Conservation and Community Benefits from Traditional Coral Reef Management at Ahus Island, Papua New Guinea

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Abstract: *We investigated traditional coral reef management practices at Ahus Island, Manus Province, Papua New Guinea, to evaluate their social role in the community and potential to conserve reef ecosystems. For generations, Ahus Islanders have prohibited spear and net fishing within six delineated areas of their reef lagoon. One to three times per year, fish are briefly harvested from the restricted areas to provide food for ceremonial occasions. Underwater visual censuses of fishes revealed a significantly greater biomass and average size of target species within the restricted areas (205 kg/ha ± 20 [SE]; 102 mm TL [total length] ± 0.7) compared with areas without fishing restrictions (127 kg/ha ± 13 SE; 85 mm TL ± 0.7). We estimated the biomass of fish removed during one of the harvest events was 5 to 10% of the available biomass within the restricted area, and in underwater visual surveys conducted before and after a harvesting event we detected no effect of harvesting on fish stocks. Compliance with the fishing restriction is attributed to its perceived legitimacy, its ability to provide the community with direct and indirect benefits, and its reflection of local socioeconomic circumstances. Limited-take closure systems that can serve the needs of a community may provide a viable conservation alternative in situations where compliance with fully closed protected-area regulations is low and resources for proper enforcement are untenable.*

Key Words: customary marine tenure, fish stocks, marine protected areas, periodic harvesting

Beneficios de Conservación y de la Comunidad por la Gestión Tradicional de Arrecifes de Coral en la Isla Ahus, Papua Nueva Guinea

Resumen: *Investigamos las prácticas tradicionales de gestión de arrecifes coralinos en la Isla Ahus, Provincia de Manus, Papua Nueva Guinea, para evaluar su papel social en la comunidad y su potencial para conservar ecosistemas arrecifales. Por generaciones, los habitantes de Ahus han prohibido la pesca con arpón y redes dentro de seis áreas delimitadas de su laguna Arrecifal. De una a tres veces por año, se realizan capturas de peces en las áreas restringidas para proporcionar alimento para ocasiones ceremoniales. Censos visuales subacuáticos de peces revelaron una biomasa y talla promedio de las especies capturadas significativamente mayores dentro de las áreas restringidas (205 kg/ha ± 20 [DS]; 102 mm LT [longitud total] ± 0.7) en comparación con áreas sin restricciones de pesca (127 kg/ha ± 13; 85 mm LT ± 0.7). Estimamos que la biomasa de los peces removidos durante uno de los eventos de captura era solo 5 a 10% de la biomasa disponible en el área restringida, y en muestreos visuales subacuaticos antes y después del evento de captura no detectamos efecto de la captura sobre las existencias de peces. El acatamiento de la restricción de pesca es atribuido a su legitimidad perceptible, a su habilidad para proporcionar beneficios directos e indirectos a la comunidad y a su reflejo en circunstancias socioeconómicas locales. Los sistemas cerrados de captura limitada que pueden satisfacer las necesidades de una comunidad pueden proporcionar una alternativa de conservación viable en*

Paper submitted December 10, 2004; revised manuscript accepted June 6, 2005.

Conservation Biology 1714–1723

DOI: 10.1111/j.1523-1739.2005.00269.x

situaciones en las que el acatamiento de las regulaciones de áreas protegidas totalmente cerradas es bajo y en las que los recursos para su debida ejecución son insostenibles.

Palabras Clave: áreas marinas protegidas, capturas periódicas, existencias de peces, posesión marina convencional

Introduction

Many coastal communities in the Pacific have traditionally used resource-management techniques similar to those of modern fisheries managers, including restrictions on gear, season, reef areas, species, size, and ownership of marine resources (Johannes 1978; Ruddle & Akimichi 1984; McClanahan et al. 1997; Adams 1998). These forms of management are often imbedded in ceremonies, religion, dietary restrictions, and other traditions rather than explicitly practiced for conservation purposes (Polunin 1984; Colding & Folke 2001; Foale & Manele 2004). For example, in New Ireland Province of Papua New Guinea (PNG), many communities prohibit fishing or gleaning within a specific reef area following the death of a village leader, landowner, or other person of significance (Wright 1985). After some time, which can last up to several years, the restricted area is harvested and the fish are used for a feast that marks the end of the mourning period. Thus, the explicit intent of the prohibition is to provide fish for a ceremony, but rebuilding fish stocks within the closure is an implicit goal needed to achieve the large harvest.

There is a debate as to whether or not these traditional practices can conserve coastal marine ecosystems (Polunin 1984; Johannes 2002*a*; Foale & Manele 2004; Pollnac & Johnson 2005). Evidence that precolonial Pacific societies significantly depleted terrestrial and marine resources (Diamond 1991; Jackson et al. 2001) has been used to argue that a conservation ethic did not exist (Diamond 1986). Resource harvesting patterns may simply be a short-term optimal foraging behavior with minimal consideration for conservation or long-term effects on resources (Aswani 1998). An alternative hypothesis, however, is that through resource shortages, island communities became aware of their ability to deplete the environment and developed practices that regulated resource use (Johannes 2002*a*).

Studies of whether traditional management and marine tenure practices are effective in conserving marine resources have so far been largely descriptive in nature and have focused primarily on resource-management practices (Johannes 1982; Polunin 1984; Hunt 1997), common-property systems (Baines 1989; Ruttan 1998; Aswani 2002), and ethnography (Carrier 1987; Hviding 1996). Many of the conclusions have been cautiously optimistic about the ability of traditional management practices to conserve resources. Of notable exception are the works of Polunin (1984) and Carrier (1987). Carrier (1987) suggests that the limited-entry system employed in Ponham Island in Manus Province of PNG is not effective at intentionally or unintentionally conserving resources. Likewise, Polunin (1984) claims that traditional closures in PNG "do not typically promote conservation in any practical sense." Neither Carrier nor Polunin, however, incorporated ecosystem assessments into their studies to reinforce these claims.

The effects of these traditional practices on the state of coral reef resources have seldom been quantified. Results of a study of reinstated traditional management (*ra'ui*) in the Cook Islands' coral reefs suggest that the management increases species diversity of corals but limited sampling weakens the conclusions (Hoffmann 2002). McClanahan et al. (1997) found that fishing restrictions imposed at sacred sites in Kenya increased the fish catch in adjacent landing areas but did not significantly improve the overall ecology and diversity of these reefs. Consequently, the effectiveness of traditional management in promoting the condition of reef resources remains ambiguous. More studies are needed that examine the socioeconomic and cultural aspects of traditional reef management and combine this information with tests of their ability to produce measurable conservation.

The community of Ahus Island, Manus Province, PNG, has six reef areas that are restricted to fishing activities. These restrictions are expected to have been in place for generations but were verified to exist for at least as long as the memory of community members (> 60 years). Throughout most of the year, spear and net fishing within the restricted (*tambu*) areas are prohibited and harvesting of invertebrates is severely limited. Line fishing, however, is unregulated within the tambu area. Up to three times per year, each of the tambu areas may be harvested with spears and nets for a brief period of time (2 to 3 hours) to provide fish for ceremonial occasions that mark significant events in the village, such as the opening of a community building or the conclusion of a mourning period.

At Ahus the reef tambu areas operate within the context of a complicated customary marine tenure system that regulates access to specific reef areas, target species, and harvesting methods, similar to that described for neighboring Ponham Island by Carrier (1987) and Carrier and Carrier (1991). Ahus Islanders claim exclusive rights to all marine resources on the reefs surrounding their island, the neighboring and uninhabited Onetta Island, and the reefs between Ahus Island and the coast of

Manus Island. Ownership rights help create an economic monopoly on marine resources among fishing communities (Malinowski 1935). The reefs surrounding Ahus Island are divided into areas owned by specific clans. It is through this clan ownership of delineated reef areas that the tambu areas are maintained and enforced. Some families also own the rights to harvest certain species (including turtle, coral, and sea cucumbers) or harvesting technology (such as traditional nets), which are not restricted spatially.

We used Ahus Island as a case study to explore some of the social processes that may influence traditional reef closures and to determine whether these practices have conservation benefits for reef ecosystems. The specific objectives were to (1) quantify the effects of the traditional reef closures on the condition of reef resources, (2) examine the social and cultural role of the traditional reef closure, and (3) examine compliance with the restrictions.

Methods

Study Site

Between May and June 2002 we conducted research at Ahus Island (01'56.48 S, 147'05.60 E), which lies off the northern coast of Manus Island, Papua New Guinea, approximately 17 nautical miles northwest of the provincial capital, Lorengau (Fig. 1). Ahus is a relatively small, low, coral island of about 28 ha, occupied by approximately 600 residents living in 105 houses. The coral reefs and lagoons surrounding Ahus and Onneta islands encompass approximately 550 ha. Fishing activities are restricted within six reef areas, together encompassing 33.2 ha (5.8% of the total reef area surrounding Ahus and Onneta). We examined three tambu areas in this study. Two

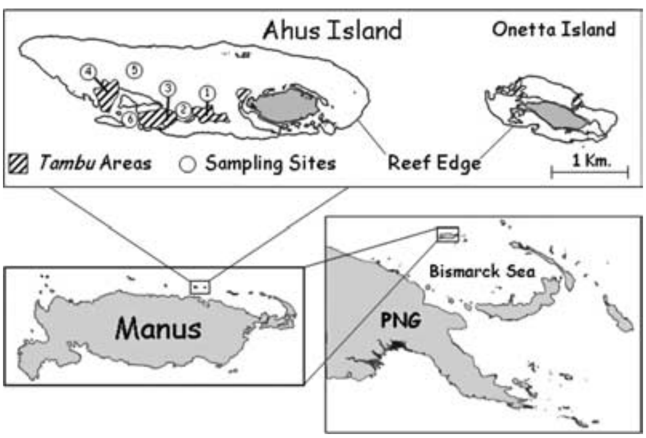

Figure 1. Restricted (tambu) areas and sampling sites on Ahus and Onetta islands, Manus Province, Papua New Guinea (PNG).

of the tambu areas, located off neighboring Onetta Island, were prone to strong currents and were not deemed suitable for underwater visual surveys. The remaining excluded tambu area contained mainly seagrass habitat and thus could not be compared with the other sites. We calculated lagoon and island area by analyzing a 1:100,000 aerial photograph with the UTHSCSA Image Tool 2.0 (University of Texas Health and Science Center, San Antonio) (Cinner et al. 2005).

Social and Cultural Aspects of the Traditional Reef Closures

The main socioeconomic indicators we examined were dependence on and use of coastal resources, perceptions of what can affect and improve fishery resources, descriptions of coastal resource governance practices, and compliance with these practices. Using the methods described in Henry (1990), we systematically surveyed 51 of the 105 households. Additionally, we interviewed key informants, recorded oral histories, and participated in resource use activities to verify the accuracy of household survey responses and to gain a better understanding of the context of coastal resource use and management.

We determined dependence on fishing, agriculture, and other occupations by asking household respondents to list the occupations their household engaged in and then ranking these occupations from most important to least important (Pollnac & Crawford 2000; Cinner et al. 2005). Thus we examined the number of occupations each household engaged in and the relative importance of each occupation. We asked household respondents the average number of days per week each member of the household was engaged in specific fishing activities in both the high and low season. We asked about the average duration of the fishing season and averaged the total number of days for both seasons based on the length of each season. To estimate the total fishing pressure on reef resources for the entire community, we multiplied the average number of fishing trips per household per week by the total number of households in the community.

We assessed awareness of restrictions or closures by asking a subset of the population (fishers) if there were places where people were not supposed to fish. If respondents suggested there were such places, we asked them to elaborate on their response and describe where and when such restrictions applied. For the purposes of this question, we considered respondents fishers if they ranked fishing among their household's three most important occupations or livelihood strategies. To assess compliance with the closure, we then asked fishers if people still fished in the area they were not supposed to. We grouped their response into the following four ordinal categories: nobody fishes there, a few people fish there, many people fish there, almost everybody fishes there. These awareness and compliance questions were slightly problematic because people could still fish there (i.e., line fishing was allowed). Unfortunately, these questions could not be modified to fit the particular circumstances at Ahus because the survey was designed as part of a larger comparative study of resource management practices in > 20 coastal communities throughout Papua New Guinea and Indonesia (Cinner 2005; Cinner et al. 2005; T.R.M. et al., unpublished data) and thus could not be changed partway through the study.

We asked respondents an open-ended question about what can decrease fish abundance, and we grouped responses based on whether respondents mentioned that human activities could decrease fish abundance or not. We also asked respondents an open-ended question about what could increase fish abundance and grouped responses based on whether respondents mentioned that tambu area activities could increase fish abundance or not. Data on governance of marine resources were determined through key informant surveys and recording of oral histories.

Reef Ecosystem Assessment

Assessments of coral reef resources were carried out within three of the six tambu areas (sampling sites 1, 3, 4, Fig. 1) as well as at three nearby "control" sites, where no management regulations were in place (sampling sites 2, 5, 6, Fig. 1). Control sites were chosen randomly from a selection of suitable sites. Sites were selected so as to be as similar as possible in reef profile, current regimes, and wave exposure such that the only obvious difference among sites was the presence or absence of management. All sampling sites were located on shallow, sheltered reefs within the lagoon of Ahus Island.

The abundance of all relatively noncryptic species of reef fishes was recorded along three 50-m belt transects placed haphazardly within each of two depth contours per site: 2 to 4 m and 6 to 8 m. Damselfish (Pomacentridae) were surveyed along belt transects measuring 2 × 50 m, and all other families were surveyed along 5 × 50 m transects. We used the discrete group sampling (DGS) method (Greene & Alevizon 1989) to record fish abundance, whereby we made four passes over each transect and recorded a discrete group of similarly shaped and behaved reef fish families on each pass.

To calculate fish biomass (kilograms fish per hectare of reef), we recorded the total length (TL) and frequency of fishes of all relatively noncryptic families in the same six transects per site described above. We used methods modified from English et al. (1994) to validate the accuracy of underwater size estimates at regular intervals throughout the sampling program. To reduce inaccuracies in the data through the misidentification of small juveniles, we recorded only fish > 3 cm TL. All reef fishes and reef-associated fishes were identified and pooled into family-level groupings, with relatively uncommon families being grouped into a single "other" category. Small, cryptic families, including Apoginidae, Blenniidae, Gobiidae and Tripterygiidae, were excluded from surveys and subsequent biomass calculations. We grouped fish into the following size categories: 3 to <5 cm, 5 to <10 cm, and thereafter into categories in 10-cm size increments. We used representative length-weight conversions for each family obtained from the ICLARM FishBase2000 (Froese & Pauly 2000) database to convert size-frequency data to biomass data. We used the midpoints of size classes in length data calculations. To allow for more precise biomass conversions based on individual length-weight conversions, we recorded fish > 40 cm TL and fish of unusual shape (e.g., aulostomids) separately at the species level with an individual size estimate.

Following the methods of McClanahan and Shafir (1990), we used standard line-intercept transect methods along 18 10-m transect tapes within each site to record substratum composition, including live coral cover, algal cover, and coral community composition. We laid 3 transects along the reef flat, just back from the reef crest, 3 transects parallel to these on the reef crest, and three more parallel to these at the start of the reef slope no deeper than 3 m. We laid a further 9 transects parallel to the reef crest on the reef slope: 3 each at 6 m, 7 m, and 8 m depth. We recorded the substrate type and length of substrate underneath the transect tape to the nearest centimeter. We identified hard corals to genus.

To provide another estimate of compliance with management regulations, we recorded the number of discarded fishing gear found inside versus outside the managed area. We recorded discarded fishing gear, including nets, spears, and traps, along the same 18 transects used to quantify the substrate composition. Additionally, we recorded discarded fishing gear along two 2 × 100 m transects laid along the reef flat, parallel to the reef crest. We recorded discarded fishing lines, but did not include these data in analyses because line fishing was not restricted by management regulations.

Effects of a Periodic Harvest on Fish Stocks

During this research, one of the largest tambu areas was harvested for a ceremonial feast to mark the opening of a *haus boi* (a meeting place for males in the community). Fishing restrictions were lifted for approximately 3 hours within one of the tambu areas and the area was fished intensively. A monofilament gill net was laid across a shallow reef channel and a fishing fleet of 65 canoes and a number of swimmers created a semicircle and drove fish into the net where they were speared.

We conducted fish biomass assessments within the tambu area before and after the harvest event to determine the effects of harvesting on fish stocks (sampling site 1, Fig. 1). We haphazardly chose three sites within the tambu area and three from nearby control areas with no fishing restrictions methods as previously outlined. In addition, we collected data on the abundance, composition, and size structure of all the fishes removed from the tambu area during the harvest. Using a digital camera (Sony DSC P-1, 3.3 megapixel, Sony, Tokyo), we photographed every fish removed from the tambu area at a common landing site ($n = 268$) and an opportunistic control sample consisting of 260 fish from 26 fishing trips (13 spear fishing, 2 net fishing, and 11 line fishing) gathered at all times of the day and night over 9 days. We were unable to tease out which of the fish caught with hooks and line during normal fishing activities were harvested from inside the tambu areas, which means the control sample includes some fish caught from the tambu areas. A graduated 30-cm scale was included in all photos for size calibration. For each fish, the standard length, total length, and fork length were measured from the digital photographs with UTHSCSA Image Tool 2.0 for Windows (University of Texas Health and Science Center, San Antonio). Length data were converted to weight estimates with a representative length-weight formula for each family, obtained from the ICLARM FishBase2000 database (Froese & Pauly 2000).

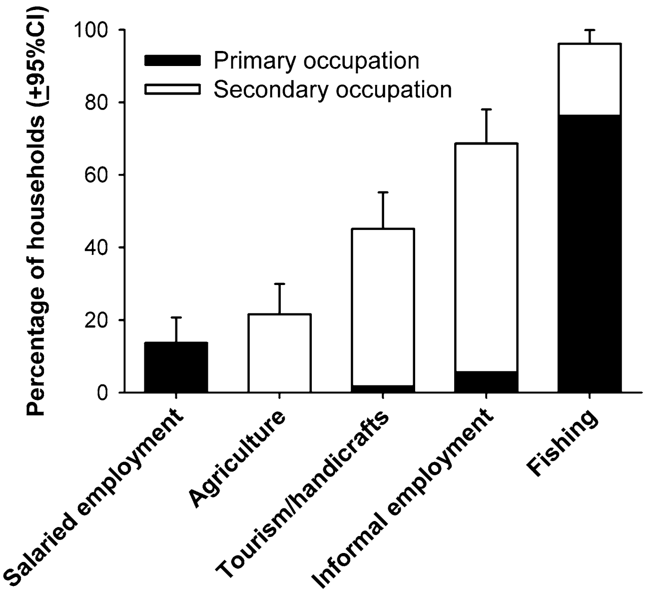

Figure 2. Distribution of primary and secondary household occupations at Ahus Island.

Statistical Analyses

We used a one-way multivariate analysis of variance (MANOVA) to compare ecological variables and data on the abundance of discarded fishing gear inside the tambu with the unrestricted control areas. To avoid pseudoreplication, we pooled data by site and used site as the replicate in analyses (Underwood 1997). All data except for fish abundance data met assumptions of normality and homoscedasticity. To meet the MANOVA assumptions we log transformed fish abundance data before the analysis. To compare fish biomass data collected in and outside the tambu area before and after a harvest event we used a two-way ANOVA with time and closure treatment as the two factors examined. We pooled data at the site level and assumptions of normality and homoscedasticity were met. We used an independent t test of mean body sizes to compare the average size of fish caught during the harvest event to fish caught from areas with no fishing restrictions. The margin of error for socioeconomic variables was calculated using a finite population correction factor, which adjusts the error based on the proportion of the community surveyed (Scheaffer et al. 1996).

Results

Livelihoods and Economics

Ahus Islanders were highly dependent on fishing. More than 96% of household respondents were engaged in the fishery and more than 76% of respondents ranked fishing as their primary occupation (Fig. 2). Because of the remoteness of the island, opportunities to engage in other economic sectors were few. For example, land shortages and poor soil led to minimal engagement in agriculture. Although 21% of the community was engaged in agriculture, none of the respondents listed it as the primary occupation. There was a mean of 2.7 ± 0.25 (95% CI) occupations per household, which is relatively low compared with an average of 3.2 ± 0.1 (SE) for 14 other coastal communities in Papua New Guinea ($n = 501$ households) (J.E.C., unpublished data). Ahus Islanders conducted an estimated 658 ± 134 (95% CI) fishing trips per week, resulting in approximately 1.2 fishing trips/week/ha of reef lagoon (including shallow reef, sand, and seagrass). Fishing with handlines and spears accounted for 52% and 47%, respectively, of the fishing pressure. Eighty-six percent of fishing households were involved in both handline and spear fishing.

Ahus Islanders demonstrated a high degree of understanding that anthropogenic activities (such as fishing and land-based pollutants) can affect fishery resources. In particular, $88 \pm 3\%$ (95% CI) of respondents mentioned that anthropogenic activities can negatively affect fishery resources and $78 \pm 2\%$ (95% CI) of respondents mentioned *tambu* areas as a means to improve the fishery. Awareness and reported compliance with the closures were moderate: $73 \pm 2\%$ of fishers claimed there were places that people could not fish and $43 \pm 2\%$ of fishers claimed that few or no people fish there. Because of the problems discussed with the nature of these questions, this most likely presents an underestimate of awareness of and compliance with the tambu areas.

Table 1. Differences in ecosystem variables inside versus outside the restricted-fishing (tambu) areas (multivariate analysis of variance).

Variable	F	*df*	p
Fish biomass	10.87	1	0.03
Average fish size (fishery target species)	7.91	1	0.04
Fish abundance (all target species)	0.16	1	0.71
Fish species richness	0.08	1	0.79
Coral diversity	2.47	1	0.19
Live hard coral cover	0.04	1	0.85
Number of discarded fishing gears	49.0	1	0.00

Effects of Management on Reef Ecosystems

The biomass of reef fishes differed significantly between tambu and control areas (MANOVA: $F = 10.87$, df $= 1$; $p < 0.05$), with tambu areas containing more than 60% greater biomass of fish (205 kg/ha ± 20 SE) than unrestricted areas (127 kg ha^{-1} ± 13 SE). In addition, the overall average sizes of fish from families commonly targeted in the fishery were significantly larger in the tambu areas (10.2 cm TL ± 0.7 SE) than in control areas (8.5 cm TL ± 0.7 SE; MANOVA: $F = 21.9$, df $= 1$, $p < 0.01$). Abundance of discarded fishing gears was significantly higher outside than inside tambu areas (MANOVA: $F = 49.0$, df $= 1$, $p < 0.01$). No significant differences were detected in overall fish abundance, fish species richness, live coral cover, or coral diversity in and out of tambu areas (MANOVA: $F = 0.8$ to 2.5, df $= 1$, $p > 0.05$; Table 1).

Effect of Harvest on Fish Stocks

There were no detectable changes in the fish biomass within the harvested *tambu* area before compared with after the harvest event (two-way ANOVA: $F = 1.7$, df $= 3$, $p > 0.05$; Fig. 3). These results were further supported by data on the biomass of fish removed during the harvest event, estimated at 190 kg, and between approximately 5 and 10% of the standing stock of fishes available within that particular tambu area, based on underwater visual surveys. The most commonly caught families of fishes during the harvest event were Kyphosidae, Acanthuridae, and Haemulidae, whereas Acanthuridae, Mullidae, and Scaridae were the most frequently caught families during normal fishing activities (Table 2). Based on observations and discussions with fishers, the fish caught during normal fishing activities were primarily harvested on reefs outside the restricted areas but contained a small proportion of fish caught with hook and line inside the tambu area. The average standard length of fishes removed during the harvest event (277.6 mm ± 4.6 SE) was significantly greater than those caught during normal fishing activities (202.0 mm ± 7.6 SE) ($t = 8.4$, df $= 518$, $p < 0.001$), although this is most likely a slight underestimate of the true difference because the sample of normal fishing activities contained some fish harvested inside the tambu.

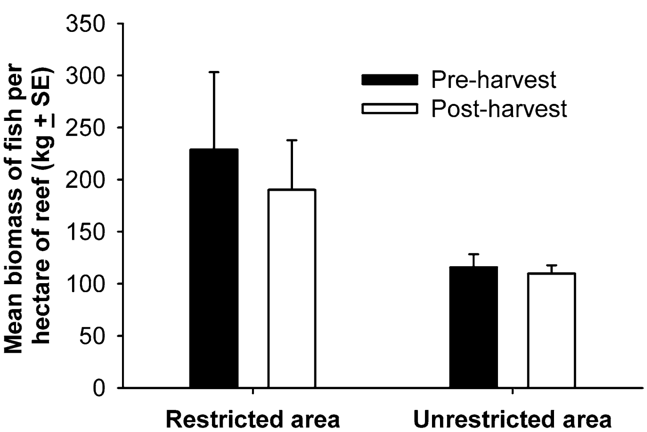

Figure 3. Biomass of fishes in an area with fishing restrictions (tambu) versus areas open to fishing at Ahus Island before and after a harvest event.

Discussion

Traditional fisheries management is undergoing a resurgence and forming a basis for modern fisheries management and conservation strategies in parts of the Pacific (Hviding 1996; King & Faasili 1999; Johannes 2002*b*). Yet the merits of this "renaissance" are unclear because to date conclusions on the effectiveness of traditional management in meeting conservation goals vary (Ruddle et al. 1992; Johannes 2002*a*, 2002*b*; Foale & Manele 2004). Our results provide empirical evidence that traditional reef closures can meet some conservation goals. Fish biomass and sizes were more than 60% and 20% higher, respectively, within tambu areas compared with control areas. This suggests that periodic restriction of net and spear fishing has a positive effect on target fish species. Consequently, the management system promotes larger and more mature fish, and this should increase reproduction and recruitment to surrounding reef areas (Russ 2002).

Periodic harvesting in the tambu area appeared to have little effect on fish stocks. Based on underwater visual censuses, we were unable to detect the effects of this short-term harvesting on the standing biomass of stocks, and quantification of the fish catch indicated that < 10% of the fish biomass in the tambu area was removed. The fish catch collected during this event was reported by fishers to be larger than average, so 10% is probably an upper estimate of what is normally removed. In addition, the biomass removed was calibrated against the biomass estimates obtained from underwater visual censuses (UVC). Because the UVC estimates may miss up to 50% of reef fishes (Ackerman & Bellwood 2000), the actual biomass of fish removed may have been as low as 5% of the standing biomass. Russ and Alcala (1999) suggest that opening

Table 2. Size of fish caught in periodic harvest of reef-closure (tambu) area and in normal fishing activity.

	Normal fishing activity			*Periodic harvest*		
Family	n	*mean standard length (mm)*	*SD*	n	*mean standard length (mm)*	*SD*
Acanthuridae	31	133.6	36.9	62	290.8	86.1
Balistidae	9	135.2	16.9	2	375.0	91.2
Belonidae	4	715.0	54.3	3	615.1	38.9
Chaetodontidae	0	–	–	2	162.3	40.8
Carangidae	22	271.6	98.2	0	–	–
Haemulidae	0	–	–	35	303.6	27.6
Holocentridae	15	123.8	15.9	0	–	–
Kyphosidae	0	–	–	68	254.0	48.4
Labridae	14	152.7	46.4	2	282.9	9.0
Lethrinidae	14	193.7	37.2	29	295.6	81.1
Lutjanidae	18	173.1	29.2	11	308.5	94.6
Monocanthidae	5	250.7	76.5	0	–	–
Mullidae	28	173.9	38.1	0	–	–
Nemipteridae	3	179.9	84.7	0	–	–
Pomacentridae	4	121.9	8.1	0	–	–
Scaridae	27	145.8	24.7	26	196.2	70.9
Scombridae	9	556.8	139.1	0	–	–
Serranidae	17	170.7	51.2	0	–	–
Siganidae	18	171.5	41.4	20	197.7	24.7
Sphyraenidae	6	425.5	59.2	0	–	–
Other	16	225.6	48.3	4	254.5	185.4
Total	260	202.4	123.3	268	269.9	85.9

an area to fishing can noticeably reduce fish stocks within a matter of months, and this is supported by harvest rates from newly opened closed areas (McClanahan & Mangi 2000). Therefore, if the harvests at Ahus were more intensive or more frequent, it is likely that the closures would not produce such pronounced conservation benefits for the fish stocks. Provided harvests continue to be carried out for only brief periods and on an infrequent basis, however, in this case no more than two or three times per year, the opening of closed areas may have only minor effects on fish populations.

The lack of significant difference in other ecological variables in tambu areas compared with unregulated areas may be due to either the limited power of the analyses or that these particular variables do not respond strongly to these gear restrictions. These results support findings in Kenya, where traditional management improved catch but not wider ecological conditions (McClanahan et al. 1997). Because the tambu primarily restricts fishing effort (spear and net fishing), the most immediate and largest responses would be expected to occur for fish stocks. Fishing is almost always size selective, whereby larger individuals are among the first to be removed from the population (Roberts & Polunin 1991). Therefore the larger average size of fishes observed within the tambu area is likely to have been caused by a reduction in overall fishing pressure due to the imposed fishing restrictions.

Line fishing is permitted within the tambu area throughout the year, the intensity of which was similar to that occurring in unmanaged areas. Line fishing at Ahus Island, and in other parts of PNG, removed larger fishes, on average, than other gear types (J.E.C. & T.R.M., unpublished data). The observed differences in size structure of fish populations inside versus outside the tambu area were, therefore, more likely to have been caused by management regulations rather than the effects of line fishing. If line fishing was prohibited within the tambu area, the differences in the average size of fishes inside versus outside the tambu area most likely would have been even greater.

The feasibility of optimizing the conservation effects of limited-take systems with scientific input deserves further investigation. Fish exhibit markedly different interspecific responses to fishing pressure, linked to differences in life-history parameters (Russ & Alcala 1998; Jennings et al. 1999; Hawkins & Roberts 2004). Existing data on the responses of species to varying levels of fishing pressure (e.g., Jennings & Polunin 1996; Russ & Alcala 1998) could be used to model the optimal frequency and intensity of harvesting that would still permit the sustainability of stocks. Data on the response of species to harvesting and protection under these management regimes could also be used to enhance developed models and adapt management strategies once implemented.

The ability of traditional management practices to conserve resources is only a part of the larger debate on what role traditional management can play in the modern conservation context (Carrier 1987; Adams 1998; Ruddle et al. 1992). Increasingly, attention is being focused on how resource management strategies can fulfill community goals. At Ahus tambu areas are an important component of maintaining local customs and economic vitality. Fishing restrictions on specific reef areas provide the community with a "bank account" of natural resources that can be accessed during special occasions. Although maintaining fish stocks within the tambu areas is clearly the goal of the restrictions, conservation in the Western sense is but a byproduct of other cultural and economic needs (Ruttan 1998). Ceremonial occasions such as the opening of a haus boi are important in Ahus Island because they not only affirm the wealth and position of the clan holding the ceremony but also can act as vehicles that help maintain critical social relationships with neighboring villages (such as trade relations and security in times of disaster) (Carrier & Carrier 1989).

Although Ahus Island is well integrated into a cash economy, access to terrestrial resources such as firewood, timber, and vegetables still depends on good trade relations with neighboring mainland villages (Carrier & Carrier 1991). Through customary marine tenure rights that restrict villages on the mainland from accessing reef-related resources, Ahus Islanders create a demand for marine products, which helps ensure that they have desirable goods to sell or trade. If, however, exchange relationships with neighboring villages are strained, Ahus Islanders could have difficulty accessing essential resources.

In PNG feasts can be used as an opportunity to reconcile or maintain exchange relationships (Schwimmer 1973). During the ceremony witnessed at Ahus, neighboring communities contributed pigs, dugong, sharks, sting rays, and turtles. These contributions were given not only to affirm that current trade relationships were acceptable but also to promote a cycle of competitive exchange, which helps ensure future trade relations. Formal tallies of all contributions were kept in the expectation of at least equal reciprocity at a later date, thus providing incentives to maintain good relations.

There is a high degree of understanding within the community that tambu areas are a means to improve the condition of fishery resources. Periodically harvesting a small percentage of the fish within the tambu areas may help reinforce this understanding by providing fishers and the wider community visible evidence that reef closures can help improve fishery resources. A comparison of fish catch data from normal fishing activities with the fish caught during the periodic harvest suggests that fish caught in the tambu areas were significantly larger. Although the comparison should be treated cautiously because different gear was used to harvest the samples, observations about the larger size of the fish caught inside the tambu areas were repeatedly made by fishers throughout the harvesting event. Therefore, this system of closure and brief, periodic harvest provides a visual depiction to community members of the benefits of the tambu for improving fish stocks.

It is not only the ability of the tambu areas to meet both conservation goals and provide the community with social and economic benefits that is impressive but also the ability to do so under the circumstances of high resource dependence, high fishing pressure, and low occupational mobility (i.e., the ability to move to alternative occupations). Because Ahus is highly dependent on marine resources and occupational mobility is low, permanent no-take zones or periodic closures where portions of the reef are closed off for years at a time (e.g., Wright 1985) could potentially create undue displacement of fishing effort or social burdens. By allowing line fishing throughout the year (which accounts for approximately half the fishing effort), Ahus tambu areas appear to reduce fishing effort enough to improve fish biomass inside the reserve without seeming to create excessive social burdens on the community.

Compliance in community-based protected areas can be low, particularly where surveillance is difficult (Crawford et al. 2004) and where external assistance is lacking (Pollnac et al. 2001). The chance of being caught violating fisheries management regulations is typically $< 1\%$, suggesting that compliance with fisheries regulations is largely driven by intrinsic motivations such as perceived legitimacy of the process and authorities, perceptions of how just and moral the regulations are, and social influences such as peers' opinions (Sutinen & Kuperan 1999). We found moderate reported compliance with the tambu but suggest this may be an underestimate of true compliance because of poor applicability of the question to the particular conditions at Ahus. In addition, a significantly lower abundance of discarded fishing gear on tambu reefs than on reefs with no fishing restrictions also indicates there was compliance with management regulations at Ahus. Although clan leaders could impose sanctions for violations of the tambu (monetary fines or community service), no active patrols enforced regulations, suggesting that compliance was largely related to intrinsic motivations. Motivations to comply with the tambu may have been influenced by regular reminders of the restrictions through participation in harvesting events, feasts, and celebrations (Berkes et al. 2000), the perceived legitimacy of the clans' rights to restrict access on the reef (Sutinen & Kuperan 1999), the important role the periodic harvests play for the community in maintaining social and trade relations, perceptions that the tambu benefits fishery resources, the seemingly minimal displacement costs because line fishing is allowed, and the high degree to which the tambu reflects social norms (e.g., perceptions of what can affect the condition of the marine environment).

Although we are cautious about drawing far-reaching conclusions from a single case study, the ability of this system to meet both conservation and utilitarian goals without active enforcement in an area of relatively high population density, high dependence on the reef fishery, and low occupational mobility suggests that potential applicability of similar limited-take systems in other areas should be explored. Traditional systems of management are not applicable or desirable in every situation. The underlying message, however, of the results of this study—that conservation may be achieved without active enforcement patrols by having a management system that meets a number of community needs and goals and is reflective of the cultural context of the community—is a concept that is widely applicable. We do not suggest that already established no-take zone reserves should be opened to periodic harvesting. In areas with minimal enforcement capabilities and where support for no-take reserves has been poor, however, incorporating limited-take systems that reflect the local socioeconomic situation and provide communities with perceived benefits, like the one described from Ahus Island, may enhance support and consequently promote reef conservation.

Acknowledgments

We thank the people of Ahus and Andra villages for allowing us to work in their communities and on their reefs, for providing assistance, and for sharing their valuable traditional knowledge. We are grateful for the assistance of field work provided by J. Ben, T. Clark, I. Liviko, W. Kiene, and R. Yamuna. We also thank the Manus Provincial Government, the PNG Department of Environment and Conservation, the National Fisheries Authority, the University of PNG, T. Poluma, H. Malai, F. Nih, and the crew from the MV Barbarian II. This work was supported by the David and Lucille Packard Foundation. We thank C. Lundquist and two anonymous reviewers for helpful comments on the manuscript.

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