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## Sustainable Extractive Strategies in the Pre-European Contact Pacific: Evidence from Mollusk Resources

Frank R. Thomas<sup>1</sup>

**Abstract.** Mollusk remains from archaeological and more recent historical contexts provide good proxies to assess environmental change, as well as human impact, both negatively and positively, as reflected, for example, by resource management practices. Rigorous testing of various hypotheses to explain change or relative stability in mollusk distribution in archaeological assemblages requires an understanding of ecological and biological (life history) characteristics of the represented species, as well as access to ethnographic and ethnoarchaeological data on the interaction between people and mollusks. A growing interest in contemporary indigenous resource management among Pacific Island communities has led some archaeologists to seek evidence for sustainable use of resources in the past, to complement the more widespread research conclusions that depict mollusk resource depression and/or shifts in species composition as consequences of negative human impact. Based on fieldwork in Kiribati, eastern Micronesia, and the application of Optimal Foraging Theory, this paper adds support to recent ethnographic, ethnoarchaeological, and archaeological case studies for the sustainable use of mollusks.

**Keywords:** archaeology, Optimal Foraging Theory, mollusk ecological and biological characteristics, sustainability, Kiribati

### Introduction

Food production in the western half of the Pacific Island region emerged at the end of the Pleistocene, after more than 30,000 years of human settlement. Agricultural expansion and intensification would eventually alter terrestrial environments on nearly every habitable island across the world's biggest ocean (Kirch and Hunt 1997). The impacts can sometimes be traced to early stages of human settlement and, in some cases, to resource depression, extirpation, and extinction (Kirch 2009). The influence of indigenous societies on marine resources on islands is less well documented (Anderson 2008; Morrison and Hunt 2007). Indeed, the influence of indigenous peoples on non-island marine resources is also understudied (Rick and Erlandson 2008). In the Pacific Islands, the study of indigenous and local knowledge of marine resource management remains

a fruitful topic, in light of suggestions that rapid dispersal across the southwest Pacific, beginning about 3,400 years ago, could have been driven, in part, by the impact of early humans on nearshore and intertidal resources (Groube's [1971] "strand looper model") that could be efficiently harvested, such as flightless birds, colony-breeding birds, turtles, reef fish, and invertebrates, including mollusks (Kennett et al. 2006; Szabó and Amesbury 2011).

Changes observed in shell midden distribution (and other marine resources) have often been attributed to direct human impact (Anderson 1979; Masse 1989; Shawcross 1975; Swadling 1986), although the influence of other processes, such as sea-level rise, tectonic events, coastal erosion or sedimentation, and storms, are sometimes acknowledged (e.g., Aswani and Allen 2009; Giovas 2018; Lambrides and Weisler 2017; Morrison and Addison 2008;

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see Harris and Weisler 2018a for a recent review) and present interpretive challenges for coastal zones and islands (Fitzpatrick 2007, 2012). In examining the sustainability of mollusk extractive strategies, the absence of changes in the archaeological record may be indicative of species resilience, low human population densities, low impact technologies, efficient use of resources (e.g., through an understanding of environmental cues and fluctuations), and the application of intentional and unintentional management practices (Johannes and Yeeting 2001; Reeder-Myers et al. 2016; Thomas 2014, 2015).

Because of their small size, limited and fluctuating resources, and relative isolation, low coral islands are often depicted as marginal habitats for human settlement. While some communities did not endure (Anderson et al. 2000; Di Piazza and Pearthree 2001), a remarkable number of low coral islands (and other small islands) continued to support human populations for centuries, indicating a long history of resilience to environmental variability (e.g., Lazrus 2015; Lilley 2008; McMillen et al. 2014).

Despite their abundance on most atolls, marine resources were on occasion subjected to avoidance practices, which would have enabled stocks to recover (e.g., Akamichi 1986; Veitayaki et al. 2015). It is against this background of anecdotal evidence for indigenous management or conservation (e.g., Zann 1985) that I sought to collect quantitative and qualitative data from the low coral islands of Kiribati, eastern Micronesia, that could provide explanatory value for understanding sustainable extractive strategies. The research was guided by Optimal Foraging Theory (Stephens et al. 2007) and the testing of predictions from three models (patch choice, patch sampling, and risk) applied to mollusk gathering. The data add support to recent ethnographic, ethnoarchaeological, and archaeological case studies for the sustainable use of mollusks. Results and

implications of this study relate closely to the broader ecological, anthropological, and archaeological literature on environmental stress, demography, and resource conservation, which is summarized in Supplement 1.

### Human Behavioral Ecology

Behavioral ecology, as a component of evolutionary ecology, appears well suited for the analysis of human behavior because of its concern with decision theory in ecological contexts (Bird and O'Connell 2006; Mithen 1989, 1990; Smith and Winterhalder 1992; Winterhalder 2002). The goal of human behavioral ecology is to study the ultimate causes of behaviors by analyzing their reproductive consequences among living populations and determining their adaptive significance in the past (Cronk 1991; Leonard and Jones 2002).

Optimal Foraging Theory (OFT) provides a focus on subsistence strategies, making it especially appealing for understanding decision-making in ethnographic and archaeological contexts (Greenwood 1984; Kohn 1989). Models derived from OFT lead to predictions about how organisms, including humans, should act under specific circumstances, such as the selection of food or prey types that maximize short-term harvest rates. An increased availability of food is assumed to increase fertility and survivorship, and minimizing the amount of time spent foraging enables foragers to pursue other fitness-enhancing activities. Thus, natural selection would favor individuals that forage more efficiently. The optimal diet is usually determined by considering the amount of energy acquired relative to energy expended, including the time required to search for and handle each prey type (handling includes time spent pursuing, capturing, harvesting, and processing a prey type).

A key assumption of OFT is that people make choices when hunting or harvesting resources. In some instances, the consequences for reproductive fitness can be

ascertained by comparing informant statements with other lines of evidence. By way of illustration, statements about the locally toxic cowrie (*Cypraea tigris*), which is consumed elsewhere in the Pacific but consistently avoided in Kiribati, were independently confirmed by the identification of a lipid potentially fatal to humans and probably related to the cowrie's diet (Thomas 2003). In this case, fitness would be reduced if this mollusk were consumed. However, explanations relating to the avoidance of other species may be difficult to obtain, as in the case of the symbolic role played by certain animals which appears to defy any cost-benefit analysis (Holt 1996). Grimble (1933-1934:19-24) listed several examples of Kiribati food prohibitions ranging from clan totems to restrictions affecting pregnant and nursing women, children, and fishermen. Many of these taboos continue to be observed, among them a general avoidance of echinoids, holothurians, and seaweeds, even though the latter two are among the country's few exports. A common attitude regarding the large holothurian *Bohadschia vitiensis*, much prized in the Asian market, is a general feeling of "disgust." This last point raises the issue of taste. While admitting that an appreciation for food is, in part, culturally determined and that optimization may be expressed within a cultural framework (Jones 1985), in other circumstances, there is sufficient individual variation even among small populations to reject taste as a general explanation for resource selectivity (Johnson and Behrens 1982). Moreover, when foraging behavior is documented, it may not be unusual to observe a lack of agreement between what people prefer to eat and what they actually consume. Indeed, the decision to continue searching for or handling a prey type is governed by factors intrinsic to the prey (e.g., density, spatial distribution), fluctuations in the environment (e.g., weather, tide conditions), as well as by certain characteristics of the forager population (e.g., single vs. group foraging, differences in

foraging ability, access to specialized technology). All these variables are constraints that determine the relative costs of obtaining a currency, such as calories or protein from different resources (Alvard and Kaplan 1991; Leonard 1989; Smith 1981).

Despite criticisms by some anthropologist that OFT is reductionistic and cannot account for the historical and socio-cultural factors that structure human societies (e.g., Ferguson 2016; Jones 2009; Meehan 1983; Soares Feitosa et al. 2018), foraging models may be more relevant to human foragers than to other organisms precisely because of the human ability to process vast amounts of information about the environment, guiding people towards the optimal choice, thereby maximizing fitness (Smith 1983). Foraging models attempt to predict the optimum state under specified environmental conditions, which are then tested against behavior exhibited by particular organisms to determine the fit between observation and prediction (Kormondy and Brown 1998:416).

### Prey Resilience

The ability of prey to withstand predation is a function of their biological (life history) and ecological characteristics. Some prey are more susceptible to over-exploitation than others because of low reproductive rates and few natural predators, resulting in restricted mobility and the absence of effective defensive mechanisms and behavioral responses to intensified predation. Overfishing and especially over-harvesting of slow-moving invertebrates, by selectively gathering the largest available mollusk, can depress a population's size range and average size. Overexploitation may lead to disruption in the entire ecosystem and to the loss of genetic diversity (McNeely et al. 1995:746-747). Extirpation, or local extinction, may also occur as evidenced by the giant clam (*Tridacna gigas*) (Munro 1989).

Catterall and Poiner (1987) have studied the life history and habitat information

to assess resilience among some Australian intertidal mollusks. Species exhibited differences in their ability to withstand similar levels of predation by virtue of their size at maturity, intertidal burying, presence of subtidal populations, benthic mobility, and the length of time for pelagic larvae to disperse before settling. The implications are that any apparent balance between prey and predator may be more closely related to a prey's biological and ecological properties that make it more difficult to deplete, rather than to the application of a conservation strategy (Poiner and Catterall 1988). The simultaneous harvest of natural mollusk predators may also lessen the overall impact of foraging strategies (McClanahan 1989, 1990). The notion that "folk management rules" (Acheson and Wilson 1996:586; Anderson 1996:174), including rules about fishing locations and techniques, are effective in conserving resources thus needs to be critically exam-

ined (Aswani 1998, 2017; Berkes et al. 2000; Gaymer et al. 2014).

## Methods

### Study Area

The research draws on more than two decades of ethnographic and ethnoarchaeological observations and interviews, supplemented by archaeological and historical ecological data from Kiribati (Gilbert Islands Group) in eastern Micronesia (Thomas 2001, 2007a, 2007b, 2009). Known since 1979 as the Republic of Kiribati, the 33 atolls and table reefs are spread over an area exceeding 3 million km<sup>2</sup> of ocean straddling the equator. The total land area, however, only slightly exceeds 800 km<sup>2</sup> (Figure 1).

While low soil fertility is often cited as a limiting factor in food production on low coral islands, in several instances, people transformed landforms into productive

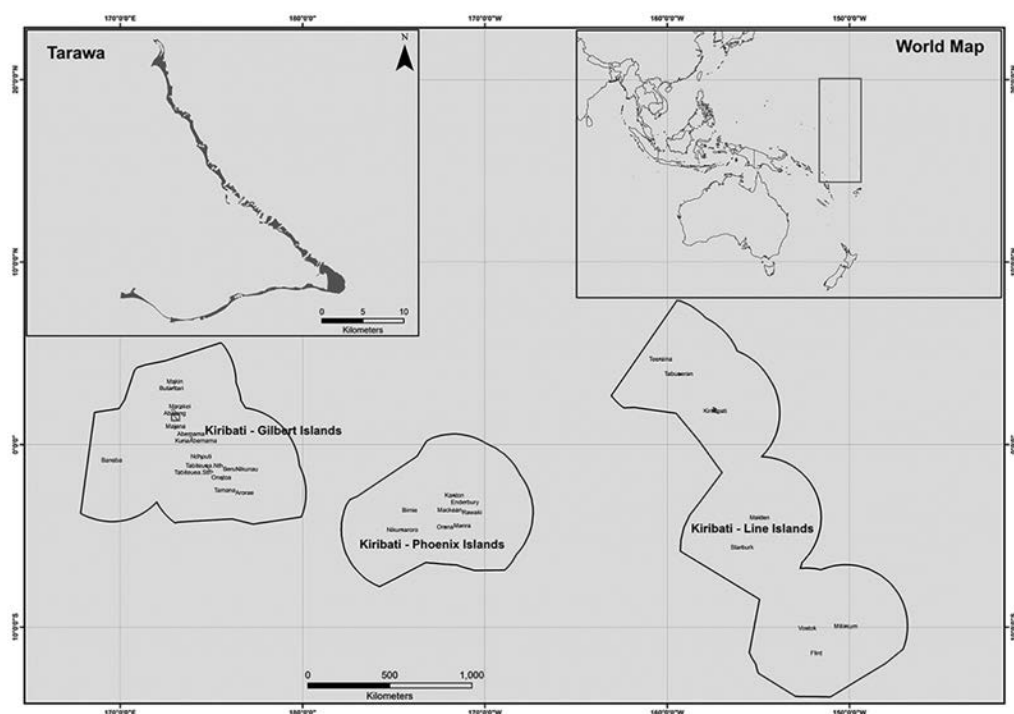


Figure 1. Map of Kiribati (source: Pacific Community - SPC).

islands through sophisticated systems of mulching, using leaves from a variety of trees, and tapping fresh water available through the Ghyben-Hertzberg lens (Catala 1957:70). Coral island societies devised subsistence strategies and applied food preservation technologies that took full advantage of available resources, including introduced root and tree crops (Barrau 1965; Di Piazza and Pearthree 2004). The very high ratio of reef to land area, typical of most atolls, provided early settlers and their descendants with an abundant source of protein as well as raw material (fish, turtle, and bird bone; coral; beach rock; and shell) for the manufacture of tools and ornaments (Koch 1986). Significantly, some coral islands appear to have been inhabited continuously for at least 1700 years (Di Piazza 1999; Kayanne et al. 2011; Levin et al. 2018; Poteate et al. 2016; Weisler 1999).

Because of a lack of extensive data related to coral island paleoclimatology (but see Sachs et al. 2009), together with a poor understanding of the extent of human-induced environmental impacts prior to Western contact, it remains unclear how people achieved sustainability (Allen 2006; Giovas 2006; Harris and Weisler 2018b). Insights gained from ethnographic and ethnoarchaeological observations, however, may help explain some of the archaeological patterns found throughout Pacific Island shell middens, illustrating the sustained use of marine resources.

### Data Collection and Observation

Today the decision to gather mollusks is governed by a host of factors, including household composition (the majority of gatherers are women and children), level of income, availability of alternate food sources, and tide conditions, to name a few. Data on mollusk gathering was collected from the atolls of Abaiang, Tarawa, Maiana, Abemama, and Tabiteuea between 1993 and 1998. Fieldwork resulted in approximately 140 hours of direct observation (290 forager-hours) during 73 foraging trips.

Foragers were generally members of households where I resided and their neighbors. For each foraging trip, the following details were recorded:

1. targeted prey type(s);
2. actual prey type(s) harvested;
3. patch (habitat) type;
4. location;
5. date and moon phase;
6. age and sex of each forager;
7. round-trip travel time;
8. one-way distance from central place (main residence)<sup>1</sup>;
9. search time;
10. handling time;
11. rate of encounter;
12. weight by prey type<sup>2</sup>;
13. general weather and tide conditions insofar as these were relevant to the foraging process.

For group foraging (when several foragers contributed to one bag or basin and proceeds were expected to be shared), it was assumed that time spent in search and handling was shared equally among foragers, particularly in cases where relatively dense resources occurred. While this assumption may seem tenuous among groups possessing different foraging abilities (e.g., adults vs. young children), sub-adults who participated in mollusk gathering activities essentially confined themselves to searching and harvesting easily accessible resources (i.e., epifaunal or shallow, infaunal species) and, thus, probably tended to match adult performance in terms of foraging efficiency.

Semi-structured interviews with mollusk gatherers (representing 65 foraging trips or approximately 90 hours of foraging effort [160 forager-hours]), as well as an analysis of mollusk landings and associated questionnaires recorded between December 1992 and February 1994, courtesy of the Tarawa Lagoon Project (representing about 190 hours of foraging time [260 forager-hours] during 83 foraging trips) (Abbott and Garcia 1995), provided additional quantitative and



qualitative information. For the interviews, the duration of foraging was estimated. As I gained proficiency in the local language, much of the information provided from the direct observations was also obtained by interview. Although not originally conducted for measuring foraging inputs and outputs, data from the Tarawa Lagoon Project included information for assessing foraging efficiency, while providing for an independent check of the harvesting patterns noted through direct observation. The net energy gained per unit foraging time could be established for the observed samples (Thomas 2007a) from published tables describing activity categories (Durnin and Passmore 1967; Norgan et al. 1974; Uliaszek 1995), adjusted to this study, together with the energy content (kcal) of 24 mollusks prey types ranging from 98.3 kcal/100 g raw, wet edible weight for the gastropod *Nerita plicata* to 41.2 kcal/100 g for the bivalve *Quidnipagus palatam* (Thomas 2003).

Calculation of the average productivity of observed prey types for each patch type was established by the on-encounter profitability per foraging bout (load)  $E/h$  (kcal/min), and overall efficiency  $E/T$  (kcal/min), where  $T$  is total foraging time (sum of time spent searching  $T_s$  and handling  $T_h$ ). Productivity between patches was then compared using a two-tailed t-test (Thomas 1999). Data on prey resilience (the ability of different species to withstand predation using traditional gatherings methods) was compiled for the 24 prey types (Thomas 1999:180).

## Results

### Patch Choice

Three main patches in the intertidal to shallow subtidal regions of the lagoon can be identified: (1) near-shore, (2) sand flat, and (3) seagrass. These patches are similarly recognized by local mollusk gatherers as: (1) *mataniwin te aba*, (2) *te tano*, and (3) *te keang*. The near-shore patch consists of

different substrates intersecting the shoreline, including fine beach sand (*te bike*) and gravels (*te atibu*). The sand flat is a wide, gently sloping expanse occupying most of the intertidal area, and comprises scattered and low shrubby communities of mangroves. Seagrass beds are highly productive grounds for a variety of mollusks and are also important in fishing because of the high concentration of nutrients. A fourth patch, "offshore," locally referred to as *te nama*, is also recognized in the deeper section of the lagoon on South Tarawa where intensive harvesting of the cockle (*Anadara uropigimelana*) took place in the 1990s. On other atolls, intensive harvesting of the giant clam (*Tridacna maxima*) took place along the leeward reef platform in the vicinity of islets known as *te atimakoro*, which corresponds to the approximate limit of free-diving (ca. < 10 m.) (Figure 2). Diving for giant clams and other mollusks is a task accomplished by men.

The ocean side of all atolls is less frequently exploited than the lagoon but includes three patch types: (1) near-shore (also referred to as *mataniwin te aba*), occasionally extending seaward up to 100 m from the high tide mark, where conglomerate tongues and/or gravelly sand spits occur; (2) reef flat (*te atibu*); and (3) reef crest (*te rakaï*). The wide reef flat consists of a hard coralline surface interspersed by sandy pockets. The reef crest is seldom exploited compared to the other patches because of the limited time foragers can collect offshore during low spring tides and low overall returns.

Mollusk gathering is focused separately in the patches, each defined as "fine-grained environments" (MacArthur and Pianka 1966:603), although, on occasion, foragers will visit and gather from more than one patch. The locations of the patches are generally well known. Seagrass beds are the focus of the most intensive harvesting insofar as tide conditions permit (Paulay 2001). Overland travel usually takes place in the direction of the



**Figure 2.** *Tridacna maxima* harvesting (photo: F. Thomas).

patches roughly facing human settlements, although, once inside the patch, considerable movement may occur parallel to the shore.

Predictably, near-shore patches (on both lagoon and ocean sides) are significantly less productive than either seagrass or sand flats (seagrass vs. near-shore, two-tailed  $t$ -test,  $t = 4.42$ ,  $df = 9$ ,  $p < .001$ ; sand flat vs. nearshore,  $t = 3.44$ ,  $df = 37$ ,  $p = .001$ ). With the exception of one foraging trip, near-shore foraging took place only when the more productive patches were not easily accessible. The low overall returns from ocean reef flats in comparison to seagrass and sand flats are significant ( $t = 3.14$ ,  $df = 16$ ,  $p = .006$ ;  $t = 2.27$ ,  $df = 34$ ,  $p = .030$ ). Yet, reef flat foraging may demonstrate patch sampling and, thus, violate the assumption of constancy in patch quality (Oaten 1977; Stephens and Krebs 1986:103).

The wide distribution of many mollusk prey types across extensive patches would probably not result in step function depletion (Kaplan and Hill 1992), where the energy gain per unit time remains constant until the last prey item is harvested, although, for certain prey types that can be easily seen and distributed within relatively small patches, foragers may remain in a given patch until the energy gain drops to zero. For example, *Tridacna maxima*, occurring on microatolls, may provide a context for this foraging strategy. In most cases, however, foragers appear to leave patches when faced with diminishing returns, which could be related to resource depression, reducing the marginal value of patches (Charnov 1976; see Supplement 1). In the context of mollusk gathering, changing tide levels likely constrains decisions to either continue searching in a high-ranking patch and face diminish returns, because



of increasing difficulty in visually locating prey with the incoming tide, or to move to a less productive patch closer to shore.

According to the “differential time allocation” hypothesis (Smith 1991: 258), foragers ought to focus on the highest-ranking patch while ignoring or dropping all others, given equal access. Because the most productive patch is expected to provide a higher gain than a lower ranking patch, it should receive a greater allocation of foraging time. A switch to a lower ranking patch may be interpreted as a sign of decelerating gain in the high-ranking patch. Conditions similar to those described above were noted when foragers shifted their gathering activities from the low- to mid-intertidal sand flat (for the bivalve *Gafrarium pectinatum*) into the upper intertidal gravelly sands (for the more widely dispersed bivalve *Asaphis violascens*) when the incoming tide limited foragers’ ability to locate prey in deeper, more productive areas.

As prey become less common as a result of predation or as they become more cryptic in light of exploitative pressure, an efficient forager may decide that it no longer pays to stay in a patch and search for increasingly elusive prey. Provided that travel time to the next best patch is not too costly, a patch type can be temporarily abandoned. Depending on the biological attributes of prey within that patch and the time lapse between visits, prey types may be able to recover from intensive harvesting. Foragers are not paying short-term costs by leaving a patch because they can do better in another one. Alvard’s (1993) distinction between conservation behavior, per se, from its effects (“epiphenomenal” conservation) is pertinent in this context in that conservation may incidentally follow optimal foraging decisions, as illustrated by patch switching.

Among all documented instances of patch switching (or movements within a patch perpendicular to the shoreline), there was little to support the suggestion

that foragers were motivated by a desire to conserve resources. Rather, the motivation always appeared to be linked to diminishing returns and the need to move to other patches. When tide conditions changed, foragers either moved from low-ranked patches to high-ranked patches or vice-versa. This behavior is consistent with short-term maximization.

### Patch Sampling

Patch depletion and subsequent high spatio-temporal variation in prey recruitment often lead to situations where mollusks become unpredictable resources, with marked differences in clumping. The gastropod *Conomurex luhuanus* and the bivalve *G. pectinatum* exhibit some of the highest degrees of clumping (the former primarily through behavioral attributes; the latter by virtue of its density). While both could be defined as “patches,” their specific distribution (epifaunal vs. infaunal) determines whether synchronous foraging by more than one forager will increase or reduce individual efficiency. For the highly conspicuous *C. luhuanus*, it does not pay for even a small party of two foragers to search a relatively restricted area. Depending on tide conditions, foragers may be separated from each other by several tens of meters. By contrast, the cryptic habits of dense *G. pectinatum* permit tighter clustering of individual foragers, sometimes on order of less than a meter, with little interference and competition. On the other hand, foragers are widely separated (often in excess of 100 m) while foraging on the ocean reef flat. This is consistent with the low density of high-ranked prey, such as *Hippopus hippopus*. Unlike other infaunal prey, such as *G. pectinatum*, foragers rarely excavate more than one *A. violascens* in a single digging motion (which usually involves digging straight down into the hard, gravelly matrix, compared to the shallower, scraping motions which characterize *G. pectinatum* harvesting in the sand flats).

Knowledge of patch quality based on environmental cues and the sharing of information with other foragers contrasts with information *while* foraging (Stephens and Krebs 1986:28). Models of information use (Stephens 2007) suggest that foragers do obtain information from conspecifics. Fluctuating resources require this kind of assessment strategy but, given the cost of sampling, under what circumstances would it be beneficial to sacrifice short-term return rates to acquire information for long-term gains?

Although yields may fluctuate from the dual impact of forager-dependent and forager-independent processes, to be of value, information about change should focus on those attributes of the environment that do not fluctuate too rapidly. In other words, environments that vary temporally at an “*intermediate rate* but in *large scale*” (Kaplan and Hill 1992:187) should be those in which foragers expend the greatest effort in acquiring information. For example, if large concentrations of mobile and aggregating *C. luhuanus* are known to occur, such knowledge would provide little benefit in the long-term because these aggregating gastropod “patches” are likely to shift<sup>3</sup>. However, the discovery of sedentary bivalves may be more valuable in planning future harvesting, bearing in mind competition from other foragers or marine organisms that feed on mollusks.

Together with rate of change, there should be large enough differences in return rates between patches or even between sections of patches to justify expanding effort in information acquisition. Patch depletion and the vagaries of successful prey recruitment (e.g., *A. uropigimelana* in the Bonriki-Temaiku seagrass area of South Tarawa) are important factors that determine the usefulness of an assessment strategy. The implication of a sampling strategy is the patch residence time, which differs from the marginal value theorem (see Supplement 1): foragers either stay longer or leave sooner than predicted by

the theorem (Stephens and Krebs 1986:91).

It is possible that a shift from the sand flat to seagrass at Bonriki-Temaiku began as a sampling strategy. Near Tebanga, on Maiana, people focused almost exclusively on *G. pectinatum*. Foragers commonly limited their activities to the mid-intertidal but, in two observed cases, appeared to be sampling the low intertidal to assess the state of resources away from the shoreline. Interviews indicated that *A. uropigimelana* had once been abundant in the area but then steadily declined, which resulted in foragers switching to *G. pectinatum*. Some foragers, however, had the opportunity to come into contact with high-ranked prey types while traveling to their small seaweed plots in the low intertidal. Reports on the status of mollusks occurring in the area filtered back to the community and encouraged people to search for *A. uropigimelana* in places they would normally bypass.

Another example of sampling strategy is illustrated by observations and interviews on the ocean reef flat. Foragers stated they were monitoring giant clam distribution. Areas surveyed were carefully selected to avoid spending time in previously searched sections. Up to three months passed before a specific patch section was revisited, possibly to allow for the recovery of heavily depleted resources. However, “patch recovery time” (Bennett 1991), in one instance, resulted in less than 20% of initial caloric intake derived from *H. hippopus*. It may be that other foraging groups had exploited some of the recovered biomass in the interim. Alternatively, given the slow growth of giant clams, foragers could have returned to the patch in search of other prey types, as large species of giant clams are sometimes gathered incidentally in the course of other fishing activities.

Natural selection specifies the conditions that may benefit from a sampling strategy, thus sacrificing short-term gains to acquire information for long-term gains, but unless intent to conserve can be established, patch sampling documented in this

study cannot be considered a conservation strategy. While the distinction between intent and behavior should be kept and predictions from foraging models are tested against behavior, the criterion of intent remains important in deciding whether a subsistence strategy is synonymous with genuine conservation or not (see Whitaker 2008 in the context of incipient aquaculture of intertidal resources). The third foraging model, risk, further examines the issue of intentional vs. unintentional management.

### Risk

Risk is closely related to sampling (Sosis 2002; Winterhalder et al. 1999). Two strategies to reduce risk include resource sharing/reciprocal territorial access and hoarding/storage (Colson 1979; Smith and Boyd 1990). Both entail costs to the individual, but the costs for not employing them in appropriate contexts may be even higher.

Sharing and hoarding may be perceived as contrasting strategies to reduce risk, and

the kinds of resources that are widely shared and those that are stored appear to be quite different. Because indigenous land tenure is still recognized, terrestrial production and food preservation belong to extended families. Most marine resources are no longer culturally regulated, which explains why a successful fisherman sometimes relinquishes part of his catch to distantly related kin or non-kin. Remnants of a more extensive marine tenure system, such as fish traps and “gardens” for the live storage of giant clams (Figure 3), are at odds with the open access policy governing lagoon and ocean habitats set up by the former British authorities. As a result, outer island councils have established by-laws in an attempt to control resource access (Thomas 2001). However, the effectiveness of these measures remains in doubt. As Teuea (2018:67) noted: recent efforts to conserve marine resources in Kiribati are “still largely driven by the government agenda and competence despite the projects being branded as community-based.”



**Figure 3.** Giant clam “garden” (photo: F. Thomas).

Sharing and hoarding need not be mutually exclusive. For example, it is conceivable for some households to hoard pandanus (*Pandanus tectorius*) paste or dried fish in times of abundance for possible sharing in times of scarcity. Risk-aversion strategies are important in determining whether intentional conservation has been selected for. Although sharing of certain marine resources does take place, in light of the open-access regime established during the colonial period, it is doubtful that sharing is meant to prevent over-exploitation (see Kaplan and Hill [1985] for a review of hypotheses to explain resource sharing). Storage in the form of giant clam aquaculture, on the other hand, may indicate the application of both intentional and unintentional management practices, as discussed below.

### Discussion

To a large measure, prey resilience, together with flexible foraging strategies targeting a broad range of taxa, would account for the sustainable harvest over centuries of several mollusk species, as illustrated by the analysis of shell middens in the Marshall Islands (Harris and Weisler 2018b), Kiribati (Thomas 2009, 2014), and other locales (e.g., Giovas 2016). Weisler (2001) presented evidence for the extirpation of the Bullmouth helmet shell (*Cypraecassis rufa*) from Utrök Atoll in the Marshalls, but the overall impression suggests little change in habitat selection, richness, evenness, or diversity. Moreover, the presence or absence of marine organisms in a particular habitat (and their subsequent representation in the archaeological record), appears to be partly determined by chaotic and unpredictable recruitment events that shape the structure of reef assemblages over time (Paulay 2001; Sale 1980; Thakar 2011).

Prey resilience is one attribute that may result in sustainability. But even highly resilient prey can become vulnerable if predation pressure increases because of

a growing predator population and/or the introduction of new extractive technologies. Patch switching can also lead to sustainable harvests, as noted above. While foragers following a diminishing returns curve are maximizing their short-term gains by moving across patches, prey are generally able to recover.

Patch sampling may lead to deviations from short-term rate maximization (as assumed in the marginal value theorem; see Supplement 1). Statements about patch sampling, where foragers may either stay longer or leave sooner than predicted, remain inconclusive. Testing the marginal value theorem would require marginal return rates for each patch over very short time scales, in addition to data on travel time between patches.

Storage is an effective risk-reduction strategy, as it involves delayed consumption. Although there are costs to storing foods (they may deteriorate rapidly, be scavenged, or stolen), the live storage of giant clams can be compared to other forms of animal domestication (Alvard and Kuznar 2001). This practice has been reported from various other Pacific Island communities (e.g., Bliege Bird et al. 1995; Hviding 1993; Kinch 2008; Moir 1989a:494–497).

As noted above, there have been several instances of local extirpation of the larger species of giant clams, notably *T. gigas* and *H. hippopus*, in pre-European contact and historic times. Because of their long planktonic stage (allowing for wider dispersal but also resulting in high mortality rates), slow growth, low reproductive success of adults, and sporadic mass mortality in wild populations, giant clams are especially at risk (Neo et al 2015; Penny and Willan 2014). Consequently, some island communities resorted to gathering live giant clams from deeper water and transplanting them to locations near the shoreline for later consumption. From Brooker Island in the Louisiade Archipelago of Papua New Guinea, Kinch (2008:183) mentions that “juvenile Tridacnidae are collected and



placed in secret locations outside village houses or on the foreshore reefs where they can be harvested as needed." The initial gathering took place during calm weather. This was not directly observed in Kiribati nor could it be confirmed that gathering of giant clams for storage correlated with people's ability to satisfy their short-term energy needs by harvesting other higher-ranked mollusk or resources, as assumed by Optimal Foraging Theory. Return rates for *T. gigas* and *H. hippopus* are variable because of the wide range of sizes of individual prey items. Nevertheless, they may be regarded as high-ranking prey, but still inferior to most other marine resources (Thomas 1999:379). Small prey items (< 40 cm) may actually fall outside the optimal diet, so that transplanting them does not involve a short-term cost. Thus, giant clam "gardening" may be regarded as an example of both intentional and unintentional conservation.

The vulnerability of giant clams even to moderate levels of human predation would make them ideal candidates for testing hypotheses about the sustainable use of these resources through the presence of archaeological "gardens," indicated by the concentration of empty valves in shallow water, particularly since *T. gigas* is not naturally found in near-shore, shallow water environments prone to turbid conditions. Giant clams, particularly larger specimens, are typically field processed by divers who remove the edible portion and leave the empty shells behind at the point of collection if the goal is to consume the meat or preserve it by adding salt shortly thereafter. In Kiribati, live tridacnids are sometimes placed inside fish traps (Thomas 1999:382). Moir's (1989b, 1990) research on Takuu Atoll (a Polynesian "outlier" in Papua New Guinea) attempted to identify evidence of former "gardens." Her ethnohistorical investigations also led to the documentation of the former practice of "aging" *T. gigas* (after removal of the animal) in seawater prior to reduction for

use as tool material. X-ray diffraction analysis and scanning electron microscopy confirmed that "aged" shell adzes were of superior workability and were also selected for ceremonial purposes.

Another dimension of marine "domestication" involves species enhancement (see Ostraff [2003:142–143] for *limu* or marine algae in Tonga; Wyban [1992] for fish ponds in Hawai'i). As noted by Thomas (2015) in Kiribati and Williams (2016) in New Zealand, mollusk "gardens" incorporate aspects of habitat improvement and the creation of ecological niches that aim to increase resource availability productivity and, in some cases, reliability. This is complemented by "garden" allocation between extended families. From Abaiang Atoll, mollusk gatherers have been observed transplanting *A. uropigimelana* and *G. pectinatum*, alongside tridacnids (Figure 4), in specially designated areas on the intertidal flat for future harvesting. These areas are sometimes demarcated by coral cobbles.

From the Northwest Coast of North America (Groesbeck et al. 2014; Lepofsky and Caldwell 2013; Lepofsky et al. 2015) there is ethnographic and archaeological data supporting similar enhancement with selective clam harvests, the removal of shells and other debris, and the mechanical aeration of the sediment matrix. Mollusk conservation is inferred from 7000-year-old middens in coastal British Columbia near residential sites with the predominance of senile shells, as opposed to mature specimens, at long-term residential sites, suggestive of less intensive harvest (Cannon and Burchell 2009).

As noted by Whitaker (2008), shell size reduction does not necessarily indicate declining foraging returns at a site if the currency being maximized is long-term productivity instead of immediate returns, with the removal of large individuals relieving competitive pressure allowing smaller individuals to move into patches and grow more rapidly. Conversely, significant





**Figure 4.** Gathering transplanted cockles alongside *Hippopus hippopus* (photo: F. Thomas).

size increases have been documented for *Gibberulus gibberulus* (humped conch) at Chelechol ra Orrak in Palau from ca. 3000 BP to present (Giovas et al. 2010) and *Nerita tessellata* (tessellated nerite) on Nevis in the West Indies (Giovas et al. 2013). In both cases, several variables may be responsible, including foraging practices reducing intraspecific competition, environmental change, and anthropogenic practices (e.g., by removing the species' predators, resulting in increased longevity, with more individuals surviving longer to become larger before the onset of maturity). For Palau, increasing horticultural activities could also have played a role resulting in eutrophication, which would have created or expanded habitats favored by this species.

The benefits of transporting unprocessed shells, even over great distances to keep them fresh for later consumption,

trade, or for other uses, have been widely documented (Bird 1997; Buchanan 1988; Moir 1989a). Conversely, shell middens may provide an incomplete picture of the range of species consumed in the past, with implications for questions about sustainability. Thomas' (2002) study of central-place foraging decisions (see also Bird 1997) among Kiribati mollusk gatherers and the archaeological reflection of those decisions may also contribute to discussions on sustainability. If we can predict when it becomes efficient to field process prey types, then their under-representation in shell middens may be explained. By way of illustration, if there is a tendency to field process tridacnids, not intended to be placed in "gardens" (Figure 5), their absence or low densities in archaeological deposits may not reflect avoidance or a conservation strategy. A number of ethnographic accounts document the processing



**Figure 5.** Giant clam field processing (photo: F. Thomas).

and, sometimes, consumption of various mollusk species at the point of collection, with their shells discarded (De Boer 2000; Deshpande-Mukherjee 2000; Quilter and Stocker 1983), thus questioning the assumption that large mollusks are more profitable than smaller ones and always end up in middens in proportion to their encounter rate.

### Conclusion

The archaeological record in the Pacific is rich with examples of stable, long-term adaptations of humans to their environment, as well as significant ecological changes brought about even by small-scale, low-technology indigenous societies prior to Western contact. Even the comparatively rich marine ecosystems have been altered by human harvesting of resources against the backdrop of changing environments (Nunn 2007; Rick et al.

2013). The interlinked topics of “sustainability” archaeology, historical ecology, and conservation biology (e.g., Dalzell 1998; Fitzpatrick and Erlandson 2018; Hayashida 2005; Lyman and Cannon 2004; Rick and Lockwood 2012) highlight the many challenges faced by Pacific Island communities as they attempt to cope with changing environments, economies, and social values, which now, more than ever, pose a threat to sustainable livelihoods.

A focus on mollusk resources in the past, as well as in the present, has provided an integrated understanding of sustainability as a possible outcome, which can result from multiple factors (Keegan et al. 2008). While examples of negative human impacts have received considerable attention by archaeologists, the research and review reported above suggest that, in several instances, mollusks persisted. In each case, the archaeological record

needs to incorporate a range of interpretative tools to explain prey resilience and overall stability (DiNapoli and Morrison 2016). Agent-based modeling applied to human-mollusk interactions (Morrison and Allen 2015) may prove useful in identifying “missing contextual information and new research questions.” For example, information about specific prey life-history traits, variation in management strategies and harvesting techniques, or differences in collection and discard that structure the archaeological record.

### Notes

<sup>1</sup> Estimated, assuming a walking speed of km/hour at constant level gradient and terrain coefficients of 1.1 and 1.2 (“dirt road” and “light bush”; cf. Brannan 1992; Jones and Madsen 1989).

<sup>2</sup> For calculation of edible meat weight and energy.

<sup>3</sup> While gastropod aggregates shift, foragers are highly knowledgeable about where to find this prey type in other sections of a patch.

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