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THE RECOVERY OF A TROPICAL MARINE MOLLUSK FISHERY: A TRANSDISCIPLINARY COMMUNITY-BASED APPROACH IN NAVAKAVU, FIJI

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*This paper presents findings from a species-by-species assessment of the collapse and recovery of a tropical mollusk fishery in Navakavu, Fiji. The results are based on field surveys, photo documentation, collection of voucher specimens, participant observation, and testimonies of past and current generations of female and male fishers. The results show the degradation of fisheries resources at almost all trophic levels over the past 40 years due to overfishing, destructive fishing techniques, and environmental degradation, as well as the positive impacts of the establishment of a locally managed marine area (LMMA) and associated marine protected area (MPA), known locally as "*Vueti Navakavu.*" Since its establishment in 2002, nearly 300 mollusk species, including gastropods, bivalves, and cephalopods, are either being seen for the first time in over 40 years or are clearly increasing in abundance and/or size class. There has been a particularly dramatic increase in the abundance of a wide range of cone shells (*Conus *spp.), cowries (*Cypraea *spp.), conches (Strombidae), murexes (Muricidae), auger shells (Terebridae), and turban snails (Turbanidae), as well as octopus, squid, and seahare, all of which are of economic, cultural, and ecological importance. The results show that sustained effective marine conservation can, in general, lead to the recovery of seriously degraded fisheries and, in particular, of tropical mollusk fauna. This assessment highlights the value of synthesizing up-to-date taxonomic and scientific knowledge with the knowledge of older fishers, who have long-term multi-species knowledge of changing fisheries.*

Keywords: *mollusks, indigenous and local knowledge (ILK), locally managed marine area (LMMA), marine species recovery, overfishing*

Introduction

The loss of marine biodiversity and ecological breakdown of marine ecosystems constitutes one of the most serious ecological crises of recent generations. First and foremost, it is a crisis driven by overfishing, which precedes all other disturbances to coastal ecosystems, including pollution, habitat degradation, coral bleaching, invasive species, coral diseases, and climate change (Jackson et al. 2001; Pandolfi et al. 2003). Currently, over 55% of the world's reefs are being threatened by overfishing and/or destructive fishing (Burke et al. 2011) and large predatory fish biomass is only 10% of pre-industrial levels (Myers and Worm 2003). Overfishing has led to trophic collapses of marine ecosystems and the "ecological extinction" of species at almost all trophic levels, including a wide

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range of mollusks, the focus of this study, and other invertebrates that were long assumed less susceptible to overfishing (Peterson 2002).

The consequences of overfishing are exacerbated by lack of awareness and the failure to acknowledge its seriousness. Because of the "shifting baseline syndrome" (Pauly 1995:430), people tend to accept the current degraded condition of the ocean's ecosystems as "normal" (Roberts 2007:14–15) and thus do not consider the past abundance of key species prior to heavy fishing (Erlandson and Rick 2008). As a result, modern management tends to focus on arresting further declines, rather than on rebuilding the richer, more productive states that existed in the past.

Local fisher knowledge, though also susceptible to shifting baselines, can adjust these environmental baselines by providing valuable insights into an area's ecological history and the conservation status of marine species (Bender et al. 2013). Such time-depth perspectives, that incorporate archaeological and other data sets, provide a wealth of information on ecology, evolution, and structure of past marine ecosystems and the history of human impacts. This information can be crucial in the development of better fisheries management plans, ecosystem restoration efforts, and sustainable oceans policy (Braje and Rick 2013; Dayton et al. 1998; Erlandson and Rick 2008; Jackson et al. 2001; Pauly 1995; Pauly et al. 1998). Such historical data and traditional ecological knowledge of local communities is particularly important in the absence of conventional datasets, such as in the developing Pacific Islands.

Globally, mollusks, like finfish, have suffered losses in entire populations, species, and functional groups since the onset of industrialization (Worm et al. 2006). Mollusks are the most diverse phylum in the marine environment, constituting critical trophic components of marine food chains and providing important ecosystem goods and services (Thaman et al. 2014). Thus, these declines in mollusk populations result in diminished ecosystem services, such as the number of viable fisheries, and filtering and detoxification services. Understanding how mollusk populations have shifted through time is fundamental to the planning and assessment of conservation efforts and to reviving biodiversity and some of these ecosystem services.

By collating indigenous and local knowledge (ILK), this study assesses the state of overfishing, the loss of marine biodiversity, and the success of over a decade of marine conservation. The main objective was to utilize older fishers' memories to gather time-depth information on the changing status of mollusk biodiversity within the traditional fishing grounds (*iqoliqoli*) of the clan (*yavusa*) of Navakavu in Fiji. The study includes data from over the past 40 years or so, encompassing the time before and after the establishment of a small traditional marine protected area in 1999, which was later designated a locally managed marine area (LMMA) in 2002. Our research documents historical overfishing, the collapse of, and subsequent recovery of a mollusk fishery in Navakavu by bringing together data gathered in an almost 20-year community-based taxon-by-taxon case study. In this context, collapse means the disappearance or seriously declining abundance of a wide range of culturally and ecologically important species; recovery means the perceived increase in abundance of previously extirpated or seriously threatened species. These data suggest that over a decade of systematic marine conservation has led to the recovery of seriously depleted or locally extinct mollusk fauna. In line with a priority of the recently established Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES) (Diaz et al. 2015), our study builds synergies between ILK and modern scientific knowledge (MSK) as a basis for assessing the long-term changes in the conservation status and the impacts of marine conservation on marine mollusks.

Importance of Marine Mollusks in Fiji

Mollusks provide a vast range of important ecosystem goods and services, both directly and indirectly (Jensen and Harlin 2006; Johannes and Hviding 2000; Johannes et al. 2000; Johnson 1992; Kay 1979). In Fiji, historically and today, marine mollusks are an important staple, supplementary, and emergency food resource. Their long-term importance is evidenced by the widespread existence of shell middens in settlement sites dating as far back as 3000 years ago (Nunn et al. 2004; Swadling 1976; Swadling and Chowning 1981). Commonly encountered taxa in the middens include *Tridacna, Anadara,* and *Trochus* spp. (Clark et al. 2001; Jones 2007; Nunn et al. 2004; Szabó 2009; Szabó and Amesbury 2011).

In the past, and until recently, many shellfish taxa played important roles in Fijian social systems. For instance, some taxa were a critical source of household income in Fiji, with women being almost exclusively responsible for their harvest and sale at local markets (Aswani and Weiant 2004; Fay et al. 2007; Vunisea 1997). Bivalve shells were widely used for cutting and scraping (Swadling and Chowning 1981) and mollusks were, and are, the preferred fishing bait of local fishers. Shell money, jewelry, and valuables remain important ceremonial exchange items between coastal and inland communities (Aswani and Sheppard 2003) and cowries are used as shell amulets for women during traditional dancing (*bulinimeke*), for decorating coconut sennit attached to traditional *kava* bowls (*bulinitanoa*), and to decorate chiefly houses (*bulinivale*). Triton trumpet shells (*Charonia tritonis*) are still blown like trumpets to announce important events, such as gatherings, births, deaths, traditional dances (*meke*), and the return of fishermen. Finally, traditional ceremonial breastplates (*civavonovono*) are still made from the shell of the winged oyster (*Pinctada margaritifera*) and decorated with whalebone ivory (Metropolitan Museum of Art 2015).

Traditional systems of taboo and marine tenure in Fiji, like other parts of the Pacific, served to limit catches and acted as an incentive for the conservation of species and the associated cultural knowledge, while engendering respect for the environment (Johannes 1982). All Fijians have sacred totemic animals, known as *icavuti*, that are passed down paternally, many of which are marine species (Hocart 1914; Ravuvu 1983; Veitayaki 2000). Common well-known mollusk *icavuti* include *kuita* (*Octopus cyanea*), *kaikoso* (*Anadara antiquata*), *davui* (*Charonia tritonis*), and various other gastropod and bivalve species (Fiji Museum 1990). Taboos associated with *icavuti* restrict particular clans, families, age groups, or sexes from catching, eating, or harming the *icavuti*. In the context of this study, the most significant traditional practice still followed in Fiji is the customary ownership of rights to these *iqoliqoli* (Iwakiri 1983; Kunatuba 1983; Veitayaki 1995;

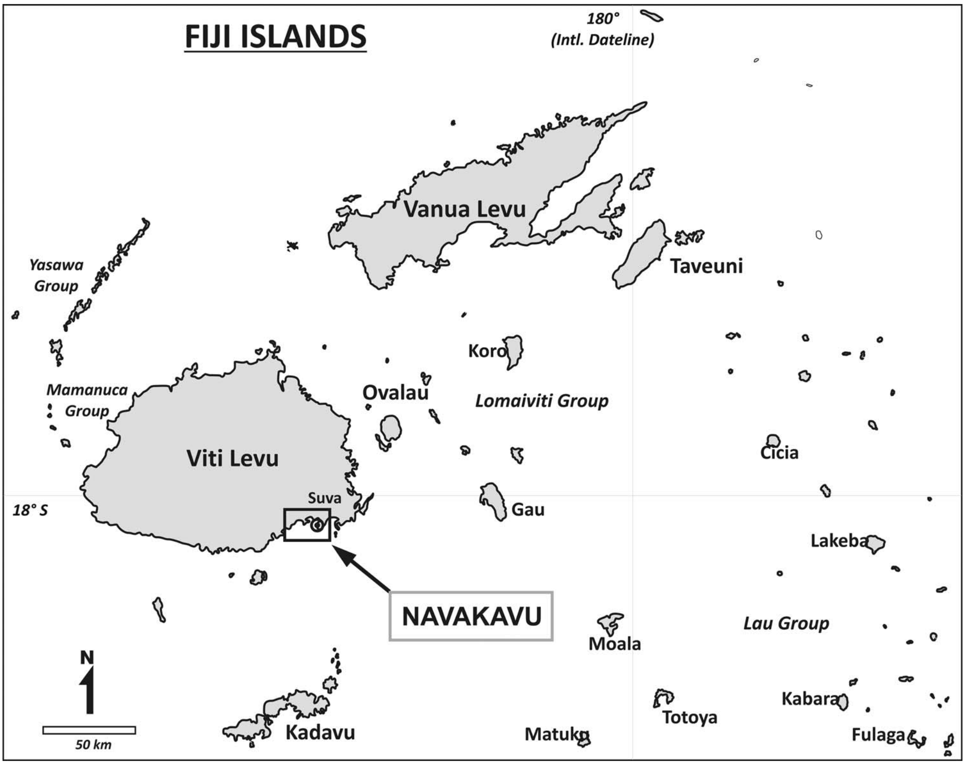

Figure 1. The Fiji Islands, showing the study area of Navakavu on the island of Viti Levu.

Waqairatu 1994). *Iqoliqoli* owners can still traditionally impose bans or restrictions on fishing in order to protect resources (Fong 1994; Ravuvu 1983).

Study Area

The Republic of Fiji (Figure 1) is an archipelagic country consisting of more than 300 islands located in the southwest Pacific Ocean. The estimated population of Fiji in 2016 was over 898,000 (UNDESA 2016) and about 90% inhabit coastal areas (FIBS 2008). Indigenous Fijians traditionally reside in villages with a defined boundary demarcating land ownership, with more than 83% of Fiji's land remaining under customary ownership. A *yavusa* normally has usage rights over their customary lands (*vanua*) that also include their *iqoliqoli* (Tawake and Tuivanuavou 2004).

The focus of this study is the *iqoliqoli* of Navakavu located on the Muaivuso Peninsula in southeastern Viti Levu (Figures 1 and 2). The area's six villages/settlements had an estimated total residential population of about 900 in 2015 (Asakaia Balawa, personal communication, July 2015). The total area of the Navakavu *iqoliqoli* is 18.5 km^2, which includes extensive areas of reefs, mangroves, seagrass, lagoons, reef channels, and open-ocean (Figure 2). The

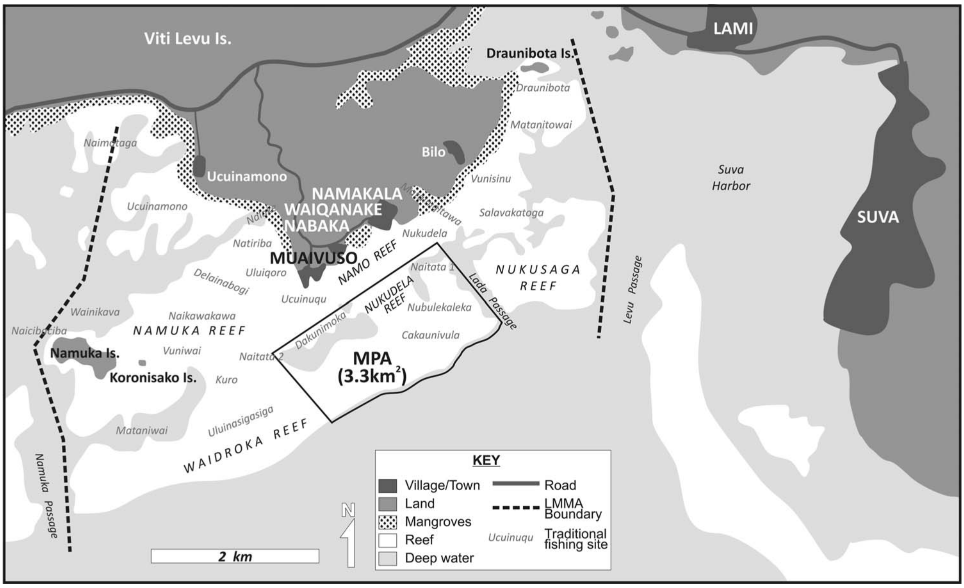

Figure 2. Navakavu and its associated locally managed marine area (LMMA) and designated marine protected area (MPA).

Navakavu *iqoliqoli* is one of the most renowned fishing areas in Fiji and a major source of the marine food products sold in Suva (Thaman et al. 2014).

The inhabitants of Navakavu have fishing traditions and empirical knowledge that have been passed on for generations. Traditional male fishers (*gonedau*) are highly regarded, as are women skilled in reef gleaning and fishing for smaller fish and invertebrates on the intertidal flats and nearshore subtidal areas. Although marine resource-use methods have changed considerably in the last 40 years because of technological and economic changes, contemporary practices still include features that were once part of the traditional system, such as the above-mentioned bans placed on a fishing ground. These traditional practices provide knowledge and skills that enhance the sustainable use of fishery resources (Veitayaki 2000).

In-depth community-based questionnaire surveys conducted in the mid-1990s showed that there was already a wide range of inshore marine organisms that had been overfished, many of the names of which were not known to the younger generation of fishers (Thaman 2008). Because of the clearly deteriorating state of the Navakavu fishery, community leaders formally approached the Institute of Applied Sciences (IAS) at the University of the South Pacific (USP) and the Fiji Locally Managed Marine Area (FLMMA) Network for assistance in the development of a management plan for their inshore marine resources. The plan was completed in 1999 after identification of serious issues and appropriate interventions through a series of community-based workshops, surveys, awareness campaigns, and technical assistance (Meo 2003; Sikolia et al. 2007; Thaman 2008). As part of the plan, in 2002, the Navakavu *iqoliqoli* was formally designated the second LMMA in Fiji under FLMMA and a larger marine protected area (MPA) (*vanua maroroi*) was established near the chiefly village of Muaivuso. The LMMA was named *Vueti Navakavu* (uplifting Navakavu) and managed by a committee of representatives from the Navakavu villages. The larger MPA covered an area of about 3.3 km^2, which was equivalent to approximately 18% of the total *iqoliqoli* area (Figure 2). Aside from one occasion where the MPA was opened for harvesting for cultural reasons, it has remained a closed MPA since 2002. The close monitoring of species abundance throughout the development of these programs provided an excellent data set to assess the impact of these conservation initiatives on the biodiversity of this area.

Methods

We employed a range of techniques for gathering data, beginning with the initial community-based "baseline" surveys documenting the state of the Navakavu *iqoliqoli* in the late 1990s and finishing with ongoing surveys on changes in the composition and abundance of marine biodiversity after the establishment of the LMMA. At all stages, the study depended largely on the memories, knowledge, and testimonies of over 20 of the most knowledgeable older men and women fishers to provide in-depth, qualitative information on the historical status of threatened local marine taxa over the past 40 years or more to assess their recovery after the establishment of the LMMA. This information was correlated with existing publications of quantitative biological survey data (Cakacaka 2008; Comley et al. 2006) and data gathered by the authors during field verification and collection and photography of voucher specimens. Although the original study focused on all taxa considered of importance to local communities, the focus of this paper is only on mollusks because of their cultural importance (Thaman et al. 2014). We used the following methods for collating community knowledge about the status of mollusks in the study area.

In the late 1990s, we administered an in-depth questionnaire with 24 older male and female fishers in the four main villages to determine the most important taxa and those considered rare or threatened and for what reasons. We then conducted focal group interviews with knowledgeable male and female fishers to correlate local vernacular names with the correct scientific names. These data provided the impetus for actions leading to the establishment of the LMMA.

Between 2007 and 2016, we also accompanied older fishers (some of whom no longer actively fished) to selected fishing sites, fishing trips, and diving trips throughout the *iqoliqoli* to confirm geographical locations of reported presence or recovery of selected species and to visually assess species diversity and abundance and habitat health. Most of these trips were carried out by master fisherman (*gone dau*) and local Navakavu co-author Balawa who, as a paid part-time research associate of USP for the past nine years, fished and collected specimens for identification and assessment of their changing abundance. This included the collection of some 200 voucher specimens of new or uncommon taxa for identification and/or curation at the USP Pacific Marine Reference Collection.

Table 1. Number of species within specified higher taxonomic categories that have been seen either for the first time ever or in over 40 years, for the first time in 20–40 years, for the first time in 10–20 years, or were judged to be increasing in abundance (N) or size within the Navakavu *iqoliqoli* since the establishment of the LMMA in 2002. (Based on field survey and interviews with older fishers from 2007–2016). Mollusks are in *italics*.

Taxon	**1st or > 40 yrs**	**20–40 yrs**	**10–20 yrs**	**+N or Size**	**Total species**
Sharks and Rays	3	6	2	1	12
Eels	17	7	4	5	33
Other Finfish	107	87	49	140	383
Echinoderms	15	9	6	19	49
Crustaceans	52	17	10	23	102
Gastropods	*118*	*56*	*12*	*32*	*218*
Bivalves	*25*	*16*	*2*	*20*	*63*
Cephalopods	*4*	*1*	*0*	*3*	*8*
Other Mollusks	*2*	*2*	*0*	*1*	*5*
Worms	4	0	3	2	9
Anemones	2	2	0	2	6
Total	349	203	88	248	888

Over 3500 field and laboratory digital photographs were taken of over 1000 taxa seen or collected over the five years of the study. Copies of these are held by the main authors and with the USP Pacific Marine Reference Collection. Our field research resulted in the compilation of a database of over 1000 different species with associated information on their changing abundance, site locations, and cultural and economic importance over the past 40 years. Our team have presented the results of our study at local and overseas conferences and to the Navakavu and other Fijian communities; these presentations were often given by co-author Balawa, who is a local fisher and a committee member of FLMMA.

Research Findings

As of mid-2016, over 1000 marine species had been identified and recorded in the study database and their recovery status assessed, most of which had been identified as being important or threatened in the original questionnaire surveys in the 1990s. The assessments showed that nearly 900 species of finfish, mollusks, crustaceans, echinoderms, turtles and other organisms had been seen either for the first time ever or in over 40 years, for the first time in 20–40 years, for the first time in 10–20 years, or were judged to be increasing in size and abundance since the establishment of the LMMA in 2002 (Table 1). Approximately one-third of these (nearly 300) species were mollusks. The results supported the earlier questionnaire survey results that had led to the establishment of the LMMA, confirming that the Navakavu *iqoliqoli* was seriously degraded and that many formerly more abundant marine species, at all trophic levels, had disappeared or declined in abundance over the past 40 years. Details of all mollusk species identified as recovering in our study are presented in Supplementary Table 1.

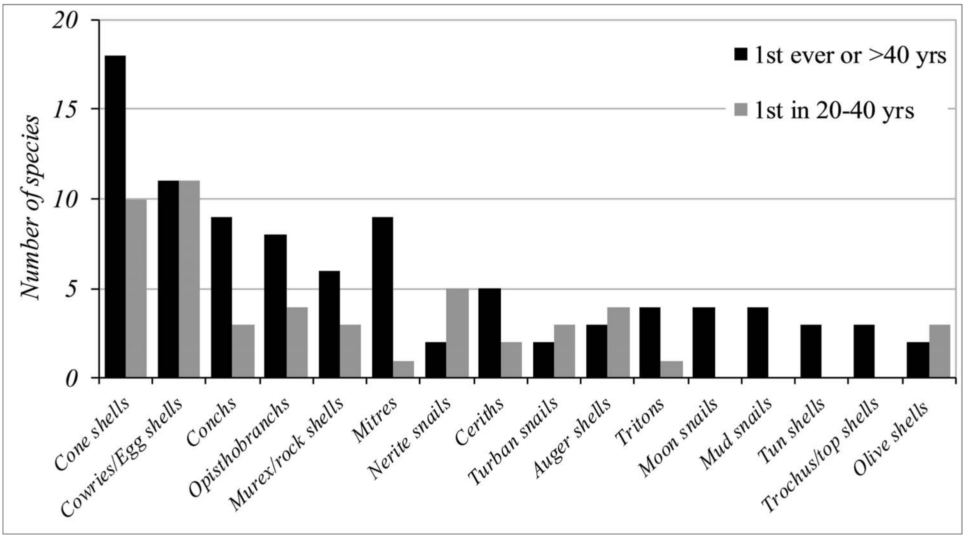

Figure 3. Numbers of gastropod species from selected taxa that have been seen either for the first time ever or for the first time in 20–40 years within the Navakavu *iqoliqoli* since the establishment of the LMMA in 2002. (Based on field survey and interviews with older fishers from 2007–2016).

Gastropods

The perceived return or increase in abundance of 218 species of gastropods (Table 1) has been dramatic. In addition to being the most speciose and highly diversified class of mollusks, many recovering species provide important ecosystem goods and services, particularly as prey for other marine organisms, as hermit crab shells, as ornaments and decorations, and are major sources of food and income. Here we focus on the most speciose or important gastropod taxa/families, which include cone shells, cowries, and conchs (Figure 3), and the conservation status and ecological and cultural importance of notable species (Table 2).

Other gastropod taxa/families have also returned (Supplementary Table 1), many of which are commonly found dead around octopus lairs and favored as hermit crab shells. These include ceriths/*vakaiyare* (Cerithidae), augers (Terebridae), moon snails/*drēdrēvula* (Naticidae), mud snails (Nassariidae), tun shells/*ikoiniuto* (Tonnidae), olive shells/*tewatewa* (Olividae), frog shells/*davuisogasoga* (Bursidae), periwinkles (Littorinidae), limpets (Lottiidae/Nacellidae/Patellidae), vase shells/*bua* (Turbinellidae), seaslugs/*bōsucu* (Onchidiidae), helmet shells/*davui kō* (Cassidae), harp shells (Harpidae), worm shells/*sucuve*/*yalokanilase*/*vevecu* (Vermetidae), and abalones/*vakoli* (Haliotidae).

Bivalves

Sixty-three bivalve species (*kai*) have shown increased abundance since the establishment of the LMMA (Table 1). Many recovering species provide important ecosystem goods and services such as prey for other marine organisms, water purification, and are major sources of food and income. Here we focus on the most speciose or important bivalve taxa/families (Figure 4) and

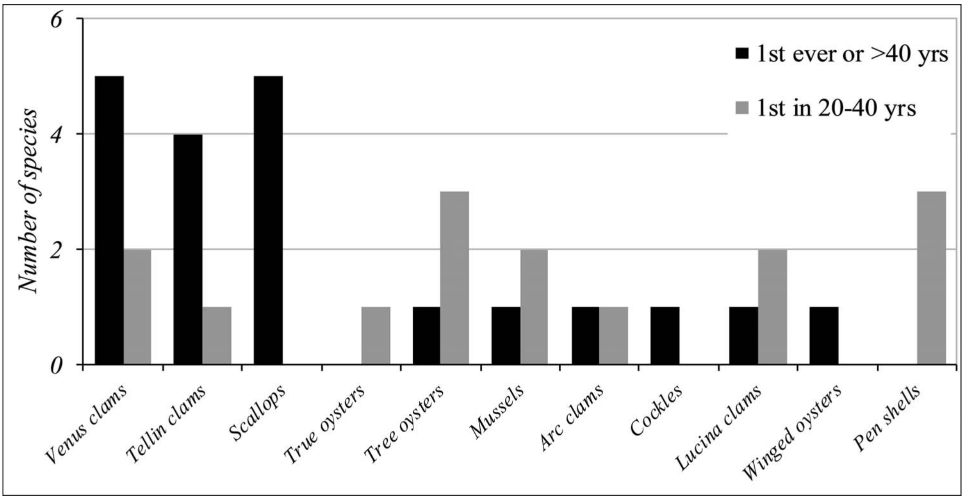

Figure 4. Numbers of bivalve species from selected taxa/families that have been seen either for the first time ever or for the first time in 20–40 years within the Navakavu *iqoliqoli* since the establishment of the LMMA in 2002. (Based on field survey and interviews with older fishers from 2007–2016).

summarize the conservation status and ecological and cultural importance of notable species (Table 3).

Other bivalve taxa/families have also returned, many of which are commonly eaten (Supplementary Table 1). These include penshells (Pinnidae), sanguine clams (Psammobiidae), jewelbox shells/*tukibū* (Chamidae), thorny oysters (Spondylidae), and a *Mactra* species (Mactridae).

Cephalopods

Octopus/*kuita* (*Octopus* spp.) have shown the most obvious recovery. Up to eight species have returned or increased in abundance, three of which have been seen for the first time ever or the first time in over 40 years (Table 1 and Supplementary Table 1). Fishers attribute the dramatic recovery of the common octopus/*kuita* (*Octopus cyanea*) to the establishment of the LMMA and reduction in the use of Derris root/*duva* (*Derris malaccensis*) fish poison and poaching. One notable octopus returnee is the ornate octopus/*kuitaova* (*Callistoctopus ornatus*), a large brown octopus with white spots that had not been caught for over 40 years and was only remembered by the oldest women fishers. The ability of octopus to rapidly recover is supported by Oliver et al. (2015), who showed that temporary closures to octopus fishing in remote southwest Madagascar led to increases in octopus catches and increases in village-level income of almost 90%. Two squid species, the bigfin reef squid/*kuitawainicina* (*Sepioteuthis lessoniana*) and the broadclub cuttlefish/*kuitanunu* (*Sepia latimanus*), have also reappeared and increased in abundance.

Other Mollusks

Two chiton species (class Polyplacophora) were among the returnees. The jeweled chiton/*tadruku* (*Acanthopleura gemmata*) returned to abundance in 2011

Table 2. Conservation status of major taxa/family of gastropods in the Navakavu *iqoliqoli*. (Based on field survey and interviews with older fishers from 2007–2016).

Taxa/Family/Species	Returned?	Uses/Ecology/Notes
Cone shells/*vuru* (Conidae)		
Conus imperialis, C. *litteratus,* C. *leopardus,* C. *marmoreus,* C. *miles,* C. *quercuinus,* C. *stiratus*, C. *vexillum,* C. *virgo*	Yes	Eaten; some included in mixed baskets for sale; sold as ornamental/specimen shells; Octopus prey-found in lairs/middens; used as hermit crab shells.
C. figulinus	*No*	Last seen in the late 1970s.
True cowries (Cypraeidae)		
Cypraea argus, C. testudinaria, C. aurantium (*bulikula*), *C. tigris* (*bulivakamatana*), *C. annularis* (*bulibuli*), *C. caputserpentis* (*bulimasi*), *C. moneta* (*bulitabace*)	Yes	Largest for ceremonial & handicrafts; others sold as ornamental/specimen shells; Some reported only around octopus lairs or as hermit crab shells. *C. tigris* sometimes eaten.
C. eburneus (pure white cowrie/ *bulinimeke*)	Yes	Highly valued as a neck amulet for women dancing the traditional Fijian *meke*.
Egg shells (Ovulidae)		
Calpurnus verrucosus (umbilical ovula/ *bulinimeke*)	Yes	Highly valued as a neck amulet for women dancing the traditional Fijian *meke*. Found for the first time in over 40 years in octopus lair/middens on Namo Reef.
Ovula ovum (white eggshell cowrie/ *bulivula*/*bulinitanoa*/*bulinivale*)	Yes	Tied to the end of coconut fiber sennit (*magimagi*) on traditional kava bowls (*tanoa*); used to decorate traditional chiefly houses (*bure*); sometimes eaten.
Conches (Strombidae)		
Lambis lambis (spider conch/*yaga*)*, L. truncata* (Seba's spider conch/ *tinaniyaga*)*, L. crocata*, *L. scorpius, Strombus gibberulus* (gibbose conch/ *gera*)*, S. bulla*, *S. lattisimus*, *S. lentiginosus*, *S. sinuatus, Euprotomus aurisdianae, Conomurex luhuanus* (blood-mouth conch/*tivikea*)	Yes	Sold & eaten locally as delicacies; Decorative; sold as ornamental/ specimen shells; Octopus prey-found in lairs/middens.
Lambis chiragra (Chiragra spider conch/ *yagatudē*)	*No*	Last seen in the late 1970s.
***Opisthobranch*/Nudibranchs (Hexabranchidae)**		
Hexabranchus sanguineus (Spanish dancer/*lobelobenikuita*)	Yes	Seen for the first time in over 40 years.
***Opisthobranch*/Seahares (Aplysiidae)**		
Stylocheilus striatus (striated seahare/ *kotia waiika*)*, Dolabella auricularia* (blunt-ended seahare/*kotia*)	Yes	Eaten as delicacies; fished out by the late 1960s & early 1990s, respectively. Collected again in late 2011.
Mitres (Mitridae)		
Mitra spp.		Octopus prey-found in lairs/middens; sold as ornamental/specimen shells.
Mitra mitra (episcopal mitre/ *isogonitavaya*)	Yes	Used to cork gourds (large fruit of the calabash gourd tree, *Crescentia cujete*) used to carry water (*dilo*).

Table 2. Continued.

Taxa/Family/Species	Returned?	Uses/Ecology/Notes
Nerite snails (Neritidae)		
Nerita spp. (*sisici*, *matadavila*)	Yes	Important algal grazers, help to keep the coastal zone waters clear; reportedly disappeared due to overharvesting & pollution due to effluent from the nearby cement works; eaten; attractive species are sold as shells; used as hermit crab shells.
N. signata (reticulate nerite/ *sisicibatidamu*)	Yes	Traditionally fed to women as a treatment for those who had difficulty producing breast milk.
Turban snails (Turbinidae)		
Turbo spp.		Eaten.
T. petholatus (tapestry turban/ *matakarawa*)	*No*	Most prized turban snail, referred to as *matakarawa*, the chiefly word for the *tabua*, the ceremonial sperm whale tooth.
Tritons (Cymatidae)		
Charonia tritonis (triton trumpet/*davui*)	Yes	Returned after over 30 years; blown traditionally like trumpets to announce important events such as gatherings, births, deaths, traditional dances (*meke*) & the return of fishermen; important traditional ceremonial exchange items between coastal & inland communities on important occasions, such as the installation of chiefs or chiefly funerals.
Cymatium & *Septa* spp.	Yes	Returned after > 40 years.
Trochus & Top shells (Trochidae)		
Tectus niloticus (trochus/*sici*); *Tectus pyramis* (top shell/*toura*)	Yes	Eaten & sold; sold as ornamental/ specimen shells/to buyers for use in button & handicraft manufacture; Octopus prey-found in lairs/middens; used as hermit crab shells.

after disappearing in the 1980s due to overexploitation and *Lorica cf. volvox* was seen for the first time. Tusk shells (Scaphopods) are also among those that were known only to older fishers, but have returned after disappearing.

Mollusks Found as Dead Shells

Several mollusk species, in particular gastropods, were found as dead shells around octopus lairs or elsewhere or as shells inhabited by marine and land hermit crabs (Figure 5). These data indicate the important ecological interrelationships that mollusks have with other marine organisms, particularly as octopus prey and as hermit crab shells. Mollusks' role in providing food and shelter to other species underpins their importance in the trophic restructuring of marine ecosystems.

Table 3. Conservation status of major taxa/family of bivalves in the Navakavu *iqoliqoli*. (Based on field survey and interviews with older fishers from 2007–2016).

Taxa/Family/Species	Returned?	Uses/Ecology/Notes
Venus clams (Veneridae)		
Periglypta puerpera (youthful venus clam/*kaidawa*)	Yes	Highly valued edible bivalve & important source of income for women fishers; heavily overfished in the 1970s.
Tapes litteratus (lettered venus/*tinanikaidawa*), *Gafrarium pectinatum* (tumid Venus clam/*waivou*)	Yes	Eaten & sold.
Tellin clams (Tellinidae)		
Tellina spp. Especially *T. palatum* (palate tellin/*kaitasirisiri* & *T. remies* (Remies tellin/*tinanikaigasa*)	Yes	Important food shellfish returning after 30 years.
True oysters (Ostreidae)		
Crassostrea gigas (giant Pacific oyster/*diōnivavalagi*)	Yes	Non-indigenous species introduced from Japan & California from 1969-1971 (Eldridge 1994), which has become abundant & an important edible resource.
Saccostrea cucullata (hooded oyster/*diōvatu*/*diōniveitiri*)	Yes	Returning on intertidal & supratidal rocks & mangroves.
Mussels (Mytilidae)		
Modiolus philippinarum (Philippine mussel/*drivi*), *Septifer bilocularis* (box mussel/*kukuvatu*), *Modiolus modiolus* (horse mussel/*kukunivavalagi*)	Yes	Eaten.
Ark clams (Arcidae)		
Anadara antiquata (antique ark clam/*kaikoso*)	Yes	Fiji's most important marine shellfish sold, which began to decline in the early 1970s.
Arca ventricosa, *Barbatia amygdalumtostum*, *B. velata* (*kaikosonivatu*)	Yes	Eaten.
Cockles (Cardiidae)		
Lyrocardium sp.	Yes	Seen for the first time.
Fragum unedo (unedo cockle), *Trachycardium* spp. (*ikarininiu*)	Yes	Used to scrape coconuts before metal scrapers were introduced.
Winged oysters (Pteriidae)		
Pinctada margaritifera (black-lipped pearl oyster/*civa*), *Pteria avicula* (black-winged oyster/*melamela*), *P. penguin* (penguin-winged oyster/*melamela*)	Yes	Highly valued; eaten; sold as ornamental/specimen shells.
Giant clams/*vasua* (Tridacninae)		
Tridacna maxima (elongate giant clam), Tridacna *squamosa* (fluted giant clam)	Yes	Highly sought after commercial seafoods.

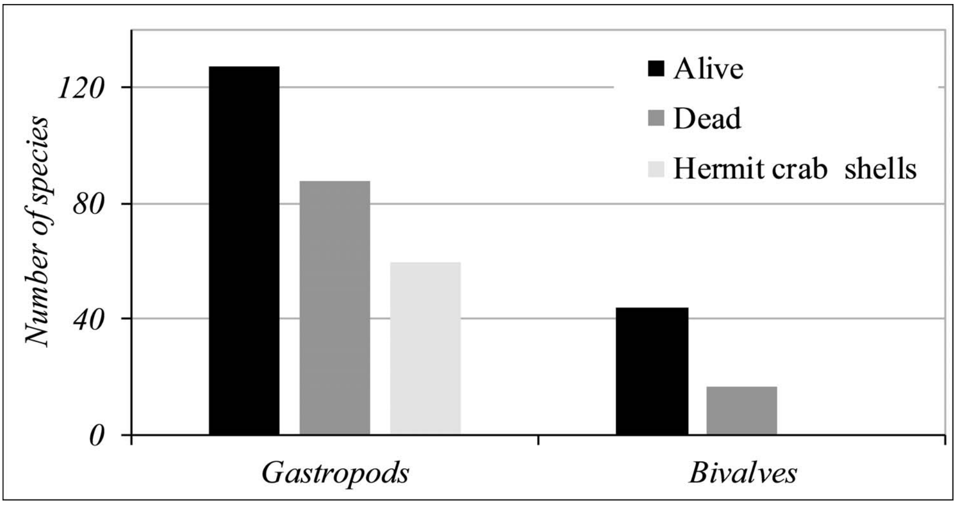

Figure 5. Number of gastropod and bivalve species found alive, dead, or as hermit crab shells. (Based on field survey and interviews with older fishers from 2007–2016).

Discussion

The compiled results from this study show that mollusks are one of the most speciose taxa in the Navakavu *iqoliqoli* and that they are highly impacted by overexploitation and ecosystem breakdown. Our results indicate that just under 300 mollusk species have started to recover after the establishment of the LMMA (Table 1). This total includes over 200 gastropod species, over 60 bivalve species, and a range of cephalopods and other mollusks.

This study validated earlier biological survey findings by Comley et al. (2006), Hubert (2007), and Cakacaka (2008), who documented the increasing abundance of a limited range of economically important finfish and only two shellfish (*Tridacna* spp. and *Anadara antiquata*) as a result of the establishment of the LMMA in 2002. Our study also identified a wide range of other taxa that have returned, including the increasing abundance of many lower trophic-level species, such as bivalve mollusks and algal grazing gastropods, including *Dolabella auricularia* and *Stylocheilus striatus*, that provide an example of ecosystem recovery and trophic restructuring which is highly dependent on sufficient numbers of these lower trophic level taxa. Our study also supports increasing evidence that indicates that biodiversity losses in marine ecosystems are still reversible if conservation and sustainable fishing interventions are put in place (Jackson et al. 2001; Pandolfi et al. 2003; Worm et al. 2006). These conservation initiatives often result in increases in species richness that will enhance the ability of marine ecosystems to provide the goods and services that underpin food and livelihood security and provide resilience to outside perturbations.

Table 4. Pressures contributing to the decline in composition and abundance of marine biodiversity and ecosystem services in Navakavu as identified by local fishers and community members surveyed from 2007–2016.

Year	Pressure (*Industrial/commercial/ traditional/subsistence/natural*)	Activity/Ecological effect
1950s-80s	Use of Derris root/*duva,* bleach, insecticides to poison fish.	Highly toxic to all forms of aquatic fauna.
1953	Earthquake & tsunami causing collapse of part of Suva Barrier Reef & subsequent submarine landslide (Houtz 1962; Rahiman et al. 2007).	Extensive devastation to the subtidal & intertidal biodiversity.
1960s-70s	Rapid growth in tourism (passenger liners).	Increased demand on shell jewelry & ornamental, souvenir, & specimen seashells.
	Promotion of commercial artisanal fishing & tourism (Tuquiri 2010).	Intensified commercial fishing for all marketable species resulting in increased fishing pressure.
1962-1984	Sand mining & uncontrolled release of waste by nearby cement factory.	Removal of bottom sediments & associated mollusks in the Navakavu *iqoliqoli*.
1970s	In-migration & re-settlement of people on Navakavu lands.	Exacerbated overfishing & depletion of mollusk resources not previously exploited at such levels.
1972	High waves & storm surge from Severe Tropical Cyclone Bebe scouring the lagoon floor.	Displaced surface & infaunal mollusks inside the barrier reef. Freshwater runoff & sediment smothered Navakavu nearshore.
1980s	Rapidly increasing Asian market & local Asian population.	Additional market pressure & demand for highly valued mollusk species (giant clams, octopus, trochus, pearl shell, triton trumpet shell, helmet shells).
	Increasing urban & industrial pollution & sedimentation.	Degradation of shellfish populations.
1995	Opening of road connecting the Navakavu area to Suva by land.	Further fueled commercialization of fisheries products.

Potential Drivers of the Loss of Mollusks

Based on in-depth consultations over time with older fishers in Navakavu, we identified several drivers that have contributed to the historical decline in fisheries, biodiversity, and ecosystem services in Navakavu. The main drivers perceived by fishers are the increasing need for food and livelihood security, industrial and commercial development, and environmental changes. Study participants attributed species disappearances and declines mainly to overfishing, exacerbated by increasing population, commercialization of a previously subsistence fishery, destructive fishing techniques, habitat degradation, and severe natural disasters (Table 4). The active promotion of commercial artisanal fishing and tourism by government and development organizations included the subsidization or provision of new technology, including ice plants, boats, and outboard engines and fishing gear, resulting in increased catches with less effort (Tuquiri 2010). The use of dynamite fishing, fish poisons, SCUBA, waterproof night diving lights, faster long-range boats, and poaching have also played central roles in the disappearance of mollusk resources. The most destructive fishing technique over the long term seems to have been the use of Derris root/*duva*, a traditional rotenone fish poison, which remains toxic in water for 2–6 days (Andrews and Holthus 1989; Hien et al. 2003; IPCS 2007; Johannes 1982). Although its use has been banned in Fiji, it is still used illegally when fishing in shallow lagoon areas (Vunisea 1997). Adding pressure to local population growth was the in-migration and the subsequent re-settlement of highly skilled fisher people from Fiji's outer islands on Navakavu lands, where they were allowed to fish. Other serious factors included waste from defouling operations (vessel hull cleaning), periodic oil spills, and release of spent oil from vessels moored in Suva Harbor, up-current from Navakavu. As these drivers continue to intensify, their associated pressures (Table 4) will also be expected to intensify; however, some have decreased over time as a result of management interventions currently in place. These include a major decrease in the use of Derris root/*duva* and destructive fishing techniques and the cessation of sand mining.

Preservation of Local Vernacular Knowledge and Conservation Ethic

Our survey recorded local vernacular names and other seriously threatened local taxonomic and ecological knowledge, much of which was unknown to the current younger generation. The recordings and resultant community discussions served to reinforce positive conservation outcomes and strengthen the resolve of the Navakavu community to maintain their adaptive LMMA management efforts. This information was also presented to scheduled classes at the local Waiqanake Junior Secondary School as a foundation for long-term understanding of the marine environment and education for sustainable development.

Ecological Role of Mollusks

This study highlights the important role mollusks play in the health of coastal marine ecosystems. In fact, mollusks are a useful basis for assessing the role of trophic restructuring in the return of finfish species because mollusks are among the preferred prey of a wide range of finfish (Supplementary Table 2) (Randall 2005) and other marine organisms. Of importance is the availability of empty gastropod shells that are salvaged by land and marine hermit crabs, which demonstrates the interrelationship among mollusk, hermit crab, and octopus populations (Figure 5). The availability of empty shells at any given place depends on the relative abundance of gastropods and hermit crabs matched for size and the population of organisms, such as octopus, that prey upon gastropods and leave the empty shells intact so that hermit crabs can reoccupy them (Tricarico and Gherardi 2006).

All of these species connections constitute a critical foundation for the trophic restructuring of marine ecosystems (Duffy 2006; Thaman 2004; Worm et al. 2006). The results support Jackson et al.'s (2001) contention that the restoration of reef ecosystems, just like their slow trophic collapse due to generations of overfishing, may take many generations to restore to health. Our study results are in line with those of other scientific surveys (Cakacaka 2008; Comley et al. 2006) that find few large consumers on any reefs, even after over 15 years of conservation, and further re-enforces the idea that ecological recovery takes many generations and must start from the lowest trophic levels. Among the lowest trophic levels are smaller fish, crustaceans, mollusks, and other organisms that make up the bulk of the diets of some mid-level consumers.

Implementing a Transdisciplinary Community-based Approach

The current Navakavu study shows that taxon-by-taxon community-based assessments of marine biodiversity can provide important "missing" time-depth information about changes in marine ecosystems, drastically shifted environmental baselines, formerly present organisms that were unknown to the current generation, drivers of the loss of biodiversity, and the impacts of marine conservation. Such information cannot be provided by short-term modern biological sampling alone. In particular, studies such as this one provide data on 1) species composition and abundance and the state of the marine environment before the onset of serious commercial and subsistence overfishing exacerbated by other drivers; 2) the nature, timing, and impact of overfishing and other drivers of environmental change on different taxa; and 3) species that are returning or have increased in abundance or size class and the associated potential for the long-term recovery and trophic restructuring of managed marine ecosystems.

The transdisciplinary community-based approach used in the Navakavu study capitalized on the time-depth nature of local knowledge and awareness that is often not paralleled in western science. Trying to build synergies between local knowledge and modern science at this level of taxon-by-taxon detail may be the only means of really assessing how fisheries have changed over the long term at the local community-level and how multi-species conservation and trophic restructuring can be realized through sustained long-term establishment, monitoring, and maintenance of LMMAs. The approach, based on traditional management practices backed up by scientific monitoring by the various stakeholders, has proved to be an important factor in the visible success of the LMMA in addressing overfishing in their *iqoliqoli*. The success of the management at Navakavu is remarkable, considering the problems that were being faced: a degraded fishing area nearby a source of pollution and fishing pressure from the city of Suva (Gillett 2014). One of the main indicators of this success was the reappearance of species that had not been seen for many years. Therefore, the ongoing taxon-by-taxon study of the return or increasing abundance of a wide range of species serves to monitor the long-term success of the LMMA and, in turn, encourages the commitment of the people of Navakavu to the LMMA.

As stressed above, these outcomes and conclusions strongly support a core principle of the IPBES Conceptual Framework: that building synergies between local knowledge and modern biological and conservation science may be the only way of assessing the changing conservation status of biodiversity as a basis for informing enlightened biodiversity conservation policy (Díaz et al. 2015). This has shown to be particulary true in the Pacific Islands, where most coastal areas are owned and/or used and managed by Indigenous communities who have their own nature-based languages, taxonomies, and traditional management and governance models. Such is the case of Navakavu, where local communities and outside scientific and conservation partners have built successful partnerships to foster adaptive co-managment of biodiversity and ecosystem services for the benefit of future generations, a sentiment so passionately and appropriately expressed in the moto of the *Vueti Navakavu* LMMA: *Kedra sasalau tawamudu na noda kawa* (Everlasting fish for our future generations).

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