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Source: Pacific Science, 67(3):425-440. 2013.
Published By: University of Hawai'i Press
DOI: http://dx.doi.org/10.2984/67.3.9
URL: http://www.bioone.org/doi/full/10.2984/67.3.9

Historical Patterns of Resource Exploitation and the Status of Papua New Guinea Coral Reefs[1]

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Abstract: Understanding human drivers of exploitation within the context of historical baselines can assist in better management of natural resources. Retrospective studies provide insight into the scale, nature, and timing of human influence on reef ecosystems. Using Papua New Guinea as a model, we assessed human influences on the historical status of reef resources through time. Reef resources were divided into seven ecological guilds, assessed over seven cultural periods and in reference to seven types of human influences. Ranking of ecological status and human influence was performed based on extensive bibliographical research. Evidence for periods of sustainability and depletion were found throughout historical and modern periods. More recently, acceleration in the rate of resource depletion has occurred as a result of increasing pressure at unprecedented scales. Subsistence lifestyles are becoming unviable or unattractive since the introduction of the cash economy during colonial times. Current challenges such as providing livelihood options and sustaining replenishment rates of reef resources have arisen from a long history of overexploitation that preconditioned the current status of reef resources under an economic climate of increasing demand for these resources. Studies of past human exploitation of reef resources can help to overcome the shifting baseline syndrome for fisheries management in marine ecosystems and help characterize the scale and intensity of human drivers influencing resource exploitation.

The health of coral reefs has increasingly become a concern due to the ecological, economic, and cultural values embedded in these ecosystems (Moberg and Folke 1999, Hatcher and Hatcher 2004, Corvalan et al. 2005). The history of coral reefs shows evidence for natural cycles of decline and recovery over multiple temporal scales (Grigg and Dollar 1990, Pandolfi 2002, Pandolfi and Jackson 2006); however, as human population and the demand for reef products and services continue to increase, humans now play an important role in driving the health of coral-reef ecosystems (Nystrom et al. 2000, Hughes et al. 2003, Bellwood et al. 2004, Richmond and Wolanski 2011). As human and natural change on coral reefs continues to result in ecosystem degradation, an understanding of historical ecological baselines and the history of human influences on reefs is important for management and ongoing studies of status and trends on coral reefs.

Identifying cause and effect linkages between human activities and reef health is problematic because unlike many natural phenomena, it is not possible to isolate and

[1] This article is part of a special issue of *Pacific Science* (vol. 67, no. 3) on the Human Dimensions of Small-Scale and Traditional Fisheries in the Asia-Pacific Region, guest editors John N. (Jack) Kittinger and Edward W. Glazier. This research was funded by an Australian Research Council Centre of Excellence for Coral Reef Studies grant (to J.M.P.). Manuscript accepted 8 September 2012. **Authors' Note:** Supplemental materials available only on BioOne (http://www.bioone.org/).

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Pacific Science (2013), vol. 67, no. 3:425–440
doi:10.2984/67.3.9 (Includes online supplements)

manipulate variables experimentally (Diamond and Robinson 2010). Recently, however, retrospective assessment techniques, such as the use of paleontological, archaeological, and historical records as well as indirect, interdisciplinary approaches (e.g., use of anecdotal newspaper accounts and community surveys), are emerging as viable tools to evaluate the history of marine coastal resources (Rosenberg et al. 2005, Lajus 2008, Lotze and Worm 2009, McClenachan 2009). Such approaches help improve our understanding of the way human use and perception of reef resources affects their status and ecological trajectory. For example, Pandolfi et al. (2003) used a diverse set of sources from historical sources to examine ecological trends of coral-reef ecosystems through time. This global assessment of reef regions revealed a long history of anthropogenic impact on reef resources that are now far from their original pristine condition. Although that study provided a rough long-term measure of the status of reef resources with respect to human use, it did not investigate in detail how human societies shape and are in turn shaped by resource status, as recent publications are beginning to address (Kittinger et al. 2011).

Here we focus on the history of human use of coral reefs in Papua New Guinea (PNG). Among Pacific island nations, PNG has the longest history of human settlement, around 50 ka (Allen 1997), and a high diversity of cultures and landscapes. More recently, the country has increased its reliance on marine resources for subsistence and income generation (Kearney 1976, Hyndman 1993, Kaly 2006). A large body of social and cultural values is associated with the PNG reef system (Allen and Bourke 2009). Thus, PNG provides an excellent system to investigate human-environmental interactions in coral reefs over long time scales.

Previous attempts to study the status of PNG's reef resources have focused on single species, such as turtles (Spring 1980, 1981, 1982*a*, *b*), dugongs (Hudson 1986, Kwan et al. 2006) or selected fisheries (Wright and Richards 1983, 1985, Dalzell and Wright 1986). Toward the 1990s a more comprehensive assessment of reef resources emerged (Huber 1994), but a historical perspective was still lacking. Later reef assessments provided greater geographic and temporal coverage and included a larger number of species (e.g., Munday 2000, Allen et al. 2003, Miller and Sweatman 2004). However, only recently have studies begun to integrate cultural and socioeconomic factors into the ecological status of coral reef resources from PNG (e.g., Cinner et al. 2005, Kinch 2005, 2006, Cinner and McClanahan 2006, Kaly 2006).

In this study we use PNG as a model Pacific island nation to: (1) provide a historical assessment of the status of reef resources, and (2) improve our understanding of the nature of human resource exploitation and its ecological consequences through historical analysis. Our analysis is constructed within a framework of the relative importance of different types of human influences on reef resources throughout history.

MATERIALS AND METHODS

Study Site

Papua New Guinea lies in the western Pacific (6° 00′ S, 147° 00′ E) within the Coral Triangle of biodiversity (Allen and Werner 2002). With more than 600 islands, its coastal area extends over 17,000 km^2 (Bualia and Sullivan 1990) occupied by approximately one-third of its population (nearly 2 million people). The country is surrounded by over 40,000 km^2 of coral reefs, where every type of reef habitat (fringing, lagoon, etc.) is represented (Callick and Tait 1993). We divided the country into 14 representative reef regions based on political, geographic, demographic, and economic characteristics, and distribution of natural resources (Table 1).

Historical Assessment of Papua New Guinea's Coral Reefs

We used a previously developed retrospective assessment technique (Pandolfi et al. 2003) to examine the trajectory of PNG's coral-reef ecosystems through time. We considered

TABLE 1

List of Representative Reef Regions Assessed in This Study

Region[a]	Includes Also
Manus	Admiralty Islands
Rabaul	Rabaul, Duke of York, Lak, Gazelle Peninsula
Madang	Long Island, Hansa Bay
MBP	Samarai, Alotau, Louisiade Archipelago, Trobriand Islands, Pocklington reefs
POM	Port Moresby, Hula, Motupore Island, Bootless Bay, Yule Island, Papuan Barrier Reef
Morobe	Tufi coast, Vitiaz Straits, Huon Peninsula, Kamiali
Kimbe	Talasea, Hoskins, Willaumez Peninsula, and other sites within West New Britain
Kavieng	Tigak Islands, New Hanover
Mussau	St. Matthias Island Group
East New Ireland	Offshore Tabar to Feni
Bougainville	Buka
Daru	PNG Torres Strait Border and other sites within Gulf Province
NW, Hermit Islands	Wuvulu to Ninigo Islands, Hermit Islands
Sepik delta	Vokeo and Schouten Island group

Note: Division was based on political and geographic characteristics, distribution of natural resources, and human activity and development.

[a] MBP, Milne Bay Province; POM, Port Moresby Province.

seven ecological guilds in PNG's reefs defined either by their structural importance (corals and sea grasses) or by their trophic role and size: large herbivores (>1 m), small herbivores (<1 m), large carnivores (>1 m), small carnivores (<1 m), and suspension feeders. A time line consisting of seven cultural periods: Prehuman (50,000 y.b.p.), Hunter-gatherer (50,000–9000 y.b.p.), Agricultural (9000 y.b.p.–1520), Colonial Occupation (1521–1849), Colonial Development (1850–1913), Early Modern (1914–1950), and Late Modern (1951–present) served as a temporal framework to assess the status of the ecological guilds. During each cultural period, a guild was assigned one of five possible ranks (1, pristine; 2, abundant/common; 3, depleted/uncommon; 4, rare; 5, ecologically extinct) to define its ecological state (details on ranking ecological states can be found in Supplemental Appendix 2 and Pandolfi et al. 2003). The resultant matrix includes seven cultural periods and seven ecological guilds, which provided a representation of the status of PNG's coral-reef ecosystems through time (Supplemental Appendix 5). Several studies have successfully adopted this method to analyze trends in time for marine ecosystems (e.g., Lotze et al. 2006, Kittinger et al. 2011).

Human Influence Indices

The nature of human influence on PNG reefs was partitioned into seven indices (Table 2). The seven Human Influence Indices (HII) were defined as broad categories encompassing impacts to coral-reef ecosystems: (1) Demographic (DEM), (2) Introduction to "novelty" (NOV), (3) Water quality degradation by anthropogenic sources (WAT), (4) Degree of reliance on marine resources (REL), (5) Destructive practices (DES), (6) Long-term, sustained exploitation (LON), and (7) Customary Marine Tenure degradation (CMT). Six of these include the most obvious, commonly encountered threats to reef resources (e.g., dynamite fishing, anchor damage, increased runoff) as well as other more cryptic and indirect aspects of reef degradation (e.g., availability of alternative protein sources such as pork to coastal villages; resource particularly appreciated in indigenous folklore such as dugong). The NOV index was applied at the village level: a village could acquire novel fishing technology by

TABLE 2

Human Influence Indices (HII) Used for the Characterization of Human Footprint on the Ecological Status of the Coral Reefs of Papua New Guinea

Parameter of Influence	Definition	Examples
Demographic (DEM)	Changes in population characteristics: number of people, their distribution and composition	Increasing population density, rural-urban migration, intervillage marriages, coastal migration
Introduction to "novelty" (NOV)	Impact originating from the introduction of novel ways of exploiting or perceiving a resource	Introduction of cash economy, novel markets such as European (bêche-de-mer) or Asian (shark fin), industries and fishing technologies (outboard motors, refrigeration, etc.); changes in diet influenced by Christian missions
Anthropogenically derived water quality degradation (WAT)	Human influence resulting in deterioration of waterways in or near reefs	Increased erosion and runoff from logging and agricultural practices, poor disposal of sewage and mine tailings, urban pollution (industrial waste into waterways)
Reliance on marine resources (REL)	The degree to which a human group (village, community) relies on a resource for livelihood	Availability of alternative protein sources such as farm animals or imported canned products, availability of alternative economies such as agriculture products, monopolization of resource, remoteness of region
Destructive practices (DES)	Impact to the structure of the reef or direct mechanical destruction of organisms caused by human activities	Mechanical (reef walking, anchor damage, trawling), cyanide/derris root poisoning, dynamite fishing, mangrove clearing
Long-term sustained exploitation (LON)	Influence on the resource coming from a traditional, long-term association with it regulating how the resource is valued and used	Resource forms part of aboriginal folklore, Traditional Ecological Knowledge (TEK) such as dugongs or turtles; special fondness for resource; exploitation observed from archaeological records through to colonial times such as giant clams and oysters
Customary Marine Tenure degradation (CMT)	Breakdown in the set of rules and rights practiced by indigenous traditional communities	Traditional tenure no longer respected, rituals surrounding resource exploitation falling into disuse, younger-elder generation gap in resource's perception and use

contact with previously unknown sources, such as another village or another group of people such as European explorers, Chinese entrepreneurs, pirates, or Christian missionaries. A seventh index accounts for the breakdown of Customary Marine Tenure (CMT), an important component of reef resource use and management in PNG (Johannes 1978).

We generated a matrix by scoring how many times a human influence index was mentioned in the literature as being associated with a guild's status for each cultural period. For each of the guilds, a cultural period-region judgment was made to assign the number of times each HII was associated with the resource in the literature reviewed. A measure of the total number of entries for each cultural period-guild combination was incorporated to keep track of potential biases in our approach arising from the limited number of references reviewed. Thus, a single reference from the literature could generate a score in more than one HII and a score in more than one guild or cultural period (see Supplemental Appendix 3 for more details). A single reference could provide more than one count when: (1) a reference alluded to more than one group within a guild, (2) a reference regarded more than one region, or (3) a reference contained information for more than one period. To avoid potential biases arising from the difference in the number of references available from each location, the relative abundance of HII counts per reef region

provided the final number in data matrix used for analysis.

Although the methodology used by Pandolfi et al. (2003) helped to obtain a trajectory for the ecological state of PNG's coral reefs from Prehuman times until the present, only the three most recent cultural periods (Colonial Development, and Early and Late Modern) were used in recording the human influence associated with such states. The exclusion of the earlier periods was due to lack of data associated with the difficulty and uncertainty of inferring human activity from archaeological data. The sea-grass guild lacked sufficient data to be included in any comparative analysis between ecological state and human influence. Thus, the final matrix illustrating the effect of human influence on resource trajectory was composed of six ecological guilds and three cultural periods (Supplemental Appendix 6).

Data Sources

We compared the reefs of PNG with the status of other reefs worldwide using data from the Pandolfi et al. (2003) study of 14 regions, plus sites from Hawai'i (Kittinger et al. 2011), Fiji (unpubl. data), and Vanuatu (unpubl. data), for a total of 23 reef sites worldwide. Information sources used in the assessment of reefs in PNG and their associated human influence were multidisciplinary. For the Hunter-Gatherer and Agricultural periods, data were derived largely from archaeological records, prehistoric studies, linguistic studies of aboriginal folklore, and historical geographic studies. Reef condition during the Colonial Occupation and Colonial Development periods was assessed based on anecdotal accounts from early European explorers and naturalists in combination with colonial government reports and ethnographic research. For the last two periods we used formal scientific reports, in-country National Fisheries Authority (NFA) documents, and detailed Rapid Assessment Programs (RAP) of marine resources. Where cultural periods could not explicitly be related to a country or region, alternative periods were used and then temporally correlated with the general framework (e.g., for Hawai'i, see Supplemental Appendix 5). To supplement the literature review, we incorporated personal communications with members of the marine resources branch of the Department of Environment and Conservation (DEC), the NFA of PNG, and nongovernmental organizations involved in marine resource assessment and conservation (World Wildlife Fund-South Pacific, Conservation International-Melanesia, The Nature Conservancy). A full list of the references used for the ecological status assessment and associated human influences is available in Supplemental Appendix 4.

Data Analysis

We used principal component analysis (PCA) to analyze the data matrix obtained from the historical assessment of each guild's ecological state through time for each of the 23 reef sites, following Pandolfi et al. (2003). In addition, we assessed the trajectory of each guild within PNG also using a PCA (R Package version 1.4.0, 2000 [R Development Core Team 2008]). Reef regions were defined as pristine for the initial (Prehuman) period, and for purposes of comparison we included a hypothetical reef for which all seven guilds were ecologically extinct (sensu Pandolfi et al. 2003). Because of the descriptive nature of historical sources on human indicators, qualitative assessments were used to present and discuss the effect of human influence on ecological state of reef resources. Recent studies further support the validity of using anecdotal records to assess past abundances of marine resources (Al-Abdulrazzak et al. 2012).

RESULTS

Status of PNG Coral Reef Resources through Time

We found a substantial body of literature providing evidence for a long history of exploitation of reef resources since first human colonization in the Pleistocene. The PCA resulted in the collapsing of the variance of ecological state among guilds into a few axes, which we evaluated as a proxy of reef ecosystem

health at each region and at each period. Only the first principal component was significant (Plate I), and it explained over 85% of the variance. Out of 23 global coral reef regions, PNG is situated 10th along a reef degradation scale (Figure 1). The reefs of PNG are more degraded than reefs in the Hawaiian Islands and the Great Barrier Reef; however, they appear to be in better condition than present-day Caribbean sites. It is surprising that during the Agricultural period the reefs of PNG were more degraded than in the later Colonial and Early Modern periods.

A PCA of the PNG guilds through time shows a clear decline in all guilds through time (Plate II). However, the large and small herbivores, small carnivores, and suspension feeders have all shown some recovery in their ecological status at various times in the past (Plate II), for example in the Early Modern period as compared with the earlier Colonial Development period. For corals, large carnivores, and, to a lesser extent, large and small herbivores, the ecological status during the Late Modern time declined markedly. The greatest degradation during Modern times is observed for the large herbivore and suspension-feeder guilds. At the same time, the seagrass guild appears to be less degraded than other guilds (but see study limitations in Supplemental Appendix 1).

Human Influences on PNG Reef Resources through Time

Archeological records and accounts by early explorers show evidence for resource depletion among precolonial societies. Examples of this can be found in shell middens, where, as predicted by optimal foraging theory (e.g., Winterhalder and Smith 2000, Grayson 2001), a decrease in larger, high-return species concomitant with an increase in lower-return species intake was observed (Figure 1). This pattern has been found in several regions of PNG during the Hunter-Gatherer period, including New Ireland (Gosden and Robertson 1991), Central Province (Swadling 1977*a*), and New Britain (Green and Anson 2000).

Although suspension feeders and small herbivores display a similar human influence profile through time, the extent to which the various human influences were associated with the ecological state of particular guilds varied widely through time. During Colonial times, most guilds were predominantly affected by the novelty and reliance indices (Plate III). Besides the influence of these two indices, the large herbivore guild was affected by degradation of CMT systems since the Colonial Occupation period. Long-term sustained exploitation was also important for most guilds over most time intervals. Destructive practices and the reliance and novelty indices were important drivers of degradation of the large carnivore guild during the Late Modern period. For large herbivores, large carnivores, and small carnivores, the long-term sustained exploitation index increased its influence in Modern times. Destructive practices appeared to have the most effect on corals in the Early and Late Modern periods and organisms within the large carnivore guild in the Late Modern period (Plate III).

DISCUSSION

Ecological Status of PNG Coral Reefs in a Global Context

The ecological trajectory of reef resources in PNG is governed by the interaction of human history and natural climatic cycles. Coral reef resources of PNG display a long history of human exploitation, from –50,000 y.b.p. to the present day. The size of the country and its complex geography, where over 800 languages and cultures are represented (Lewis 2009), provide a setting where any given resource could be overexploited in one region and conserved in another. An example of this is the village-specific taboo that Trobrianders placed on elasmobranchs, where some had developed special capture methods and others would not consume this resource at all (Malinowski 1918, Silas 1926). Such patchiness in both the seascapes and history of resource exploitation in PNG helps explain its position in the middle of the trajectory of coral reef degradation in relation to other regions of the world (Plate I). Furthermore, it is not surpris-

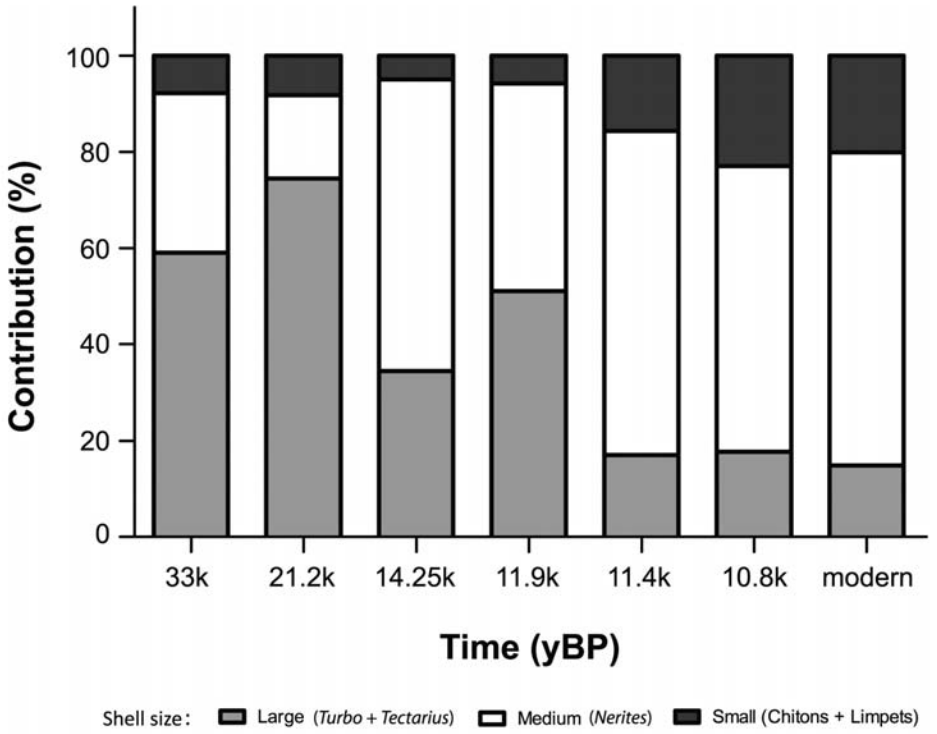

FIGURE 1. Relative contribution of shell size categories through time at the Matenkupkum archeological site, southeastern New Ireland. Note a reduction in both percentage shell contribution and large species representation through time. Modified from Gosden and Robertson (1991).

ing to observe an acceleration in degradation in Late Modern times due to demands and pressures imposed by a more globalized economy. New techniques, tools, and markets became gradually available in recent times across the country, applying nationwide pressure on natural reef resources.

Reefs appeared to be more degraded during the Agricultural times than the Colonial and Early Modern periods as indicated by broad-scale archeological evidence suggesting a reduction in ecological state of some resources. These reef resources include mainly edible, tool, and ornamental mollusks within the suspension feeder (e.g., *Anadara* spp.), small herbivore (e.g., *Strombus* spp.), and small carnivore (e.g., *Nassa* spp.) guilds. A reduction in species population size (Allen 1997) or successive community shifts to the predominance of smaller shell species (Anderson 1981) were observed in New Ireland (Gosden and Robertson 1991), Central Province (Swadling 1977*a*, *b*), and New Britain (Green and Anson 2000) among other sites. In the New Ireland site, with over 30,000 years of human history, precolonial societies were well capable of altering the ecological status of early exploited resources. Here, older shell middens were composed of a higher proportion of larger edible shell species than more recent middens that were increasingly composed of medium and smaller-shelled species (Figure 1). The preferred larger shell species did not recover to the early stages even after millennia (Gosden and Robertson 1991). Such a pattern where smaller sizes or alternative species are used to compensate for the loss of preferred species is commonly known as "fishing down the food web" (Pauly et al. 1998). In PNG this pattern

also exists in trepang fisheries, where less-profitable species (e.g., pineapple sea cucumber, *Thelenota ananas*) are starting to be extracted as once-preferred species (e.g., sandfish, *Holothuria scabra*) are overfished (Skewes et al. 2002).

Two episodes of recovery (where ecological state appears to be doing better at a later period than at an earlier one [Kittinger et al. 2011]) were uncovered in this study. First, reefs were more degraded during the Agricultural period, and most free-living guilds recovered in the later Colonial Occupation period. Second, the suspension feeder, small herbivore, small carnivore, and large herbivore guilds appear more degraded in the Colonial Development period than during the Early Modern period. We attribute the first recovery period to a decrease in pressure on resources that were heavily exploited at the time of European arrival. For example, Christian missions introduced restrictions on turtle meat consumption (Spring 1982*b*), and shells used as currency were no longer used for trade with the introduction of Western-like cash economies (Epstein 1963). Because of these social and economic changes, some guilds improved during the Colonial Occupation period relative to the earlier Agricultural period.

Similarly, during the Early Modern period, boom-and-bust fisheries (where a commercially attractive resource was exploited indiscriminately until it all but disappeared in a particular region), characteristic of Colonial Development times, were placed on hold as World War I and World War II disrupted markets for these resources (Carrier 1981, Kinch 2002*b*). At the same time exploitation was reduced either as alternative materials were introduced (e.g., plastics preferred over mother-of-pearl products [Anonymous 1959, Glucksman and Lindholm 1982]) or as competition increased with increasing production from other countries. These factors help explain why some guilds (such as small herbivores and small carnivores) appear to recover during the Early Modern period relative to the Colonial Development period.

High fishing pressure and changes in exploitation rate in Modern times have led to greater degradation in the large herbivore and suspension-feeder guilds versus other guilds (Plate II). Low reproductive output for dugongs and poor recruitment for turtles increased the vulnerability of the large herbivore guild to overfishing. In addition to these life history characteristics, increased demand (Spring 1982*a*, Hudson 1986), introduction of more efficient methods of fishing (Spring 1981), and gradual loss of rituals and traditions surrounding catch of these animals (Spring 1982*b*, Hudson 1986) played a part in their declining population sizes (Pernetta and Hill 1981, Spring 1982*a*, Hudson 1986, Kwan et al. 2006). Similarly, the suspension-feeder guild is becoming increasingly rare due, at least partially, to increasing demand from Asian markets for mollusks such as giant clams (Chesher 1980, Kinch 2002*a*). Giant clams are particularly vulnerable to high fishing pressure because when a shell bed is fished out, there is large uncertainty about future recruitment from other beds to assist with recovery (Braley 1984, Pearson and Munro 1991). The depletion of subsistence shellfish such as clams, oysters, and pearl in PNG (Chesher 1980) and other Pacific islands (Sant 1995) due to overexploitation has occurred alongside increased exports and international demand, and increases in urban and rural human populations.

Role of Human Influences on Reef Resource Trajectory

Each of the seven types of human influence we investigated (Table 2) placed various amounts of pressure on reef resources across periods and guilds. The main patterns from historical analysis of the last three cultural periods are an interaction of the novelty and reliance indices, the role of destructive practices on large carnivores and corals, and increases in the long-term sustained exploitation index for the large and small carnivore and large and small herbivore guilds in Modern times (Plate III).

INTERACTION BETWEEN NOVELTY AND RELIANCE INDICES: During the Colonial Development period, and to a lesser extent the Early Modern period, most guilds (but

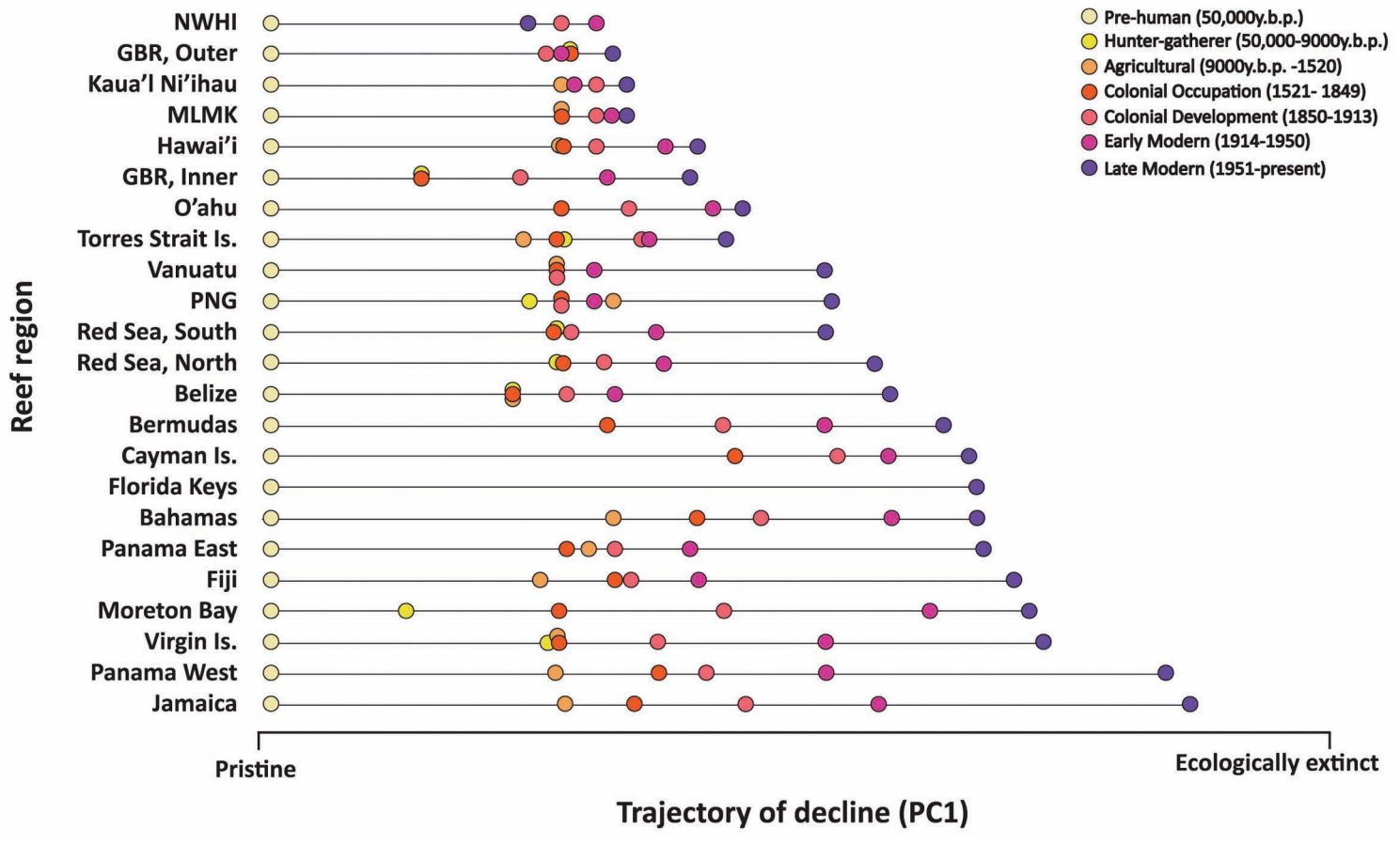

PLATE 1. Principal Component Analysis (PCA) of ecological status of reef resources through history based on the ecological state of all seven guilds of reef inhabitants for 23 coral reef regions (the original 14 regions studied in Pandolfi et al. [2003] with the addition of 9 new regions). Only the first principal component was included. On the left is the pristine ecosystem state, and to the right is the hypothetical ecological extinct state. MLMK, the Hawaiian Islands of Moloka'i, Lāna'i, Maui, and Kaua'i.

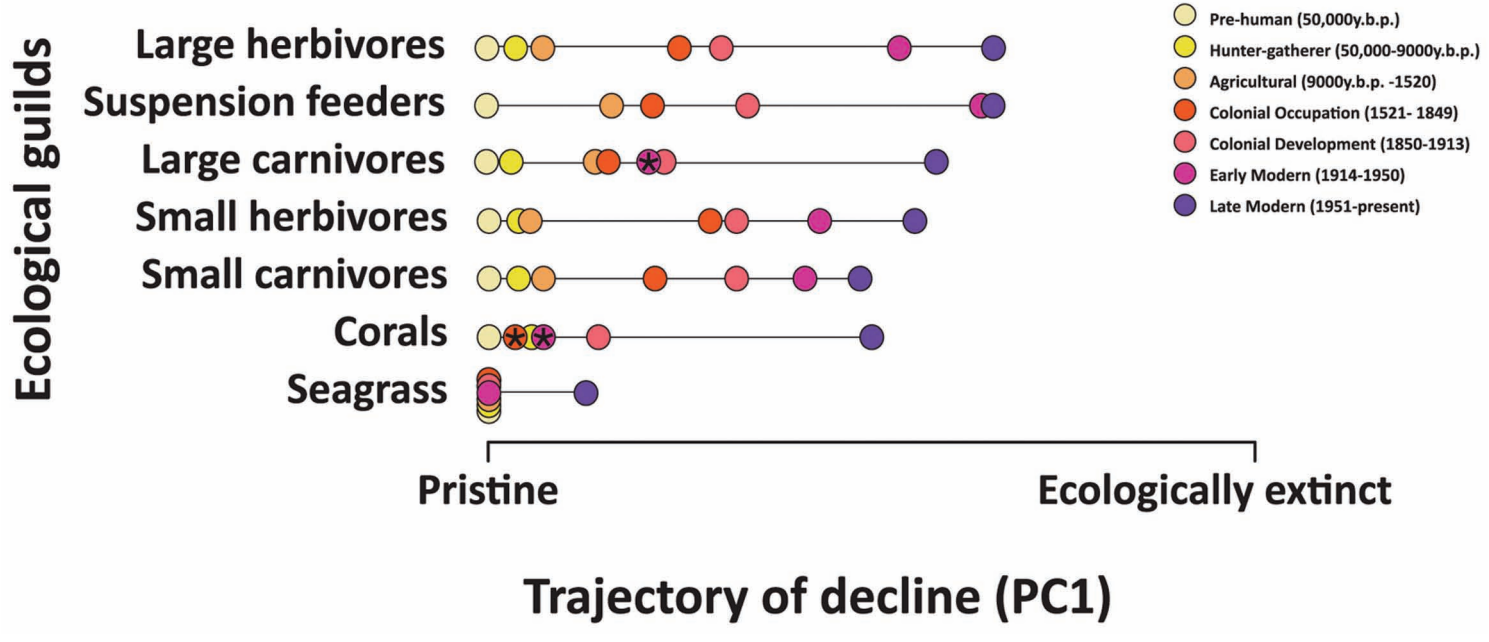

PLATE II. Principal Component Analysis (PCA) of ecological status of each of the seven guilds through history for Papua New Guinea reefs. Only the first principal component was included. On the left is the pristine ecosystem state, and to the right is the hypothetical ecological extinct state. The asterisk (*) denotes times when recovery has occurred.

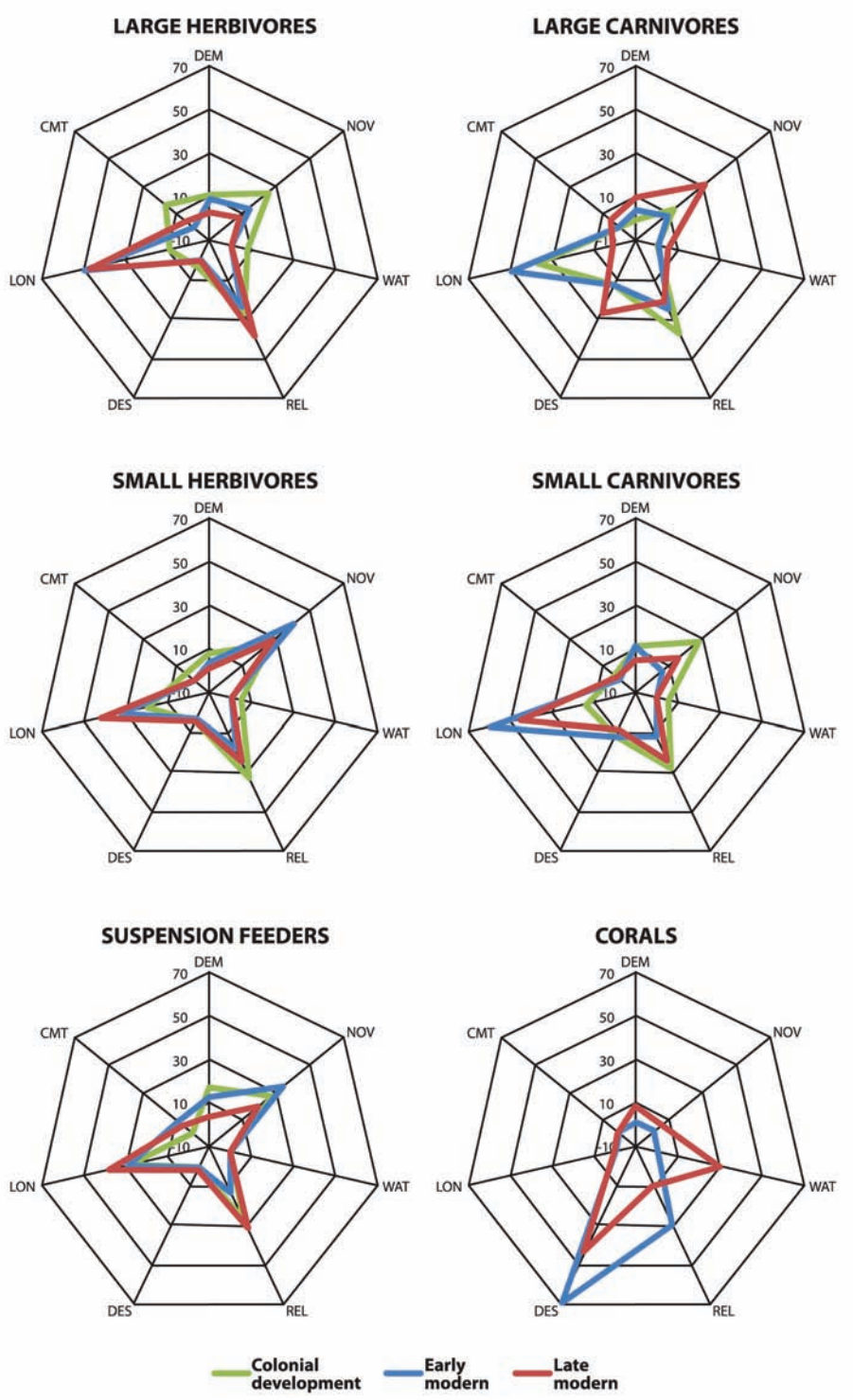

PLATE III. Role of human influence indices (HII) on the six marine guilds (large and small carnivores, large and small herbivores, filter feeders and corals) in Papua New Guinea over the last three historical periods (Colonial Development, Early Modern, Late Modern). The axes on the AMOEBA plot (Ten Brink et al. 1991) represent each of the HIIs. Each historical period is represented by a line of different color for each of the guilds. For the HII: DEM, Demographic; NOV, Introduction to "novelty"; WAT, Anthropogenically derived water quality degradation; REL, Reliance on marine resources; DES, Destructive practices; LON, Long-term sustained exploitation; CMT, Customary Marine Tenure degradation.

not corals) were largely affected by the novelty and reliance indices (Plate III), as well as the long-term sustained exploitation index. The colonizers introduced change in the exploitation patterns by direct means such as escalating the rate of exploitation with export-driven fisheries of mother-of-pearl and trepang. However, and just as important, is the change they introduced indirectly by (1) disrupting traditional social networks, (2) reducing the viability and attractiveness of self-sufficient lifestyles, and (3) promoting social inequality (Hogbin 1951, Gare 1973, Chesher 1980). These three indirect drivers of change are not mutually exclusive, and their consequences are very prevalent in fisheries challenges today in the region (Dalzell and Wright 1986, Johannes and MacFarlane 1990).

Colonial governments actively disrupted traditional networks in an attempt to reduce the authority of local chieftains (Hogbin 1951, Epstein 1963, Dubbeldam 1964, Healey 1990), phase out the prevalent barter-trade economies, and force indigenous Papuans to engage with the gradually established capitalist economy. It was also done passively, for example, by introducing foreign, more efficient methods and gears for fishing. Because neither the colonial capitalist economy nor the foreign fishing methods had associated management measures restricting fishing effort, they were unlikely to confer any sort of protection to resources. Boom-and-bust colonial fisheries for trepang and mother-of-pearl products (e.g., pearl oyster shell, trochus), as well as the high reduction in turtles and dugongs are clear examples of how rapidly resources were depleted under increased pressure with lack of traditional rituals and observances (e.g., Sack and Clark 1979, Spring 1982*a*, Hudson 1986, Kinch 2002*a*).

The introduction of the colonial export industry not only disrupted traditional networks but also integrated local reef resources into global markets and gradually introduced the perception of resources as commodities to indigenous coastal villagers. This perception was not always adopted immediately; in fact it often encountered resistance by the social, cultural, and economic structures of many coastal peoples (Williams 1964, Harding 1967, Valentine 1973, Dalzell 1998), especially in areas previously relatively isolated from colonial influence. Yet even without direct contact with colonial powers, coastal villagers found it increasingly hard to keep isolated from the cash economy. Reliance on the resources shifted to production not only for subsistence but for export markets. Examples of this pattern are available in each of the three cultural periods assessed for human influence. During colonial times, for example, copra plantations became profitable overnight. As more and more people became involved with copra plantations, coastal villagers were less able to maintain a profitable trading economy (Harding 1967). Similarly, during New Guinea's Australian Mandate (beginning of the Early Modern period when the League of Nations gave Australia a mandate to administer the territory of New Guinea from 1920 until the Japanese invasion during World War II), younger members from coastal villages located in regions of impoverished agricultural soils began to earn the newly desirable cash from the colonizers' enterprises (Johnston 1937). Presently (Late Modern period), bad years for crops during El Niño events, combined with the ever-increasing need for cash, resulted in younger generations engaging more and more in commercial fishing industries such as the live reef fish food trade (LRFFT), tuna canneries, and the aquarium trade (Jenkins et al. 2006). Besides adding pressure to commercially exploited resources, such industries have been associated with habitat-destructive fishing methods (e.g., cyanide and dynamite fishing, trawling) or Malthusian overfishing (extending the areas fished or the time spent fishing in search of an increasingly scarce and thus more unprofitable resource [Johannes 1982]).

The promotion of social inequality is also an important indirect driver of change in exploitation patterns introduced by colonizers. For example giant clam "gardens" were a relatively secure source of food for coastal villagers in the past, and the community shared the resource (Chesher 1980, Kinch 2002*a*). With the introduction of the cash economy,

giant clams were harvested by a few and sold for export to Asian markets. The result is that an item that in the past was able to feed many members of the community nowadays only provides net gains to a few members of the community in the form of cash. Furthermore, because of the disruption in traditional networks and the zeal for cash, there was little or no incentive to exploit such resources sustainably.

LARGE CARNIVORES, CORALS, AND DESTRUCTIVE PRACTICES: Destructive practices appeared to have the most effect on corals in the Early and Late Modern periods and on organisms within the large carnivore guild in the Late Modern period (Plate III). There are many destructive techniques that result in direct elimination of corals and substrata, such as dynamite fishing, reef walking, and anchor damage, activities that have increased through time. For large carnivores, there was a nearly universal perception of such organisms as "nuisance" or "dangerous" (Monckton 1922, Aufenanger 1975, Burgin 1982). Such perceptions in many cases resulted in the passive social acceptance of their decline. Active "trophy killing" of snakes, crocodiles, and sharks was encouraged for rituals or to avoid interference with fishing operations but not necessarily for consumption (Monckton 1922, Aufenanger 1975). Crocodile populations were rapidly decimated by interest in crocodile hides for export starting in the Early and Late Modern periods (Anonymous 1967, Burgin 1982). Evidence for destructive (cyanide, dynamite) fishing for sharks and large reef fish (e.g., serranids, lutjanids) is available as far back as Colonial times (Walker 1909, Struben 1961). Such practices, although officially banned, are still common (Anonymous 1996, 1998, Huber and Opu 2000, Jenkins et al. 2005, Hamilton and Matawai 2006), particularly in the LRFFT (Barber and Pratt 1998). Bycatch of leatherback turtles, sea snakes, sharks, and dolphins is another pervasive destructive practice that affects this guild in Modern times (Tseng et al. 1984, O'Shea 1996, Naru 2004). Despite acknowledging their important role in the ecosystem as predators, public perception of large carnivores in PNG has translated into few advocates for their protection (Burgin 1982).

Long-Term Associations and Sustained Exploitation of Resources

In Modern times we found abundant evidence for a long history of exploitation (Plate III) of large herbivores and large and small carnivores by coastal villagers. In most cases, the present-day abundance of resources such as dugongs and turtles (Spring 1982*a*, Hudson 1986) is largely reduced compared to their historical abundance. The main consequence of this is that dramatic reductions in population size caused by past generations limited the potential yield of current fisheries, and until such resources are able to recover it is unlikely that they will support any viable fishery. For example, comparison of dugong catches from the 1980s with catches from before World War I in Daru shows that the number of individuals fished is very similar (approx. 20 per year). However, low levels of fishing effort using rudimentary fishing technology characterized the fishery before World War I, whereas in the 1980s fishing effort substantially increased due largely to availability of modern technology (e.g., fiberglass or metal boats, outboard motors). After the 1980s, dugong availability has decreased and effort has increased to maintain the catch level. Overfishing is a major driver for this pattern, but sea grass decline is probably contributing to the overall dugong decline (Hudson 1986).

Current Challenges

Maintaining viable subsistence lifestyles has proven to be a considerable challenge for coastal communities since colonial times. Incentives need to be considered to encourage young generations to engage with activities that do not involve destructive fishing practices. For these reasons coastal communities would benefit from being included in commercial fisheries plans or other sustainable-development initiatives.

After observing a dynamic, long history of exploitation of reef resources in PNG, rec-

ognizing the shifting baseline in the perception of fisheries in the country should remain a priority. Failing to correct this perception could trigger four major risks: (1) With the global economy increasingly making transport to markets easier, localized depletions could be masked by expansion of fishing areas or adoption of more efficient fishing methods, as has been observed (Berkes et al. 2006, Cinner et al. 2012); (2) the continuation and institutionalization of past destructive practices could mean current fishing communities run the risk of repeating the mistakes of resource exploitation in the past; (3) without an accurate reconstruction of past history of exploitation, there is an increased risk of overestimating the potential maximum sustainable yield of a fishery, thus precluding future generations of the opportunity to use such resources (McClenachan and Kittinger 2012); and (4) the erosion of local culture and traditions may increase when there is no consideration of the historical human association with resources. To overcome this, we recommend ongoing monitoring and documentation of the ecological status of reef resources, as well as the patterns in human exploitation associated with them. Education is also a key element to ensure that such documentation and monitoring is incorporated into efforts to manage reefs sustainably. Finally, encouraging local communities to bridge the gap between older and younger generations is a self-sustainable way to avoid shifting baselines in the future.

CONCLUSIONS

In this study we reviewed the status and history of resource exploitation in Papua New Guinea from Prehuman to Modern periods. It is clear that the coral reefs in this region have experienced cycles of sustainability and depletion over time. The patchiness of the country's seascape means that a particular resource could be overexploited in one location but not necessarily in another. Although there is local variability at the country scale, reefs in PNG are less degraded than sites in the Caribbean but substantially more degraded than healthier reef sites in Hawai'i and the Great Barrier Reef (Plate I). There is clear evidence of resource exploitation and depletion before colonial influences, suggesting that indigenous peoples may not have harvested resources in a sustainable manner. However, colonial influences, mainly via the introduction of the cash economy, had a major, durable, and outstanding effect on the patterns of exploitation of coastal villagers. Under the new cash economy, self-sufficient lifestyles became less viable and more unattractive, and pressure to exploit reef resources for cash increased. This, along with the phasing out of many of the rituals and observances that previously conferred some protection to reef resources, increased the risk of overfishing. This combination of factors has already taken their toll on some of the most ecologically vulnerable resources such as dugongs, turtles, and giant clams. This study also uncovered a lack of baseline information in PNG for some important marine resources such as sea grasses. The long history of exploitation of PNG marine resources along with the patchiness of resource exploitation and the breakdown of traditional management practices held by coastal societies means that actions to protect and manage these resources are needed and that these should involve local communities. Although the current trajectory is one of decline, historical evidence indicates a capacity for recovery, and active management may still hold promise for initiating and sustaining recovery of PNG's marine resources.

ACKNOWLEDGMENTS

We thank T. Brewer, J. C. Ortiz, and the people of PNG for their great disposition and invaluable insights into the use of marine resources, especially J. Kinch, S. Ewen, P. Lahui, National Fisheries Authority staff, Department of Environment and Conservation staff, Motupore Island Research Centre staff, and World Wildlife Fund staff. Our thanks also extend to the guest editors of this special issue of *Pacific Science* and two anonymous reviewers whose comments greatly improved the quality of the manuscript.

Literature Cited

Al-Abdulrazzak, D., R. Naidoo, M. L. D. Palomares, and D. Pauly. 2012. Gaining perspective on what we've lost: The reliability of encoded accounts in historical ecology. PLoS One 7 (8): e43386. doi:10.1371/journal.pone.0043386.

Allen, B., and R. M. Bourke. 2009. People, land and environment. Pages 27–127 *in* R. M. Bourke and T. Harwood, eds. Food and agriculture in Papua New Guinea. ANU E Press, Canberra.

Allen, G. R., and T. B. Werner. 2002. Coral reef fish assessment in the 'coral triangle' of southeastern Asia. Environ. Biol. Fish. 65 (2): 209–214.

Allen, J. 1997. The impact of Pleistocene hunters and gatherers on the ecosystems of Australia and Melanesia: In tune with nature? Pages 22–38 *in* P. V. Kirch and T. L. Hunch, eds. Historical ecology in the Pacific islands: Prehistoric environmental and landscape change. Yale University Press, New Haven, Connecticut.

Allen, J. R., J. P. Kinch, S. A. McKenna, and P. Seeto. 2003. A rapid marine biodiversity assessment of Milne Bay Province, Papua New Guinea: Survey II (2000). RAP Bulletin of Biological Assessment. S. A. McKenna, ed. Conservation International, Washington, D.C.

Anderson, A. J. 1981. A model of prehistoric collecting on the rocky shore. J. Archaeol. Sci. 8:109–120.

Anonymous. 1959. Territory of New Guinea. Pacific Islands Yearbook. Pacific Publications, Sydney.

Anonymous. 1967. Annual report, 1965–1966, Department of Agriculture, Stock, and Fisheries, Port Moresby, Papua New Guinea. p. 169.

Anonymous. 1996. Is someone dynamiting your reefs? If so, you are losing opportunities for development. Christensen Research Institute, Madang, Papua New Guinea. p. 6.

Anonymous. 1998. Cyanide fishing in Milne Bay, Papua New Guinea. Environment 40 (8): 7.

Aufenanger, H. 1975. The great inheritance in north-east New Guinea: A collection of anthropological data. Anthropos Institute, St. Augustin, Germany.

Barber, C. V., and V. R. Pratt. 1998. Poison and profits: Cyanide fishing in the Indo-Pacific. Environment 40 (8): 4–34.

Bellwood, D. R., T. P. Hughes, C. Folke, and M. Nystrom. 2004. Confronting the coral reef crisis. Nature (Lond.) 429:827–833.

Berkes, F., T. P. Hughes, R. S. Steneck, J. A. Wilson, D. R. Bellwood, B. Crona, C. Folke, L. H. Gunderson, H. M. Leslie, J. Norberg, M. Nystrom, P. Olsson, H. Osterblom, M. Scheffer, and B. Worm. 2006. Ecology: Globalization, roving bandits, and marine resources. Science (Washington, D.C.) 311:1557–1558.

Braley, R. D. 1984. Reproduction in the giant clams *Tridacna gigas* and *T. derasa in situ* on the north-central Great Barrier Reef, Australia, and Papua New Guinea. Coral Reefs 3:221–227.

Bualia, L., and M. Sullivan. 1990. The impacts of possible global warming generated sea level rise on selected coastal environments in Papua New Guinea. Pages 193–199 *in* J. C. Pernetta and P. J. Hughes, eds. Implications of expected climate changes in the South Pacific region: An overview. Nairobi, United Nations Environment Programme, No. 128.

Burgin, S., ed. 1982. Crocodiles and crocodile conservation in Papua New Guinea. Traditional conservation in Papua New Guinea: Implications for today. Monograph 16. Institute of Applied Social and Economic Research, Boroko.

Callick, R., and M. Tait. 1993. The Papua New Guinea handbook. National Centre for Development Studies, Research School of Pacific Studies, The Australian National University, Canberra.

Carrier, J. G. 1981. Ownership of productive resources on Ponam Island, Manus Province. J. Soc. Océan. 70–71 (tomme 37): 205–216.

Chesher, R. H. 1980. Stock assessment commercial invertebrates of Milne Bay coral reefs. Department of Primary Industry Fisheries Report, Port Moresby.

Cinner, J. E., M. J. Marnane, and T. R. McClanahan. 2005. Conservation and community benefits from traditional coral reef management at Ahus Island, Papua New Guinea. Conserv. Biol. 19 (6): 1714–1723.

Cinner, J. E., C. Huchery, N. Graham, and M. A. MacNeil. 2012. Global impacts of local human population density and distance to markets on the condition of coral reef fisheries. Conserv. Biol. (in press). doi:10.111/j.1523-1739.2012.01933.x.

Cinner, J. E., and T. R. McClanahan. 2006. Socioeconomic factors that lead to overfishing in small-scale coral reef fisheries of Papua New Guinea. Environ. Conserv. 33 (1): 73–80.

Corvalan, C., S. Hales, and A. McMichael. 2005. Ecosystems and human well-being, health synthesis: A report of the Millennium Ecosystem Assessment. World Health Organization, Geneva.

Dalzell, P. 1998. The role of archaeological and cultural-historical records in long-range coastal fisheries resources management strategies and policies in the Pacific islands. Ocean Coast. Manage. 40 (2–3): 237–252.

Dalzell, P., and A. Wright. 1986. An assessment of the exploitation of coral reef fishery resources in Papua New Guinea. Pages 477–481 *in* J. L. Maclean, L. B. Dizon, and L. V. Hosillos, eds. The first Asian fisheries forum. Asian Fisheries Society, Manilla.

Diamond, J. M., and J. A. Robinson, eds. 2010. Natural experiments of history. Harvard University Press, Cambridge.

Dubbeldam, L. F. B. 1964. The devaluation of the Kapauku-Cowrie as a factor of social disintegration. Am. Anthropol. 66 (4): 293–303.

Epstein, T. S. 1963. European contact and Tolai economic development: A schema of economic growth. Econ. Dev. Cult. Change 11 (3): 289–307.

Gare, N. C. 1973. The New Guinea environment: What changes for the year 2000? Sci. New Guinea 1 (2): 3–7.

Glucksman, J., and R. Lindholm. 1982. A study of the commercial shell industry in Papua New Guinea since World War Two with particular reference to village production of Trochus (*Trochus niloticus*) and green snail (*Turbo marmoratus*). Sci. New Guinea 9 (1): 1–10.

Gosden, C., and N. Robertson. 1991. Models for Matenkupkum: Interpreting a late Pleistocene site from southern New Ireland, Papua New Guinea. Pages 20–45 *in* J. Allen and C. Gosden, eds. Report of the Lapita Homeland Project. Occasional Papers in Prehistory No. 20. Department of Prehistory, Australian National University, Canberra.

Grayson, D. K. 2001. Did human hunting cause mass extinction? Science (Washington, D.C.) 294:1459.

Green, R. C., and D. Anson. 2000. Excavations at Kainapirina (SAC), Watom Island, Papua New Guinea. N. Z. J. Archaeol. 20:29–94.

Grigg, R. W., and S. J. Dollar. 1990. Natural and anthropogenic disturbance of coral reef ecology. Pages 439–452 *in* Z. Dubinsky, ed. Ecosystems of the world 25: Coral reefs. Elsevier Science Publishers, Amsterdam.

Hamilton, R. J., and M. Matawai. 2006. Live reef food fish trade causes rapid declines in abundance of squaretail coral grouper (*Plectropomus areolatus*) at a spawning aggregation site in Manus, Papua New Guinea. SPC Live Reef Fish Information Bulletin (16): 13–18.

Harding, T. G. 1967. Voyagers of the Vitiaz Strait: A study of a New Guinea trade system. University of Washington Press, Seattle.

Hatcher, B. G., and G. H. Hatcher. 2004. Question of mutual security: Exploring interactions between the health of coral reef ecosystems and coastal communities. Ecohealth 1:229–235.

Healey, C. 1990. Maring hunters and traders: Production and exchange in the PNG Highlands. University of California Press, Berkeley.

Hogbin, I. 1951. Transformation scene: The changing culture of a New Guinea village. Routledge & Kegan Paul Ltd., London.

Huber, M. E. 1994. An assessment of the status of the coral reefs of Papua New Guinea. Mar. Pollut. Bull. 29 (1–3): 69–73.

Huber, M. E., and J. Opu. 2000. Assessment of natural disturbances and anthropogenic threats to coral reef biodiversity in PNG. Pages 37–48 *in* P. L. Munday, ed. The status of coral reefs in Papua New Guinea. Global Coral Reef Monitoring Network (GCRMN) Report, Townsville.

Hudson, B. E. T. 1986. The hunting of dugong at Daru, Papua New Guinea, during 1978–1982: Community management and education initiatives. Pages 77–94 *in* A. K. Haines, G. C. Williams, and D. Coates, eds. Torres Strait fisheries seminar. Australian Government Publishing Service, Port Moresby.

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J. B. C. Jackson, J. Kleypas, J. M. Lough, P. Marshall, M. Nystrom, S. R. Palumbi, J. M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. Science (Washington, D.C.) 301:929–933.

Hyndman, D. 1993. Sea tenure and the management of living marine resources in Papua New Guinea. Pac. Stud. 16 (4): 99–114.

Jenkins, A. P., C. L. Jenkins, and J. B. Reynolds. 2006. Successes and challenges of managing coral reefs in Papua New Guinea through locally managed marine areas. Pages 1524–1530 *in* Y. Suzuki and T. Nakamori, eds. Proceedings of the 10th International Coral Reef Symposium. International Society for Reef Studies, Okinawa.

Jenkins, A. P., R. Yen, R. Samuel, and T. Parras. 2005. Papua New Guinea: Problems and progress in Madang Lagoon. LMMA Network: Improving the practice of marine conservation. The Locally Managed Marine Area Network (LMMA), Papua New Guinea. http://www.lmmanetwork.org/Site_Page.cfm?PageID=28.

Johannes, R. E. 1978. Traditional marine conservation methods in Oceania and their demise. Annu. Rev. Ecol. Syst. 9:349–364.

———. 1982. Traditional conservation methods and Protected Marine Areas in Oceania. Ambio 11 (5): 258–261.

Johannes, R. E., and W. MacFarlane. 1990. Torres Strait traditional fisheries studies: Some implications for sustainable development. Pages 389–401 *in* D. Lawrence and T. Cansfield-Smith, eds. Sustainable development for traditional inhabitants of the Torres Strait region. Great Barrier Reef Marine Park Authority by the Australian Government Publishing Service, Canberra.

Johnston, L. F., ed. 1937. Official handbook of the Territory of New Guinea administered by The Commonwealth of Australia under mandate from the Council of the League of Nations. Commonwealth Government Printer, Canberra.

Kaly, U. 2006. Socioeconomic survey of small-scale fisheries in Milne Bay Province, Papua New Guinea. National Fisheries Authority and the Coastal Fisheries Management and Development Project, Kavieng.

Kearney, R. E. 1976. The expansion of fisheries in Papua New Guinea. Waigani Seminar. South Pacific Commission, Waigani, PNG.

Kinch, J. 2002*a*. Giant clams: Their status and trade in the Milne Bay Province, Papua New Guinea. Traffic Bull. 19 (2): 67–75.

———. 2002*b*. Overview of the beche-de-mer fishery in Milne Bay Province, Papua New Guinea. SPC Beche-de-mer Information Bulletin 17: 2–16.

———. 2005. From prehistoric to present: Giant clam (Tridacnidae) use in Papua New Guinea. Early Human Impact on Mega Mollusks Workshop, Isla de Margarita, Venezuela. University of Papua New Guinea, Port Moresby.

———. 2006. A socio-economic assessment of the Huon Coast leatherback turtle nesting beach project. Final technical report to the Western Pacific Regional Fishery Management Council. WPRFMC, Honolulu. http://www.wpcouncil.org/protected/Documents/Kinch%20report_final.pdf.

Kittinger, J. N., J. M. Pandolfi, J. H. Blodgett, T. L. Hunt, H. Jiang, K. Maly, L. E. Mc-

Clenachan, J. K. Schultz, and B. A. Wilcox. 2011. Historical reconstruction reveals recovery in Hawaiian coral reefs. Plos One 6 (10): e25460. doi:10.1371/journal.pone.0025460.

Kwan, D., H. Marsh, and S. Delean. 2006. Factors influencing the sustainability of customary dugong hunting by a remote indigenous community. Environ. Conserv. 33 (2): 164–171.

Lajus, J. 2008. Understanding the dynamics of fisheries and fish populations: Historical approaches from the 19th century. Pages 175–187 *in* D. J. Starkey, P. Holm, and M. Barnard, eds. Oceans past: Management insights from the history of marine animal populations. Earthscan, London.

Lewis, M. P., ed. 2009. Ethnologue: Languages of the world. 16th ed. SIL International, Dallas, Texas. http://www.ethnologue.com/.

Lotze, H. K., H. S. Lenihan, B. J. Bourque, R. H. Bradbury, R. G. Cooke, M. C. Kay, S. M. Kidwell, M. X. Kirby, C. H. Peterson, and J. B. C. Jackson. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science (Washington, D.C.) 312:1806–1809.

Lotze, H. K., and B. Worm. 2009. Historical baselines for large marine animals. Trends Ecol. Evol. 24 (5): 254–262.

Malinowski, B. 1918. Fishing in the Trobriand Islands. Man 18:87–92.

McClenachan, L. 2009. Documenting loss of large trophy fish from the Florida Keys with historical photographs. Conserv. Biol. 23 (3): 636–643.

McClenachan, L. E., and J. N. Kittinger. 2012. Multicentury trends and the sustainability of coral reef fisheries in Hawai'i and Florida. Fish Fish. doi:10.1111/j.1467-2979.2012.00465.x.

Miller, I., and H. Sweatman. 2004. Status of coral reefs in Australia and Papua New Guinea in 2004. Pages 303–336 *in* C. Wilkinson, ed. Status of coral reefs of the world 2004. Australian Institute of Marine Science, Townsville.

Moberg, F., and C. Folke. 1999. Ecological goods and services of coral reef ecosystems. Ecol. Econ. 29:215–233.

Monckton, C. A. W. 1922. Last days in New Guinea: Being further experiences of a New Guinea resident magistrate. Dodd Mead & Co., New York.

Munday, P. L. 2000. The status of coral reefs in Papua New Guinea: Executive summary. Pages 1–3 *in* P. L. Munday, ed. The status of coral reefs in Papua New Guinea. Global Coral Reef Monitoring Network (GCRMN) Report, Townsville. http://gcrmn.org/publications-info-center/publications/.

Naru, C. 2004. Papua New Guinea community programmes. Melanesian Marine Turtle Conservation Forum. Paradise Lodge, Gizo, Solomon Islands, World Wildlife Fund Pacific.

Nystrom, M., C. Folke, and F. Moberg. 2000. Coral reef disturbance and resilience in a human-dominated environment. Trends Ecol. Evol. 15 (10): 413–417.

O'Shea, M. T. 1996. A guide to the snakes of Papua New Guinea. Independent Publishing Limited, Port Moresby.

Pandolfi, J. M. 2002. Coral community dynamics at multiple scales. Coral Reefs 21 (1): 13–23.

Pandolfi, J. M., and J. B. C. Jackson. 2006. Ecological persistence interrupted in Caribbean coral reefs. Ecol. Lett. 9:818–826.

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

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres Jr. 1998. Fishing down marine food webs. Science (Washington, D.C.) 279: 860–863.

Pearson, R. G., and J. L. Munro. 1991. Growth, mortality and recruitment rates of giant clams, *Tridacna gigas* and *T. derasa*, at Michaelmas Reef, central Great Barrier Reef, Australia. Aust. J. Mar. Freshwater Res. 42:241–262.

Pernetta, J. C., and L. Hill. 1981. A review of marine resource use in coastal Papua. J. Soc. Océan. 70–71 (37): 175–191.

R. Development Core Team. 2008. R: A language and environment for statistical computing, reference index version 1.4.0. R. Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Richmond, R. H., and E. Wolanski. 2011. Coral reef research: Past efforts and future horizons. Pages 3–10 *in* Z. Dubinsky and N. Stambler, eds. Corals and coral reefs. Springer, London.

Rosenberg, A. A., W. J. Bolster, K. E. Alexander, W. B. Leavenworth, A. B. Cooper, and M. G. McKenzie. 2005. The history of ocean resources: Modeling cod biomass using historical records. Front. Ecol. Environ. 3 (2): 84–90.

Sack, P., and D. Clark, eds. 1979. German New Guinea annual report. Australian National University Press, Canberra.

Sant, G. 1995. Marine invertebrates of the South Pacific: An examination of the trade. Species in Danger. TRAFFIC International, Cambridge, United Kingdom.

Silas, E. 1926. A primitive Arcadia: Being the impressions of an artist in Papua. T. Fisher Unwin Ltd., London.

Skewes, T., J. Kinch, P. Polon, D. Dennis, P. Seeto, T. Taranto, P. Lokani, T. Wassenberg, A. Koutsoukos, and J. Sarke. 2002. Research for sustainable use of beche-de-mer resources in Milne Bay Province, Papua New Guinea. Final Report. CSIRO Division of Marine Research, Cleveland, Australia. http://aciar.gov.au/project/FIS/2001/059.

Spring, C. S. 1980. Turtles, men and magic. Division of Wildlife, Port Moresby.

———. 1981. Marine turtles in the Manus Province. J. Soc. Océan. 70–71 (37): 170–174.

———. 1982*a*. Status of marine turtle populations in Papua New Guinea. Pages 281–289 *in* K. A. Bjorndal, ed. Biology and conservation of sea turtles. Smithsonian Institution Press, Washington, D.C.

———. 1982*b*. Subsistence hunting of marine turtles in Papua New Guinea. Pages 291–295 *in* K. A. Bjorndal, ed. Biology and conservation of sea turtles. Smithsonian Institution Press, Washington, D.C.

Struben, R. 1961. Coral and colour of gold. Faber & Faber, London.

Swadling, P. 1977*a*. Central Province shellfish resources and their utilisation in the prehistoric past of Papua New Guinea. Veliger 19 (3): 293–302.

———. 1977*b*. Depletion of shellfish in the traditional gathering beds of Pari. Pages 182–187 *in* J. H. Winslow, ed. The Melanesian environment. Australian National University Press, Canberra.

Ten Brink, B. J. E., S. H. Hosper, and F. Colijn. 1991. A quantitative method for description and assessment of ecosystems: The AMOEBA approach. Mar. Pollut. Bull. 23:265–270.

Tseng, W. Y., N. Rajeswaran, and A. Twohig. 1984. Shark fins: A potential, small, fish-processing industry. Page 7 *in* Department of Fisheries Research Report No. 8. Lae University of Technology.

Valentine, C. A. 1973. Changing indigenous societies and cultures. Pages 227–234 *in* I. Hogbin, ed. Anthropology in Papua New Guinea: Readings from the Encyclopaedia of Papua and New Guinea. Melbourne University Press, Clayton.

Walker, H. W. 1909. Wandering among South Sea savages and in Borneo and the Philippines. Witherby & Co., London.

Williams, M. 1964. Stone Age island: Seven years in New Guinea. Collins, London.

Winterhalder, B., and E. A. Smith. 2000. Analyzing adaptive strategies: Human behavioral ecology at twenty-five. Evol. Anthropol. 9 (2): 51–72.

Wright, A., and A. H. Richards. 1983. The yield from a Papua New Guinea reef fishery. Page 17 *in* Fisheries Report, DPI 83-07. Department of Primary Industry, Darwin.

———. 1985. A multispecies fishery associated with coral reefs in the Tigak Islands, Papua New Guinea. Asian Mar. Biol. 2:69–84.