CSIRO PUBLISHING

Pacific Conservation Biology, 2016, **23**, 1–7
http://dx.doi.org/10.1071/PC16016

Traditional ecological knowledge, shifting baselines, and conservation of Fijian molluscs

Karen Bao[A] *and Joshua Drew*[A,B]

[A]Department of Ecology, Evolution and Environmental Biology (EEEB), Columbia University, 1200 Amsterdam Ave, New York, NY 10027, USA.
[B]Corresponding author. Email: j.drew@columbia.edu

Abstract. Understanding a region's ecological history is crucial in formulating conservation plans. In the absence of conventional datasets, historical data and traditional ecological knowledge of local communities can elucidate trends over time and help set goals for preservation and restoration. These methods can contribute to the conservation of biologically and culturally significant species, including coral reef molluscs, in the South Pacific, which have experienced intensified threats such as overfishing and habitat degradation in recent decades. Through fisher interviews in a small coastal community in Fiji, we investigate changes in distribution, biomass, and human perception of common mollusc populations in a Fijian reef. We found evidence of a decline in mollusc populations, but only older fishers with more fishing experience perceived this decline, suggesting a shift in baseline perceptions of biodiversity.

Additional keywords: artisanal fisheries, benthic invertebrates, historical ecology

Received 16 April 2016, accepted 27 August 2016, published online xx xxxxx xxxx

Introduction

Molluscs are important to both coral reef ecosystems and human societies. They physically modify reef environments, serve as substrates for colonising organisms, and are an important link in reef foodwebs (Cabaitan *et al.* 2008; Neo *et al.* 2015). In addition, molluscs constitute a major source of dietary protein in subsistence fishing cultures of the South Pacific (Chapman 1987) and often carry cultural and economic significance (Jones 2009*a*). However, several genera are in decline across the region: giant clams (*Tridacna*), pearl oysters (*Pinctada*), cone snails (*Conus*), *Turbo* snails, and *Trochus* snails, among others, have been depleted from many reefs due to overharvesting (Lucas 1994; Bruckner 2001) and ecological change (Bellwood *et al.* 2004).

In Fiji, indigenous Fijians (iTaukei) have the legal right to fish in specified areas (qoliqoli), although national governments formally manage these areas (Clarke and Jupiter 2010). Additionally, Fiji, along with other Pacific Island nations, has begun implementing Marine Protected Areas (MPAs) and other management plans to prevent further resource overexploitation and habitat degradation. These formal MPAs, along with informal (i.e. not legally recognised) community-based management plans (Jupiter *et al.* 2014; Wendt *et al.* 2016), provide an opportunity for exploring place-based community conservation in the tropical Pacific.

In community-based conservation in Fiji and beyond, memory and local perception of ecosystems play a major role in management (Dayton *et al.* 1998; Swetnam *et al.* 1999). Over time, assessments of healthy ecosystems can change due to the *shifting baseline syndrome*, in which each generation of locals unintentionally accepts smaller, sparser populations as normal (Pauly 1995; Drew and Kaufman 2013). Describing an ecosystem at a time before its exploitation can combat the shifting baseline syndrome. Mollusc harvesting has been underway in Fiji for centuries (Hornell 1940), but commercial exploitation of molluscs in Fiji was only systematically recorded starting in the 1970s (Lewis *et al.* 1988), suggesting that baseline levels of population size and diversity had been impacted before formal records were established. To set a historical baseline in systems lacking pertinent datasets we may access traditional ecological knowledge, the body of knowledge passed down through generations about the relations of humans with other living beings and their environment (Berkes *et al.* 2000). Traditional ecological knowledge, which may vary by age and gender, can shed light on historical changes in targeted populations; re-establishing baselines can aid the formulation of integrated conservation practices by elucidating reef function before major human impacts (Baum and Myers 2004; Drew 2005;).

Using data from fisher interviews, we examine the ability of Fijian villagers to perceive changes in shellfish populations over time. Our study was conducted in Nagigi, a small fishing village on the island of Vanua Levu and the subject of previous work evaluating the relationship among gender, fishers' knowledge, and conservation of reef fishes (Fig. 1) (Golden *et al.* 2014). Forming mollusc-specific conservation policies will extend the protection of Nagigi's MPAs to these species. On the basis of

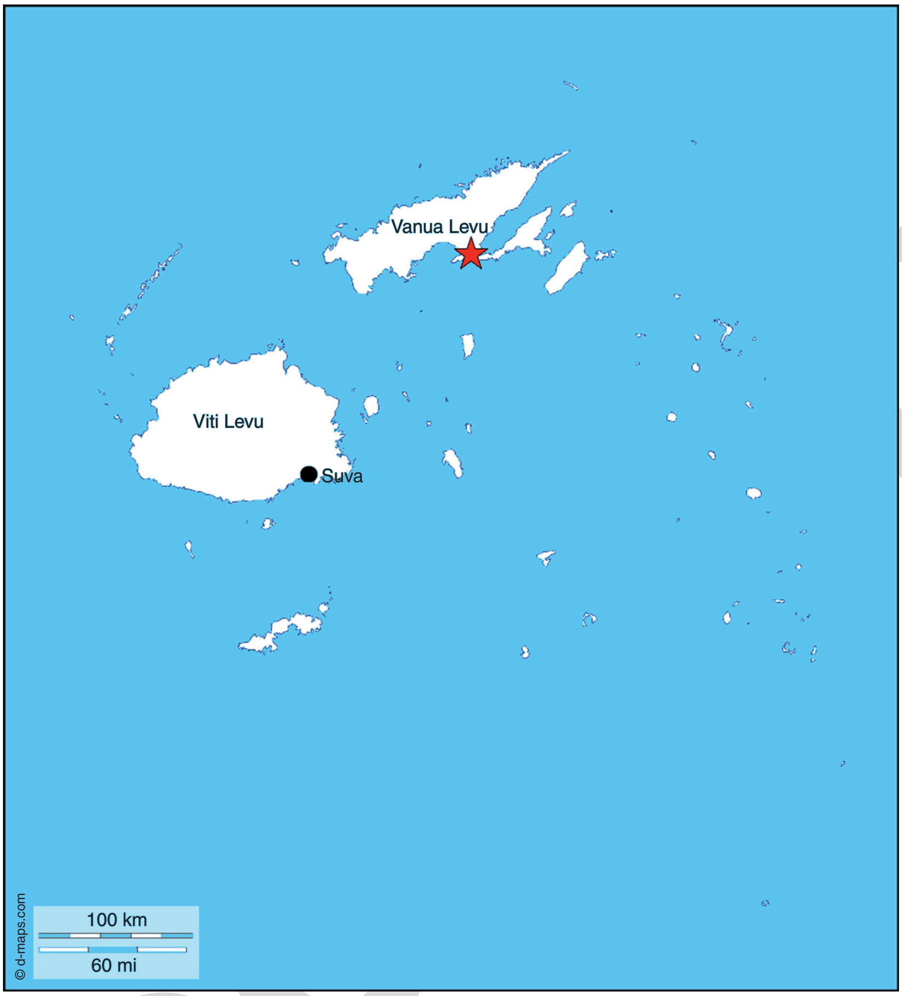

Fig. 1. The republic of Fiji. The star indicates the village of Nagigi.

patterns of shellfish exploitation across the region (Chapman 1987) we hypothesise that molluscs will show significant decline in size and abundance over time due to exploitation and ecological change, and that the shifting baseline syndrome is present in Nagigi.

Methods

Fisher interviews

During June 2015, we interviewed 33 Nagigi fishers individually and in groups of up to three to access their traditional ecological knowledge. We selected informants based on recommendations from the village liaison and previous interviewees. With one exception, group interviews were with fishers of similar age (couples or groups of friends) to avoid a person from an older generation swaying younger ones' opinions. We used an Institutional Review Board–approved questionnaire and obtained interviewees' written consent as per Columbia University protocol IRB-AAAO8003, which protects the subjects' privacy. Interviews were conducted either in people's homes or in communal areas, and we recorded them on a Sony IC PX333 voice recorder.

To gain an understanding of perceptions across generations and experience levels, this study included fishers of both genders and a range of ages from 18 to 68 years old. We conducted the interviews in English, which is widely spoken in Fiji; however, four interviews required the assistance of a translator from the community who was familiar with both the general Fijian language (Bauan) and the local dialect. We identified molluscs by their Fijian common names (Table 1), and used a field guide and shell samples as visual aids.

Nagigi's fishers provided their gender, age, primary occupation, whether they had any official status, such as a conservation officer ('fish warden'), and their family relations to previous interviewees. We asked fishers about their length of residency and familiarity with the fishery (see interview questions, available as Supplementary material to this paper), and whether they had noticed changes over time. If they noted smaller or sparser mollusc populations, we recorded that they considered the reef 'depleted' compared with a past state. Additionally, as a proxy for estimating changes in size of molluscs over time, the fishers indicated the size of the largest *Tridacna* specimen they have ever caught (either by showing the actual shell or using their

Table 1. A list of scientific, English common, and Fijian (Bauan) names for invertebrates mentioned by informants in Nagigi, Fiji

All information was compiled during interviews and verified using Jansen *et al.* (1990)

Scientific name	English common name	Fijian common name
Mollusca (phylum)	shellfish	*vivili*
Trochus niloticus	trochus shell	*sici, tebe*
Trochus pyramis	top shell	*tovu*
Tridacna gigas	giant clam	*vasua*
Tridcana maxima	small giant clam	*katavatu*
Tridacna squamosa	fluted giant clam	*cega*
Pinctada margaritifera	blacklip pearlshell	*civa*
Pinctada martensii	pygmy pearlshell	*civaciva*
Turbo petholatus	tapestry turban	*matakarawa*
Turbo intercostalis	turban shell	*la*
Conus spp.	cone snail	*koi ni masi*
Anadara cornea	ark shell	*kaikoso*
Atactodea striata	surf clam	*sigawale*
Lambis lambis	spider conch	*yaga*
Nautilus pompilius	nautilus shell	*kuita nu*
Charonia tritonia	triton shell	*davui*
Strombus spp.	conch	*tivikea* (adult), *golea* (juvenile)
Cypraeidae (family)	cowrie	*buli*
Chama spp.	jewel box shell	*bu*

hands on the floor to estimate length), and named the year in which they caught it. All lengths were measured with a ruler to the nearest centimetre.

Data analysis

To evaluate change over time in perceptions of mollusc populations, we executed *t*-tests for whether villagers perceived the reef as depleted of *vivili* (shellfish). Both age and years of fishing experience were normally distributed (Shapiro–Wilk normality test: age, W = 0.9501, $P = 0.136$; experience, W = 0.9413, $P = 0.074$). The *t*-tests determined whether the mean age and years of fishing experience differed between the villagers who said populations were depleted and those who did not.

To assess the effect of fishing experience on the largest clam individuals have ever caught – a proxy for clam size over the years – we performed a two-way ANOVA. First, data were normalised on largest clam caught – the response variable – using a log-transformation. We binned fishers into three equally sized groups by age, assigning them the following 'age ranks': 1 (19–33 years old), 2 (34–51), and 3 (52–68). Because about one-third of fishers learned to fish after adolescence, we also binned them by years of experience: less experienced (2–19 years), somewhat experienced (19–37 years), and experienced (37–54 years). Using dependent variables, including sex, age rank, fishing experience, frequency of fishing, and use or non-use of free-diving equipment such as fins and goggles, we executed model simplification and found the only significant effects were fishing experience and free diving access as non-interacting variables. We then performed a two-way ANOVA to test whether the individual and interacting effects of these factors affected the size of the largest clam the fishers had caught. Lastly, we performed a Chi-square test to examine whether there were differences between genders in fishers' perceptions of how the reefs had changed.

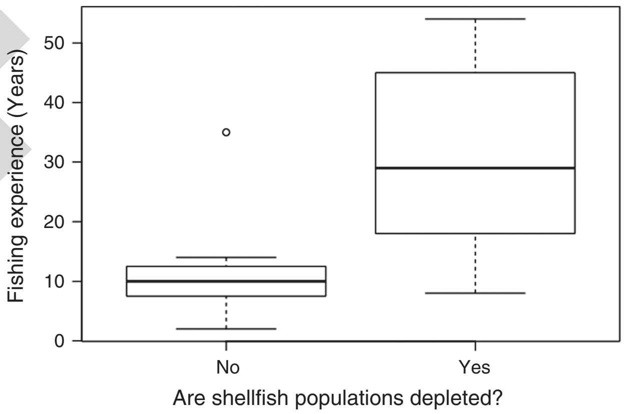

Fig. 2. Relationship between fishing experience and the view that shellfish are more depleted.

Results

Interview results

Both age and fishing experience affected perceptions of the reef's shellfish populations, with years of fishing experience having a more significant effect (Fig. 2, age; Fig. 3, years fishing).

The 27 fishers who said mollusc populations are depleted were significantly older than the six who said populations were not depleted, at 30.9 years older ($P = 0.03$). More strikingly, those who said populations were depleted had more fishing experience (29.7 years) than those who said populations were healthy (12.4 years) ($P = 0.003$) (Fig. 2).

Fishing experience and age also affected the size of the largest clam that fishers remembered catching, although neither

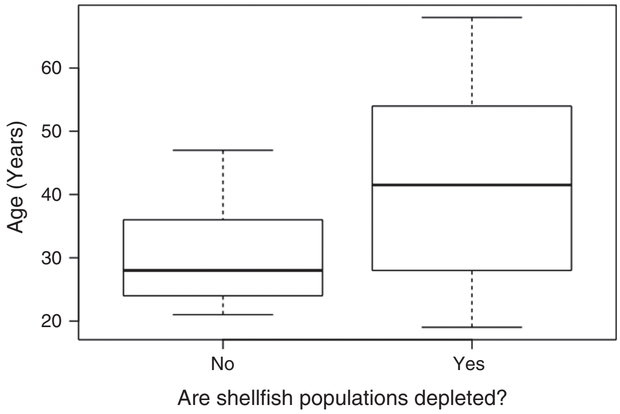

Fig. 3. Relationship between fisher's age and the view that shellfish are more depleted.

Fig. 4. The relationship between the amount of experience a fisher has and the largest *Tridacna* sp. caught.

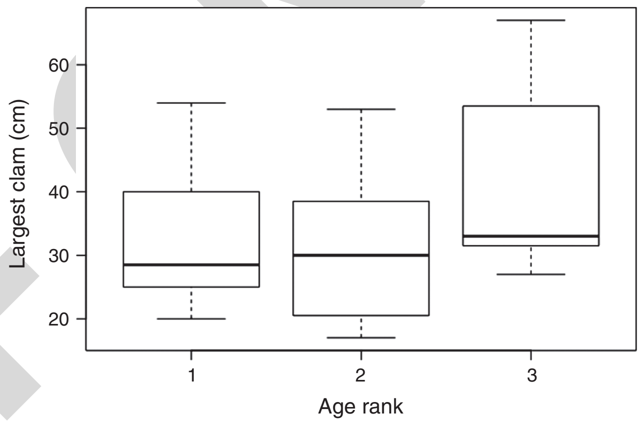

Fig. 5. The relationship between the age of a fisher and the largest *Tridacna* sp. caught. Age classes are young (19–33 years old), middle-aged (34–51), and old (52–64).

of these findings were statistically significant (ANOVA: for fishing experience, $F_{2,30} = 3.016$, $P = 0.064$; for age rank, $F_{1,31} = 2.288$, $P = 0.14$) (Fig. 4, experience; Fig. 5, age). We conducted model simplification in an ANOVA, including other effects such as gender, age rank, occupation, and whether the person free dives, starting with all variables and removing individual and interacting effects where $P > 0.05$. After completion, we found that presence or absence of diving and years of fishing experience together were the two significant effects (ANOVA: $F_{2,30} = 4.06$, $P = 0.028$), indicating that experience and free diving combined to increase access to large shellfish.

The Chi-square test to examine whether gender correlated with fishers' perception of the reef was conducted on a sample size of 16 women and 17 men. Our results indicate that gender is not correlated with reef perception ($\chi^2 = 0.88809$, d.f. = 1, $P = 0.346$). When we examined the relationship between gender and largest clam caught there were also no significant correlations (Welch's *t*-test: $t = -1.1456$, d.f. = 27.576, $P = 0.2618$).

Lastly, our qualitative interviews suggest that Nagigi's fishers target a wide range of mollusc species, but their purpose and favoured species varied. All interviewees ($n = 33$) said they fish for 'all *vivili*'. Of the 33 interviewees, 25 said they sell *Trochus niloticus* shells for income, and five said they sell *Pinctada margaritifera*. All other species were fished for subsistence purposes.

Discussion

We show that perceived changes in mollusc populations correlate significantly with both fishing experience and age, supporting the shifting baselines hypothesis in Nagigi. This phenomenon may inform future marine resource management in this village and in similar sites. While our study joins a list of others highlighting shifts in perceptions of a 'natural' reef community (Sáenz-Arroyo *et al.* 2005; Knowlton and Jackson 2008; Thurstan *et al.* 2015; Martin *et al.* 2016), most of these have focused on vertebrates. We show that, as with finfish, invertebrate populations are susceptible to overharvesting and the cultural amnesia that occurs with the shifting baseline syndrome. Our work mirrors that of Roy *et al.* (2003), showing historical declines in hard-shelled invertebrate populations, but our study views the results through the dual lenses of historical ecology and traditional ecological knowledge. Like Alleway and Connell (2015), we show how the loss of key invertebrates from the environment can lead to an 'intergenerational amnesia' and acceptance of lower biodiversity levels as the natural state (Bunce *et al.* 2008). However, it is important to note that perceptions of change can be influenced by non-biological factors such as the rapidity of change and the informants' overall livelihoods (Albert *et al.* 2013).

Interviews: shifting baselines in shellfishing

Fisher interviews are a well established technique to assess attitudes and perceptions of past abundance, diversity and distribution of tropical marine resources (Sáenz-Arroyo *et al.* 2005), and the data from those interviews have been shown to be reliable (Berkes *et al.* 2000; Beaudreau and Levin 2014). For example, in Ono-i-Lau, Fiji, household estimates of subsistence fishing and consumption largely matched observed quantities, which indicates the relative accuracy of individual reporting (Kuster *et al.* 2006; Jones 2009*a*, 2009*b*).

Older and more experienced fishers were more likely to say the reef was depleted than their younger and less experienced counterparts. This effect depends less on the absolute number of years that they resided in the village than the number of years physically interacting with the reef: perception depended more on years of fishing experience than on age, and depends on both the absolute amount of change as well as the rate of that change (Albert *et al.* 2013). Since fewer young villagers collect shellfish than before, it may be challenging to engage younger villagers in conservation dialogues. Not only was the reef more vibrant before they were born, a greater proportion of them do not observe the reef as it continues to change. Lastly, as they have more opportunities outside the village, and therefore may have a higher standard of living (Albert *et al.* 2013), they may not see the loss of biodiversity as an imminent threat to their way of life.

The fact that fishing experience and free diving together affected the estimate of the biggest clam fishers had caught may have implications about changes in fishing happening at depth. Free diving for clams allows fishers to search deeper waters, up to 10 m below the surface (Interviewees 1, 6, 10, 18, 19, 20, pers. comm.). As fewer younger people are learning this skill, fishing pressure is becoming more concentrated in shallow waters and Nagigi's shallow areas may become even more depleted of molluscs. While molluscs may grow larger at depth, potentially providing a depth refuge, the advantages of these depth refuges may be species-specific. For example, *Tridacna* spp. clams house symbiotic photosynthetic algae within their mantle tissues, so populations are limited by light availability (Watson 2015).

While no interviewees had direct access to compressed gas infrastructure (either SCUBA or hookah equipment), it is important to mention the synergies between the extensive sea cucumber (bêche-de-mer – *Holothuria*) collecting in Fiji and the opportunity to collect other invertebrates. The sea cucumber trade in Fiji is extensive, with both men and women participating and using a variety of gear (Purcell *et al.* 2016). Sea cucumbers are collected, preprocessed, and stored in villages until a middleman purchases the accumulated catch. Because sea cucumber harvesting in Fiji often occurs multiple days per week (Purcell *et al.* 2016), it provides an opportunity for fishers to opportunistically collect other valuable invertebrates at depth. This collecting below free-diving limits may shift directed shellfish harvesting towards shallower depths as individuals may feel that the deep areas have been 'picked over' and it is not worth the expense in time and equipment to forage at depth. Overall, bêche-de-mer abundance was quite low in Nagigi (Eastwood *et al.* 2016).

Older interviewees noted that young people 'go to the sea' less often than their parents and grandparents, and with fewer skills such as free diving. Older fishers expressed concern about loss of the information that has been in their families for generations. Due to economic incentives, younger people typically leave the village for urban centres such as the Fijian capital, Suva, and often parents hope their children will move away from Nagigi for college or employment (Interviewee 3). Two of the youngest interviewees said they attend college in urban centres. Our data suggest that Fiji's shift towards a market economy and changes in the educational environment are resulting in a loss of traditional ecological knowledge (Ohmagari and Berkes 1997; Gómez-Baggethun *et al.* 2010). In Nagigi, we see a similar pattern where increases in formal education detract from 'on the reef' schooling and oral transmission of traditional ecological knowledge.

Despite the interviewees reporting a decrease in the *per capita* hours of fishing in Nagigi, it seems that more people in total are going to the reef and depleting it, according to 11 interviewees. One subject, age 54, said: 'many people', especially 'young people', collect molluscs, 'but they aren't knowledgeable' about the life story traits of these organisms, optimal collecting techniques, and the seasons during which to find them. It is likely that fishing without this knowledge could lead to more, smaller molluscs being removed, contributing to reef depletion. Because many of the targeted shellfish in Nagigi are sedentary broadcast spawners, the depletion of mature individuals may lead to rapid extinction due to Allee effects, wherein gamete densities become too low to produce positive recruitment values (Neo *et al.* 2013).

Potential biases

The Nagigi interviews may have been affected by selection bias, as interviewees tend to be related. Also, when interviewed in a small group, as opposed to individually, fishers tend to agree with each other on the current health of the reef. They may also have exaggerated the size of the biggest clam they have ever caught to make it seem more impressive, or they may have forgotten. Although this psychological source of error likely affected results, it would not have significantly skewed results upward (Roman *et al.* 2011). Lastly, perceptions of reef health do not always match objective ecological realities. Factors such as environmental stochasticity, confirmation bias, and a desire to report what interviewees believe to be the 'correct' responses can all influence the relationship between reported observations and objective evaluations of the environment (Yasué *et al.* 2010).

Steps in the conservation of Nagigi's molluscs

Although there are convincing accounts of mollusc population decline, outright banning exploitation indefinitely to speed recovery would deprive Nagigi's people of food and economic resources. Setting well enforced size limits for removal based on life-history traits has been a hallmark of many conservation plans (Joaquim *et al.* 2008; Golden *et al.* 2014) and may offer an alternative fisheries management avenue for the village. However, this particular course of action needs to be carefully executed. Jupiter *et al.* (2014) highlighted that size limits have had a variable track record in the Pacific, with examples of their imposition working poorly in some fisheries (e.g. *Trochus*: Foale 1998; and bêche-de-mer: Kinch *et al.* 2006), and relatively well in others (*Trochus* in Vanuatu: Léopold *et al.* 2013). Community support and enforcement will be important in the long-term efficacy of size limits and other conservation measures in Nagigi.

In Nagigi, *Trochus niloticus* was by far the most heavily targeted commercial species, followed by *Pinctada margaritifera* and *Tridacna* spp. Because Nagigi's heavily targeted mollusc species tend to grow slowly but are fecund when they do spawn, introducing and enforcing size limits based on life-history traits such as age of first reproduction may prove to be a successful conservation action. *Tridacna*, for example, are protandrous hermaphrodites (Beckvar 1981), meaning that older and larger individuals are functional females. Limiting catches to female individuals over a certain shell diameter would prevent a skewed sex ratio from blocking reproduction. These molluscs' chances of survival can be supplemented by limiting degradation of the coral substrate. Therefore, reducing wading and boating on the inner reef may help habitat recovery and increase juvenile recruitment. Banning boating and/or wading in protected 'zones' has been effective in areas like the Great Barrier Reef Marine Park (Day 2002; Grech *et al.* 2013). Coupling this strategy with stock enhancement from giant clam nurseries operated by the Fijian government could provide a viable tool to counteract the negative impacts on population growth brought about by the Allee effect.

Conclusion

In Nagigi, older villagers have reported a decline in quantity and size of large molluscs, indicating that greater reef management efforts are needed. In addition, the shifting baseline syndrome is manifesting itself within the village's shellfisheries, meaning that younger generations more readily accept sparser mollusc populations of smaller individuals as the norm, threatening their incentive to protect the reef.

This project recommends specific policy proposals supplementing Nagigi's proposed MPA, which currently spells out guidelines for bony fish (Golden *et al.* 2014). Policies such as size limits for *Trochus niloticus*, *Pinctada margaritifera*, and *Tridacna* spp., as well as expansion of MPA grounds into deeper waters and coral habitat preservation, are recommended in order to capture appropriate microhabitats (Dumas *et al.* 2013). To ensure that marine reserve policies are followed, a discussion should be opened about increasing enforcement measures in Nagigi.

More broadly, our findings demonstrate that exploitation of Pacific marine resources, coupled with creeping amnesia about the vivid splendour of reefs in the past, is altering fishers' perceptions of what a 'natural' reef looks like (Albert *et al.* 2013). Within Fiji, existing examples show that even low levels of exploitation can lead to localised extirpation of giant clam species (Seeto *et al.* 2012), and with increases in technology, globalisation and climate variability, recording the diversity of fauna and the associated traditional ecological knowledge becomes paramount. However, there are also examples of how community-based management within Fiji can lead to conservation successes in restoring giant clam populations (Tawake *et al.* 2001). Our research, while focused on one village, establishes a methodological framework that will allow researchers across the region to better document changes in fisheries resources and help describe baselines before they are irrevocably altered.

Acknowledgements

We thank M. McKeon and M. Crist for support in the field. S. Rodriguez, S. Jones and M. Palmer gave useful comments on an earlier draft. S. Mangubhai provided insight into Fijian conservation regulations. This work was done with permission of the *roko tui* of Cakaudrove Province as well as the *tironga ni koro* for Nagigi. Thank you to the villagers of Nagigi for hosting us and providing us information. Funding for this project came from the Columbia EEEB Senior Thesis Research Grant and from the Mindlin Foundation.

References

Albert, S., Love, M., and Brewer, T. D. (2013). Contrasts in social and ecological assessments of coral reef health in Melanesia. *Pacific Science* **67**, 409–424. doi:10.2984/67.3.8

Alleway, H. K., and Connell, S. D. (2015). Loss of an ecological baseline through the eradication of oyster reefs from coastal ecosystems and human memory. *Conservation Biology* **29**, 795–804. doi:10.1111/COBI.12452

Baum, J. K., and Myers, R. A. (2004). Shifting baselines and the decline of pelagic sharks in the Gulf of Mexico. *Ecology Letters* **7**, 135–145. doi:10.1111/J.1461-0248.2003.00564.X

Beaudreau, A. H., and Levin, P. S. (2014). Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems. *Ecological Applications* **24**, 244–256. doi:10.1890/13-0817.1

Beckvar, N. (1981). Cultivation, spawning, and growth of the giant clams *Tridacna gigas*, *T. derasa*, and *T. squamosa* in Palau, Caroline Islands. *Aquaculture* **24**, 21–30. doi:10.1016/0044-8486(81)90040-5

Bellwood, D. R., Hughes, T. P., Folke, C., and Nyström, M. (2004). Confronting the coral reef crisis. *Nature* **429**, 827–833. doi:10.1038/NATURE02691

Berkes, F., Colding, J., and Folke, C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications* **10**, 1251–1262. doi:10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2

Bruckner, A. W. (2001). Tracking the trade in ornamental coral reef organisms: the importance of CITES and its limitations. *Aquarium Sciences and Conservation* **3**, 79–94. doi:10.1023/A:1011369015080

Bunce, M., Rodwell, L. D., Gibb, R., and Mee, L. (2008). Shifting baselines in fishers' perceptions of island reef fishery degradation. *Ocean and Coastal Management* **51**, 285–302. doi:10.1016/J.OCECOAMAN.2007.09.006

Cabaitan, P. C., Gomez, E. D., and Aliño, P. M. (2008). Effects of coral transplantation and giant clam restocking on the structure of fish communities on degraded patch reefs. *Journal of Experimental Marine Biology and Ecology* **357**, 85–98. doi:10.1016/J.JEMBE.2008.01.001

Chapman, M. D. (1987). Women's fishing in Oceania. *Human Ecology* **15**, 267–288. doi:10.1007/BF00888026

Clarke, P., and Jupiter, S. D. (2010). Law, custom and community-based natural resource management in Kubulau District (Fiji). *Environmental Conservation* **37**, 98–106. doi:10.1017/S0376892910000354

Day, J. C. (2002). Zoning – lessons from the Great Barrier Reef Marine Park. *Ocean and Coastal Management* **45**, 139–156. doi:10.1016/S0964-5691(02)00052-2

Dayton, P. K., Tegner, M. J., Edwards, P. B., and Riser, K. L. (1998). Sliding baselines, ghosts, and reduced expectations in kelp forest communities. *Ecological Applications* **8**, 309–322. doi:10.1890/1051-0761(1998)008[0309:SBGARE]2.0.CO;2

Drew, J. A. (2005). Use of traditional ecological knowledge in marine conservation. *Conservation Biology* **19**, 1286–1293. doi:10.1111/J.1523-1739.2005.00158.X

Drew, J., and Kaufman, L. (2013). Functional endemism: population connectivity, shifting baselines, and the scale of human experience. *Ecology and Evolution* **3**, 450–456. doi:10.1002/ECE3.446

Dumas, P., Jimenez, H., Peignon, C., Wantiez, L., and Adjeroud, M. (2013). Small-scale habitat structure modulates the effects of no-take marine reserves for coral reef macroinvertebrates. *PLoS One* **8**(3), e58998. doi:10.1371/JOURNAL.PONE.0058998

Eastwood, E. K., López, E. H., and Drew, J. A. (2016). Population connectivity measures of fishery-targeted coral reef species to inform marine reserve network design in Fiji. *Scientific Reports* **6**, 19318. doi:10.1038/SREP19318

Foale, S. (1998). Assessment and management of the trochus fishery at West Nggela, Solomon Islands: an interdisciplinary approach. *Ocean* *and Coastal Management* **40**, 187–205. doi:10.1016/S0964-5691(98)00044-1

Golden, A. S., Naisilsisili, W., Ligairi, I., and Drew, J. A. (2014). Combining natural history collections with fisher knowledge for community-based conservation in Fiji. *PLoS One* **9**(5), e98036. doi:10.1371/JOURNAL.PONE.0098036

Gómez-Baggethun, E., De Groot, R., Lomas, P. L., and Montes, C. (2010). The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes. *Ecological Economics* **69**, 1209–1218. doi:10.1016/J.ECOLECON.2009.11.007

Grech, A., Bos, M., Brodie, J., Coles, R., Dale, A., Gilbert, R., Hamann, M., Marsh, H., Neil, K., Pressey, R. L., and Rasheed, M. A. (2013). Guiding principles for the improved governance of port and shipping impacts in the Great Barrier Reef. *Marine Pollution Bulletin* **75**, 8–20. doi:10.1016/J.MARPOLBUL.2013.07.013

Hornell, J. (1940). Report on the fisheries of Fiji. Government Printer, South Africa.

Jansen, A. A. J., Parkinson, S. and Robertson, A. F. S. (1990). 'Food and Nutrition in Fiji: a Historical Review. Volume 1: Food Production, Composition, and Intake.' (Institute of Pacific Studies.)

Joaquim, S., Matias, D., Lopes, B., Arnold, W. S., and Gaspar, M. B. (2008). The reproductive cycle of white clam *Spisula solida* (L.) (Mollusca: Bivalvia): implications for aquaculture and wild stock management. *Aquaculture* **281**, 43–48. doi:10.1016/J.AQUACULTURE.2008.05.018

Jones, S. (2009*a*). 'Food and Gender in Fiji: Ethnoarchaeological Explorations.' (Lexington Books.)

Jones, S. (2009*b*). A long-term perspective on biodiversity and marine resource exploitation in Fiji's Lau Group. *Pacific Science* **63**, 617–648. doi:10.2984/049.063.0408

Jupiter, S. D., Cohen, P. J., Weeks, R., Tawake, A., and Govan, H. (2014). Locally-managed marine areas: multiple objectives and diverse strategies. *Pacific Conservation Biology* **20**, 165–179. doi:10.1071/PC140165

Kinch, J., Mesia, P., Kere, N., Manioli, J. and Bulehite, K. (2006). Socio-economic baseline assessment for the eastern Marovo Lagoon, Western Province, the Solomon Islands. IWP-Pacific Technical Report No. 35.

Knowlton, N., and Jackson, J. B. (2008). Shifting baselines, local impacts, and global change on coral reefs. *PLoS Biology* **6**, e54. doi:10.1371/JOURNAL.PBIO.0060054

Kuster, C., Vuki, V. C., and Zann, L. P. (2006). Validation of the accuracy of household reporting of subsistence fishing catch and effort: a Fijian case study. *Fisheries Management and Ecology* **13**, 177–184. doi:10.1111/J.1365-2400.2006.00492.X

Léopold, M., Beckensteiner, J., Kaltavara, J., Raubani, J., and Caillon, S. (2013). Community-based management of near-shore fisheries in Vanuatu: what works? *Marine Policy* **42**, 167–176. doi:10.1016/J.MARPOL.2013.02.013

Lewis, A. D., Adams, T. J. H., and Ledua, E. (1988) Fiji's giant clam stocks - A review of their distribution, abundance, exploitation and management. In 'Giant clams in Asia and the Pacific, ACIRA Monograph Series No. 9'. (Eds J. W. Copland and J. S. Lucas). pp. 66–72. (Australian Centre for International Agricultural Research: Canberra.)

Lucas, J. S. (1994). The biology, exploitation, and mariculture of giant clams (Tridacnidae). *Reviews in Fisheries Science* **2**, 181–223. doi:10.1080/10641269409388557

Martin, S. L., Van Houtan, K. S., Jones, T. T., Aguon, C. F., Gutierrez, J. T., Tibbatts, R. B., Wusstig, S. B., and Bass, J. D. (2016). Five decades of marine megafauna surveys from Micronesia. *Frontiers in Marine Science* **2**, 116. doi:10.3389/FMARS.2015.00116

Neo, M. L., Erftemeijer, P. L., van Beek, J. K., van Maren, D. S., Teo, S. L., and Todd, P. A. (2013). Recruitment constraints in Singapore's fluted giant clam (*Tridacna squamosa*) population – a dispersal model approach. *PLoS One* **8**(3), e58819. doi:10.1371/JOURNAL.PONE.0058819

Neo, M. L., Eckman, W., Vicentuan, K., Teo, S. L. M., and Todd, P. A. (2015). The ecological significance of giant clams in coral reef ecosystems. *Biological Conservation* **181**, 111–123. doi:10.1016/J.BIOCON.2014.11.004

Ohmagari, K., and Berkes, F. (1997). Transmission of indigenous knowledge and bush skills among the Western James Bay Cree women of subarctic Canada. *Human Ecology* **25**, 197–222. doi:10.1023/A:1021922105740

Pauly, D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology & Evolution* **10**, 430. doi:10.1016/S0169-5347(00)89171-5

Purcell, S. W., Ngaluafe, P., Aram, K. T., and Lalavanua, W. (2016). Trends in small-scale artisanal fishing of sea cucumbers in Oceania. *Fisheries Research* **183**, 99–110. doi:10.1016/J.FISHRES.2016.05.010

Roman, S., Jacobson, N., and Cadrin, S. X. (2011). Assessing the reliability of fisher self-sampling programs. *North American Journal of Fisheries Management* **31**, 165–175. doi:10.1080/02755947.2011.562798

Roy, K., Collins, A. G., Becker, B. J., Begovic, E., and Engle, J. M. (2003). Anthropogenic impacts and historical decline in body size of rocky intertidal gastropods in southern California. *Ecology Letters* **6**, 205–211. doi:10.1046/J.1461-0248.2003.00419.X

Sáenz–Arroyo, A., Roberts, C. M., Torre, J., and Cariño-Olvera, M. (2005). Using fishers' anecdotes, naturalists' observations and grey literature to reassess marine species at risk: the case of the Gulf grouper in the Gulf of California, Mexico. *Fish and Fisheries* **6**, 121–133. doi:10.1111/J.1467-2979.2005.00185.X

Seeto, J., Nunn, P. D., and Sanjana, S. (2012). Human-mediated prehistoric marine extinction in the tropical Pacific? Understanding the presence of *Hippopus hippopus* (Linn. 1758) in ancient shell middens on the Rove Peninsula, southwest Viti Levu Island, Fiji. *Geoarchaeology* **27**, 2–17. doi:10.1002/GEA.21385

Swetnam, T. W., Allen, C. D., and Betancourt, J. L. (1999). Applied historical ecology: using the past to manage for the future. *Ecological Applications* **9**, 1189–1206. doi:10.1890/1051-0761(1999)009[1189:AHEUTP]2.0.CO;2

Tawake, A., Parks, J., Radikedike, P., Aalbersberg, B., Vuki, V., and Salafsky, N. (2001). Harvesting clams and data involving local communities in monitoring can lead to conservation success in all sorts of unanticipated ways: a case in Fiji. *Conservation in Practice* **2**, 32–35. doi:10.1111/J.1526-4629.2001.TB00020.X

Thurstan, R. H., McClenachan, L., Crowder, L. B., Drew, J. A., Kittinger, J. N., Levin, P. S., Roberts, C. M., and Pandolfi, J. M. (2015). Filling historical data gaps to foster solutions in marine conservation. *Ocean and Coastal Management* **115**, 31–40. doi:10.1016/J.OCECOAMAN.2015.04.019

Watson, S. A. (2015). Giant clams and rising CO_2: light may ameliorate effects of ocean acidification on a solar-powered animal. *PLoS One* **10**(6), e0128405. doi:10.1371/JOURNAL.PONE.0128405

Wendt, H. K., Weeks, R., Comley, J., and Aalbersberg, W. (2016). Systematic conservation planning within a Fijian customary governance context. *Pacific Conservation Biology* **22**, 173–181. doi:10.1071/PC16001

Yasué, M., Kaufman, L., and Vincent, A. C. J. (2010). Assessing ecological changes in and around marine reserves using community perceptions and biological surveys. *Aquatic Conservation: Marine and Freshwater Ecosystems* **20**, 407–418. doi:10.1002/AQC.1090