold, 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, https://doi.org/10.1016/j.marpol.2013.02.013.
[37] D. Romero Manrique de Lara, S. Corral, Local community-based approach for sustainable management of artisanal fisheries on small islands, Ocean Coast. Manag. 142 (2017) 150–162, https://doi.org/10.1016/j.ocecoaman.2017.03.031.
[38] J.E. Cinner, S. Aswani, Integrating customary management into marine conservation, Biol. Conserv. 140 (2007) 201–216, https://doi.org/10.1016/j.biocon.2007.08.008.
[39] S. Jentoft, The community: a missing link of fisheries management, Mar. Policy 24 (2000) 53–59, https://doi.org/10.1016/S0308-597X(99)00009-3.
[40] E.H. Allison, F. Ellis, The livelihoods approach and management of small-scale fisheries, Mar. Policy 25 (2001) 377–388, https://doi.org/10.1016/S0308-597X(01)00023-9.
[41] H.L. McMillen, T. Ticktin, A. Friedlander, S.D. Jupiter, R. Thaman, J. Campbell, J. Veitayaki, T. Giambelluca, S. Nihmei, E. Rupeni, L. Apis-Overhoff, W. Aalbersberg, D.F. Orcherton, Small islands, valuable insights: systems of customary resource use and resilience to climate change in the Pacific, Ecol. Soc. 19 (2014) 44, https://doi.org/10.5751/ES-06937-190444.
[42] E. Schemmel, A.M. Friedlander, P. Andrade, K. Keakealani, L.M. Castro, C. Wiggins, B.A. Wilcox, Y. Yasutake, J.N. Kittinger, The codevelopment of coastal fisheries monitoring methods to support local management, Ecol. Soc. (2016), https://doi.org/10.5751/ES-08818-210434.
[43] M. Wiber, F. Berkes, A. Charles, J. Kearney, Participatory research supporting community-based fishery management, Mar. Policy 28 (2004) 459–468, https://doi.org/10.1016/j.marpol.2003.10.020.
[44] T. Bambridge, The Rahui: Legal Pluralism in Polynesian Traditional Management of Resources and Territories, ANU Press, 2016.
[45] ITSTAT (1998) "Tableaux de l'Economie Polynésienne", chapter 19 on Commerce.
[46] V.S. Lockwood, Development and return migration to rural French Polynesia, Int Migr. Rev. 24 (1990) 347–370..
[47] F. Torrente, Ancestral fishing techniques and rites on 'Anaa Atoll, Tuamotu Islands, French Polynesia, SPC Tradit. Mar. Resour. Manag Knowl. Inf. Bull. 35 (2015) 18–25.
[48] F. Torrente, T. Bambridge, S. Planes, J. Guiart, E.G. Clua, Sea swallowers and land devourers: can shark lore facilitate conservation? Human Ecol. (2018) 717–726.
[49] M.S. Allen, The historical role of bonefishes (*Albula spp.*) in Polynesian fisheries, Hawaii. Archaeol. (2014) 51–72.
[50] A. Filous, R.J. Lennox, E.E.G. Clua, A.J. Danylchuk, Fisheries selectivity and annual exploitation of the principal species harvested in a data-limited artisanal fishery at a remote atoll in French Polynesia, Ocean Coast. Manag. 178 (2019), 104818, https://doi.org/10.1016/j.ocecoaman.2019.104818.
[51] A. Filous, R.J. Lennox, R.R. Coleman, A. Friedlander, E.E.G. Clua, A.J. Danylchuk, Life history characteristics of an exploited bonefish (Albula glossodonta) population in a remote South Pacific Atoll, J. Fish. Biol. 95 (2019) 562–574.
[52] A. Filous, R.J. Lennox, J.P. Eveson, R. Raveino, E.E.G. Clua, S.J. Cooke, A. J. Danylchuk, Population dynamics of roundjaw bonefish Albula glossodonta at a remote coralline Atoll inform community-based management in an artisanal fishery, Fish. Manag. Ecol. (2019) 1–15, https://doi.org/10.1111/fme.12399.
[53] A. Filous, R.J. Lennox, S.J. Cooke, A.J. Danylchuk, The spawning migrations of an exploited Albulid in the tropical Pacific : implications for conservation and community-based management, Environ. Biol. Fishes (2020), https://doi.org/10.1007/s10641-020-00996-3 (The).
[54] A. Filous, R.J. Lennox, E.E.G. Clua, S.J. Cooke, A.J. Danylchuk, Length-based assessment of an artisanal albulid fishery in the South Pacific: a data-limited approach for management and conservation, Mar. Coast. Fish. 11 (2019) 1–16..
[55] C.P. Goodyear, Spawning Stock Biomass Per Recruit in Fisheries Management: Foundation and Current Use, Canadian Special Publication of Fisheries and Aquatic Sciences, 1993.
[56] D. Pauly, Anecdotes and the shifting baseline syndrome of fisheries, Trends Ecol. Evol. 10 (1995) 430.
[57] A.M. Friedlander, J.M. Shackeroff, J.N. Kittinger, Customary marine resource knowledge and use in contemporary Hawai'i, Pac. Sci. 67 (2013) 441–460, https://doi.org/10.2984/67.3.10.
[58] H. Govan, Achieving the potential of locally managed marine areas in the South Pacific, SPC Tradit. Mar. Resour. Manag Knowl. Inf. Bull. 16 (2009).
[59] S. Aswani, R.J. Hamilton, Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands, Environ. Conserv. 31 (2004) 69–83, https://doi.org/10.1017/S037689290400116X.
[60] S. Aswani, M. Lauer, Incorporating fishermen's local knowledge and behavior into geographical information systems (GIS) for designing marine protected areas in Oceania, Hum. Organ. 65 (2006) 81–102, https://doi.org/10.17730/humo.65.1.4y2q0vhe4l30n0uj.
[61] F. Berkes, Community-based conservation in a globalized world, Proc. Natl. Acad. Sci. 104 (2007) 15188–15193.
[62] J.B. Frey, F. Berkes, Can partnerships and community-based conservation reverse the decline of coral reef social-ecological systems? Int. J. Commons 8 (2014) 26–46.
[63] R.E. Johannes, M.M.R. Freeman, R.J. Hamilton, Ignore fishers' knowledge and miss the boat, Fish Fish. 1 (2008) 257–271, https://doi.org/10.1111/j.1467-2979.2000.00019.x.
[64] J.A. Drew, A.P. Henne, (2006) Conservation biology and traditional ecological knowledge: integrating academic disciplines for better conservation practice.
[65] L. Gaspare, I. Bryceson, K. Kulindwa, Complementarity of fishers' traditional ecological knowledge and conventional science: Contributions to the management of groupers (*Epinephelinae*) fisheries around Mafia Island, Tanzania, Ocean Coast. Manag. 114 (2015) 88–101.
[66] S. Mackinson, Integrating local and scientific knowledge: an example in fisheries science, Environ. Manag. 27 (2001) 533–545, https://doi.org/10.1007/s002670010168.
[67] B. Erisman, W. Heyman, S. Kobara, T. Ezer, S. Pittman, O. Aburto-Oropeza, R. S. Nemeth, Fish spawning aggregations: where well-placed management actions can yield big benefits for fisheries and conservation, Fish Fish. 18 (2017) 128–144, https://doi.org/10.1111/faf.12132.
[68] A. Gruss, J. Robinson, S.S. Heppell, S.A. Heppell, B.X. Semmens, Conservation and fisheries effects of spawning aggregation marine protected areas: what we know, where we should go and what we need to get there, ICES J. Mar. Sci. 71 (2014) 1515–1534, https://doi.org/10.1093/icesjms/fst176.
[69] S.A. Heppell, B.X. Semmens, S.K. Archer, C.V. Pattengill-Semmens, P.G. Bush, C. M. McCoy, S.S. Heppell, B.C. Johnson, Documenting recovery of a spawning aggregation through size frequency analysis from underwater laser calipers measurements, Biol. Conserv. 155 (2012) 119–127, https://doi.org/10.1016/j.biocon.2012.06.002.
[70] R.Q. Grafton, Social capital and fisheries governance, Ocean Coast. Manag. 48 (2005) 753–766, https://doi.org/10.1016/j.ocecoaman.2005.08.003.
[71] P. Damerell, C. Howe, E.J. Milner-Gulland, Child-orientated environmental education influences adult knowledge and household behaviour, Environ. Res. Lett. (2013), https://doi.org/10.1088/1748-9326/8/1/015016.
[72] A. Knafo, N. Galansky, The Influence of children on their parents' values, Soc. Pers. Psychol. Compass 2 (2008) 1143–1161, https://doi.org/10.1111/j.1751-9004.2008.00097.x.
[73] L.M. Campbell, N.J. Gray, E.L. Hazen, J.M. Shackeroff, Beyond baselines: rethinking priorities for ocean conservation, Ecol. Soc. (2009), https://doi.org/10.1371/journal.pbio.0060054.
[74] A.J. Hobday, Sliding baselines and shuffling species: implications of climate change for marine conservation, Mar. Ecol. 32 (2011) 392–403, https://doi.org/10.1111/j.1439-0485.2011.00459.x.

[75] S.K. Papworth, J. Rist, L. Coad, Evidence for shifting baseline syndrome in conservation, Conserv. Lett. 2 (2009) 93–100, https://doi.org/10.1111/j.1755-263X.2009.00049.x.
[76] S. Cummins, G. Snively, The effect of instruction on children's knowledge of marine ecology, attitudes toward the ocean, and stances toward marine resource issues, Can. J. Environ. Educ. 5 (2000) 306–324.
[77] J. Lambert, Students' conceptual understandings of science after participating in a high school marine science course, J. Geosci. Educ. 53 (2005) 531–539, https://doi.org/10.5408/1089-9995-53.5.531.
[78] 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, S. J. Campbell, A.H. Baird, F.A. Januchowski-Hartley, S. Hamed, R. Lahari, T. Morove, J. Kuange, Comanagement of coral reef social-ecological systems, Proc. Natl. Acad. Sci. 109 (2012) 5219–5222, https://doi.org/10.1073/pnas.1121215109.
[79] A. Barker, Improving local capacity in coastal management: experiences and lessons from the developing world, J. Coast. Res. (2005) 387–393.
[80] F. Berkes, Community conserved areas: policy issues in historic and contemporary context, Conserv. Lett. 2 (2009) 20–25.
[81] P. Christie, A.T. White, Best practices for improved governance of coral reef marine protected areas, Coral Reefs 26 (2007) 1047–1056, https://doi.org/10.1007/s00338-007-0235-9.
[82] S. Gordon, The economic theory of a common-property resource : the fishery, J. Polit. Econ. 62 (1954) 124–142.