Historical Ecology in the Pacific Islands

Prehistoric Environmental and Landscape Change

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Thirty-five years ago Raymond Fosberg (1963:5) wrote, "It is clear that the arrival of man has invariably increased, to some extent, the degree of instability in these [island] systems. With the advent of modern man this increase has frequently assumed catastrophic proportions." At the same symposium in 1961, Cumberland (1963:191) pointed to early "Moa-hunters" in New Zealand as responsible for massive disturbance and modification; hunting and the widespread use of fire had driven several species of birds to extinction. In contrast, Cumberland (1963:263) argued, the Maori—then believed to be descendants of a second Polynesian migration to New Zealand—were conservationists and nowhere caused wholesale transformation of the environment or disastrous disturbance of the ecosystems. These and similar views expressed at the symposium pointed to an emerging paradox: Polynesians were seen as conservationists, yet island environments had been greatly transformed.

Archaeologists and natural scientists have learned a great deal in the Pacific through interdisciplinary research since the Fosberg symposium. Their studies document biotic and landscape transformations resulting in
some cases from natural causes, in others from human agency. Recently, Nunn (1991, 1994) has stressed the significance of natural environmental changes. In contrast, numerous studies (Christensen and Kirch 1996; Flannery et al. 1991; Hughes 1985; Kirch 1984c, 1983; Kirch et al. 1986; Kirch and Yen 1985; McGhee 1989; Olsen and James 1984; Steadman 1990a) have demonstrated the fragility of island environments and the significant role of direct and indirect human-induced changes, especially to island biota. We have begun to attain a more sophisticated understanding of the relative importance of changes in island environments induced by natural agencies, prehistoric human populations, and post-European contact populations. This success owes a great deal to the collaborative, interdisciplinary efforts of archaeologists, geologists, and biologists.

In this chapter we present the results of interdisciplinary research at the To'aga site on Ofu Island, part of the Manu’s Group of American Samoa (Fig. 6.1). Our archaeological work, which included studies of coastal geomorphology and sediments, marine and mammalian fauna, avifauna, and land snails, points to the dynamic interplay of natural and human-induced change on Ofu Island. We suggest that this change is paradigmatic of many other cases in the Pacific. As the chapters in this volume illustrate, documenting change in island environments provides an essential historical context for research in such fields as ecology, evolutionary biology, biogeography, and archaeology.

THE OFU ISLAND ENVIRONMENT

The Manu’s Group, an inaccessible cluster of three small, relatively young islands—Ta’u, Ofu, and Ofu—lies 100 km west of the larger island of Tutuila (Fig. 6.1). Ofu and Ofu’u are closely adjacent, separated by a narrow and shallow strait, now spanned by a concrete causeway. The weathered volcanic cone of Ofu is only 3.4 km², reaching a maximum elevation of 659 m; approximately 91% of Ofu’s land is comprised of slopes steeper than 30 degrees. Ofu’s geologic youth (averaging 0.3 million years; Metcalfe 1985:318) is attested by its precipitous topography, shaped by faulting and landslide events that have formed sheer cliffs around much of the island. Erosion by intermittent streams has only slightly altered the island’s morphology. Coastal terraces range from only 50 to 150 m in width and are found along the western and southeastern shorelines. These coastal terraces are especially important to the island’s human history, and today are where the island’s roughly 230 people live.

Samoa lies within the humid tropics, with near constant temperature and humidity and abundant rainfall (Buxton 1930-17). Average temperatures vary
from only 22.7 to 26.2°C, with humidity ranging between 80 and 86%. The total annual average rainfall (recorded from Tutuila Airport) is 3,100 mm (Nakamura 1984, Table 1). Rainfall is variable, and there are extended dry seasons, with droughts that can significantly affect agricultural production. The wet season (October to March) can bring torrential rains and damaging floods—some associated with tropical storms and hurricanes (Nakamura 1984:2). Visher (1925:27, Table 6) indicates an annual frequency of two to three hurricanes in the area of Samoan, some hitting the islands directly and bringing devastation to crops, houses, and human life. The terrestrial rains cause landslides, and storm surge can reshape the shoreline and configuration of the coastal terrace in a matter of hours (e.g., see Batlin-Smith 1988).

Soils on Ofu are young and in consequence poorly developed (Nakamura 1984). Most of the steep interior is covered with "Ofu silty clay," a deep well-drained soil formed in volcanic materials. In the steepest areas (slopes 40 to 70%) this soil is covered in forest. On the gentler slopes (15 to 40%) these silty clays are under shifting cultivation. These interior gardening zones are confined to the western slopes and to the northern slopes of Tutuila.
Mountains. Very steep slopes and areas of talus, such as on the interior edge of Te'aga, have a soil that Nakamura (1984:11) describes as a very steep rockoutcrop association. On the interior edge of the coastal terrace is ‘Asia very stony silty clay loam’ (Nakamura 1984:10), characterized as very deep well drained not formed in colluvium derived essentially from basic igneous rock. The zone of stony colluvium is used for subsistence gardening, primarily cultivation of bananas and breadfruit. Finally, the coastal terrace that skirts most of the south and west shores of Ofu has a "somewhat excessively drained soil... derived from coral and shell [Ngendeus mucky sand] (Nakamura 1984:15). This zone supports extensive subsistence gardening, including cultivation of traditional root crops and arboretum (Kirch 1993a).

Contemporary vegetation communities on Ofu attest to several millennia of human land use. The vegetation of the lower elevations and coastal terraces of the island is strongly anthropogenic, with a mosaic of coconut stands, breadfruit and banana orchards, and areas gardened with second growth, a "transported landscape" in the sense of Anderson (1952). (See Kirch 1993a:13-20 for descriptions of the floral dominants along vegetation transects across the coastal terrace at Te'aga.) Only on the higher, steeper slopes does rainforest prevail. Yunker (1945b) lists 421 taxa, including mosses, ferns, lichens, and flowering plants. In his botanical survey of the three islands of Manu'a.

The vertebrate terrestrial fauna of Ofu is quite restricted, although somewhat richer in invertebrates (land snails and insects). The only indigenous mammal is the Fruit Bat (Pteropus samoensis), found in abundance and well taken for food. The Pacific Rat (Rattus exulans), domestic pigs (Sus scrofa), and dogs (Canis familiaris) were introduced prehistorically by Polynesians. The modern avifauna of Ofu includes native landbirds and nesting seabirds (Wingard 1982). The higher elevation forests of Ofu are inhabited by the hoopoe (Ornismus palmarum), and the mourning, or Crimson-crowned Fruit-Dove (Ptilinopus porphyreus), both occasionally taken for food. White-collared Kingfishers or ti'ota (Halcyon chilorea variegata, a Manu'a subspecies), Banded Rails, or ca'a (Gallirallus philippinensis), the Polynesian Starling, or mutiu (Aplonis tambica), and the star or Wattled Honeyeater (Haliartus carunculatus), are relatively common in the coastal bush and gardens. A variety of seabirds and some migratory birds also now on Ofu, including the taut'e, or White-tailed Tropicbird (Phaethon lepturus), and the seasonal migrant, hali, or Lesser Golden-Plover (Pluvialis dominica folia). The only other vertebrates on Ofu are small lizards in the families Gekkonidae and Scincidae.
Houhip-i-'Eco!Ecology of Ofu Island

Of particular significance to paleoenvironmental reconstruction are the terrestrial mollusks often preserved by and recovered from archaeological contexts. These include endemic, indigenous, and synanthropic taxa introduced by prehistoric Polynesians or after European contact. Kirch (1992b) has analyzed land-snail assemblages from the Ta-'aga site, and we draw on these results here.

Ofu is surrounded by a fringing reef, providing microhabitats for abundant fish, shellfish, and other food resources. The fringing reef is widest and most sheltered at the western side of the island. Here a diverse array of mollusks inhabit the algal crest and reef flat, including bIVALves like Pteridapecten reticulatus, Tritacna maximax, Hippopus hippocrepis, and Asphixia violacea, as well as gastropods like Terebra maculata, Turbo serassii, Nerita spp., Cyprea spp., Drupa spp., Tairi armigera, and Conus spp. Many of these shellfish have been important sources of protein, as shown by the analysis of the archaeological faunal remains (Nagasaki 1993). Also present on the reef are spiny lobsters (Panulirus spp.), sea slugs (Holothuroidea), sea urchins (Echinoidea), octopus, and a variety of edible seaweeds. Approximately 800 tons of indigo fishes occur in Ofu's waters (Jordan and Seale 1960), and they form a significant part of the traditional Samoan diet. Among the fish commonly taken are jacks (Caranx spp.), parrotfish (Sparus spp.), wrasses (Labidae), and acanthurids. The open sea beyond the reef provides rich pelagic resources, such as the prized tuna (Scomistidae). Marine turtles (Chelonia mydas and Eretmochelys imbricata) are not commonly seen in Ofu waters today, but they were undoubtedly once more common, as archeofossil evidence attests to their heavy exploitation in prehistoric times.

In sum, the contemporary environment of Ofu, as of many other Pacific islands, reflects in natural geological and biotic history, as well as the consequences of human settlement and some three millennia of cultural manipulation. Precisely because Ofu is a rather small island it may be ideal for modeling the dynamic interplay of natural and human-induced factors. In spite of its diminutive size, Ofu supports a variety of habitats, including the persistence of comparatively pristine rainforest. However, the island also has a substantial anthropogenic component, particularly on the coastal terraces and areas of low elevation where the vegetation has been transformed into an economic landscape. Ofu is thus a microcosm of larger high islands, where the human hand has affected microenvironments differentially. Ofu, unlike some other small islands (e.g., Mangui, Kirch et al. 1992; Kirch, Chapter 8), has not seen massive environmental degradation. Rather, the island's ecological history reflects the delicate balance between human impacts and natural resilience and recovery. Understanding Ofu's
environmental history has implications in comparative context for many other Pacific islands.

THE TO'AGA ARCHAEOLOGICAL PROJECT

Archaeological investigations of the To'aga coastal terrace on Ofu Island were carried out from 1986 to 1989 (Kirch and Hunt, eds., 1993). Numerous surface stone structures and pottery-bearing deposits at least 2,000 years old (based on comparative evidence from Western Samoa) (Green 1974) were discovered in 1986. In 1987 and 1989 we conducted excavations totaling 27 m\(^2\), systematically sampled along 17 transects designed to crosscut the geomorphic variability of the coastal terrace (Fig. 6.2). Details of the fieldwork and results from several specialized analyses are reported in the monograph we edited (Kirch and Hunt, eds., 1993).

A major objective at To'aga was to reconstruct the island's occupational chronology in relation to the geomorphological and paleoenvironmental history of the coastal lands. For this reason, we paid special attention to details of coastal-terrace stratigraphy and correlation across units. Geomorphological analysis of sediment samples and radiocarbon dating were used to reconstruct the depositional history and chronology of the coastal terrace. Our excavations also recovered extensive faunal remains (marine and terrestrial vertebrate remains, marine mollusks, and terrestrial gastropods), which provided critical data on the human-use biota over the past three millennia.

The chronology of human occupation and of coastal-terrace formation along Ofu’s southern coast is indicated by a suite of 14 radiocarbon age determinations, spanning the period from about 3500 cal B.P. to 1600 cal B.P. (Kirch 1993c, Fig. 6.1). Polynesian populations had colonized Ofu by at least 3257 to 2879 cal B.P. (Beta-25901), and there are indications from two older samples that colonization might have occurred slightly earlier. These first settlers produced earthenware pottery for at least 1,000 years (Hunt and Erleleis 1993), then abandoned ceramics for reasons that remain unclear. Other artifacts recovered in our excavations include stone adzes, shell ornaments and fishhooks, hammerstones, and coral and sea urchin spine abraders. There is evidence for interisland transport, perhaps of ceramics and, more definitively, of fine-grained basalt adzes (Weisler 1993).

We now turn to a review of the evidence from the To'aga site for changes in the geomorphology and biota of the Ofu coastal terraces, evidence from which the historical ecology of the island of the past 1,000 years may be reconstructed. The full data sets on which our summary is based have been publish-
Figure 6.2 Schematic profile along the 1987 excavation transect at Tō'ega, showing the main geomorphic features and stratigraphic zones.
ed elsewhere (Kirch and Hunt, eds., 1993), and we shall draw only on selected examples to illustrate our key points.

LANDSCAPE CHANGE

During excavation and mapping of the To'aga coastal plain we noted that archaeological deposits containing pottery—known in Samoa to be approximately 2,000 to 3,000 years old—were restricted to a zone along the interior of the coastal terrace. This interior edge of the coastal terrace is defined by 500 m high cliffs, large boulder talus slopes, and gravely clay-loam soils. Moving only a few meters seaward, terrace stratigraphy changed to interbedded strata of terrigenous colluvium (derived from mass wasting and slope wash) and calcareous sands of biogenic origin. Near the present shoreline, deposits consisted of unconsolidated calcareous sands with only recent cultural materials. Exposed beach rock and the undercutting of large shoreline trees indicated active coastal erosion. These initial observations suggested that the coastal terrace along Ofu’s southern shore was geomorphically dynamic, that a sequence of shoreline progradation had occurred during prehistoric occupation of the area, and that a new phase of erosion was under way. Any understanding of the chronology of occupation and deposition of cultural remnants—our “site formation,” as it is known to archaeologists—would have to account for the formation of the coastal terrace. Careful stratigraphic analysis, radiocarbon dates, and geologic comparisons in the region provided the elements of a model for environmental change at To’aga. The long-term geomorphic sequence at To’aga includes interrelated factors of sea-level change, island subsidence, and sedimentary budget. Kirch (1993b) has constructed and modeled this sequence, testing it against our field geomorphological and archaeological data (Kirch and Hunt 1993).

The stratigraphic profiles revealed by several transect excavations revealed a consistent depositional history for the To’aga coastal terrace. The reconstructed sequence for Transect 5 provides an example of landscape evolution of the coastal terrace:

Stage 1 (>3200–2900 cal B.P.): A narrow coastal bench at the base of the steep talus was formed. The active shoreline at this time would have been in the vicinity of Units 16–17, considerably inland of the modern shoreline. The “salt-and-pepper” lithology of the beach ridge sediments (mixed sandly and calcareous grain) indicates episodes of volcanic boulders along the coastline, providing a source of volcanic lithic grain. In addition, the presence of larger clastics (coral cobbles, branch coral fragments) indicates a fairly high energy shoreline.
Stage 2 (ca. 3200–2800 cal B.C.): Humans began to occupy the narrow bench formed during Stage 1, resulting in non-concentrated midden deposits that contain this, fine-tempered, orange- or red-slipped pottery in Units 28 and 15/28/30. The main area of occupation was probably farther inland from Unit 28, and then in a newly formed and located colliuvium. The deposits exposed in Units 28 and 15/28/30 appear to represent the seaward periphery of such an occupation, down the slope of the former beach ridge toward the old shoreline. Archaeological exposure of the possible main occupation zone would require the use of heavy machinery, since as much as 5–15 m overburden of boulder talus and colluvium would probably have to be moved.

Stage 3 (ca. 2800–2000 cal B.C.): Deposition of calcareous sands onto the beach ridge continued, with significant seaward progradation of the shoreline occurring late in this phase. . . .

Stage 4 (ca. 2000–1400 cal B.C.): A stabilized land surface formed during these four centuries over the now wider and prograded coastal terraces, marked by a palaeosol horizon (Layer HIA-1 in Units 15/29/30, Layer 1C in Unit 16, Layer IVB in Unit 17).

Stage 5A (ca. 1600–1400 cal B.C.): The stabilized coastal terrace in the vicinity of Units 16 and 15/28/30 was occupied during this terminal phase of ceramic manufacture and use on Ofu Island. . . .

Stage 5B (ca. 1400–1000 cal B.C.): Ceramic occupation on the coastal terrace in the vicinity of Unit 17 resulted in the construction of a low house mound formed by several successive gravel (diluvial) pavements.

Stage 6 (< 1000 cal B.C.): A tongue of clay-silt colluvium was deposited out onto the coastal terrace, probably due to increased up-slope forest clearance, agricultural activity, and subsequent erosion. At this time the coastal terrace was used for re-cropping and shifting cultivation, continuing into the present era. [Kirch and Hunt 1993:67–68]

Accounting for the depositional history revealed at Transect 5 and other localities—with a rapid coastal progradation commencing after about 2000 B.C.—requires a morphodynamic model that takes account of regional eustatic sea-level variations, local tectonics, and changing local sediment budgets. A rapid eustatic rise to global sea level associated with the terminal Pleistocene is well established (e.g., Fairbridge 1961, Sheppard 1963). More complex are mid-to-late Holocene changes, varying dramatically with local conditions and processes. Using global Holocene data, Bloom (1980, 1983) argued for a 1–2 m higher sea level for the South Pacific. Substantial evidence from several South Pacific islands now supports Bloom’s model for 1 to 2 m higher levels during the period between 4000 and 2000 B.C. (see Kirch 1993b, Fig. 4.4, for a summary). Nunn’s work on Fijian shorelines, for example, points to a 1 to 2 m
higher stand of the sea (Nunn 1990, 1994). In the central Pacific, comparable evidence has come from recent research in Tonga (e.g., Kirch 1984: Nunn 1994), Western Samoan Samoas (e.g., Nunn 1992, 1994), the Cook Islands (Stoddart et al. 1995; see also Chapter 7), and French Polynesia (e.g., Prinz and Montgomery 1986). The general pattern provides strong evidence for 1–2 m higher sea level from about 5000 yr until sometime between 1000 and 2000 yr, when sea levels fell to modern positions.

A second factor in explaining the depositional history at To'aga is local island subsidence. As with most volcanic archipelagos of the central Pacific, the Samoan Islands formed on a "hot spot" on the Pacific Plate. As the plate migrates, islands subside as they age. Subsidence also occurs with point loading, where the volcanic mass of a young island causes crustal deformation. While there is no direct geological documentation of subsidence of Oufa Island, evidence from Mulifanua in Western Samoa suggests how rapidly the Samoan Islands may be sinking. Mulifanua is a volcanic tuff, with volcaniclastic deposits that have been dated to 5350 ± 35 yr B.P. (Crosier 1890). This deposit correlates to the modern mean high tide of 1.8 m above the reef flat. This elevation correlation provides solid evidence of local tectonic subsidence. "Thein situ tuff materials in Units 25 and 28 were clearly deposited on a narrow terrace or beach ridge that must have been at least 1 m, and more likely 2 m, above the present mean high tide of 3.5 m; this means that the To'aga site has undergone between 2–3 m of tectonic subsidence over the past three thousand years, as suggested by the morphodynamic model. ... The alternative hypothesis—that there was no tectonic subsidence—would require the deposition of the occupation deposit under water, a physical impossibility given the sedimentological evidence" (Kirch and Hunt 1989:68). Corroborating evidence was also obtained from Transect 9 (Figure 6.3).

Sea-level change and subsidence alone do not account for the shoreline progradation at To'aga. As Chappell (1982) points out, the sedimentary
Figure 6.3 Schematic profile along Transect 9 at 1' 10" site, showing the relation of buried occupation deposits to the modern shoreline and sea level.
Budget is an important factor in the propagation process. While some sediment was provided by weathering of the volcanic cliffs above the site, most of the coastal terrace is composed of marine biogenic sediment—calcareous sands and larger clastics of coral or reef conglomerate. Sediment is formed by wave erosion and biologic processes, such as generation of sand by parrot fishes that rasp and grind coral to extract algae. High-energy storm swash and cyclones are also important means of generating rapid accumulation of sediments, transforming many coastal and still landforms in a matter of days (e.g., Bryan-Smith 1980). Under normal Holocene conditions, during periods of rapid sea-level rise when corals are actively growing below mean sea level, the generation of sediment would be reduced. When sea level dropped or was stable, coral growth would have caught up, allowing erosion and an increased sediment budget (Kirch 1996b, Fig. 5.8). We modeled these factors in temporal context for the morphodynamics of the Ofo coastal terrace.

Terrigenous sediment also contributed to the buildup of the coastal terrace, through the processes of rockfall, mass wasting, and sheet erosion. The presence of people on Ofo from nearly 2000 B.P. accelerated the erosion of terrigenous sediment when land was cleared by slash-and-burn techniques for agriculture. That humans played a role in erosion and landscape change is shown by the presence of charcoal beds in the earliest charcoal deposits at To'aga (Kirch and Hunt 1990; see also Kirch and Yan 1982 for discussion of similar evidence for Tokopia Island). In the Ofo case, however, human-induced erosion played only a relatively minor role, in concert with other dynamic processes in the dynamic development of the coastal terrace.

In sum, Holocene glacio-eustatic rise in sea level reached a maximum at +1.5 m in the South Pacific between 4 to 2 kyr B.P. Before about 2200 B.C., the Holocene sea-level maximum would have worked to erosive forces on the cliff that now defines the interior of the To'aga coastal terrace; indeed, this feature has been described as a remnant sea cliff by Sites and McCoy (1968). Evidence from To'aga indicates that sea level assumed its modern position about 2000 B.C. after which time the coastal terrace prograded primarily though rapid deposition of biogenic sediment. With tectonic subsidence of Ofo, the local relative sea level was stable or fell slightly, a period when the biogenic sediment budget would have increased significantly (Kirch 1993b). Over the past 1,000 years, as sea level stabilized and subsidence continued, the sediment budget declined and shoreline erosion recommenced. Human activities also contributed to the formation processes of the coastal terrace. Forest clearance for swidden cultivation and the associated use of fire would, by inference, have meant destruction of natural habitats for native plants,
birds, and other fauna. The model for dynamic changes to the Ofa coastal terrace is graphically summarized in Figure 6.4.

**CHANGES IN ISLAND BIOTA**

Vertebrate and invertebrate fauna deposited as food remains, and in some cases as a natural component in the sedimentary process, are well preserved in the calcareous deposits of the To'aga site. Indeed, the To'aga excavations produced one of the largest and best preserved faunal assemblages yet recovered from Western Polynesian archaeological contexts. We examine here three sources of evidence for biotic changes from To'aga: (1) the fish, shellfish, and mammalian remains (analyzed by Loa Nagaoka 1983), (2) the avifaunal records (analyzed by David Readman 1983), and (3) the subfaunal land snails (analyzed by Kirch 1983d). These independent lines of evidence provide a complementary view that forms a reliable measure of biotic change on the island.

One of the impacts wrought by prehistoric human populations on Pacific islands was the introduction of larger vertebrate animals, especially the domestic pig and dog, and the fowl, Chicken (*Gallus gallus*)—though not abundant—is the most common of the Polynesian-introduced domesticates in the To'aga faunal assemblage (16% of the most common land species found in the avifaunal assemblage). It is present in an early-dated context, about 2000 to 2300 cal BP, indicating that chicken was introduced to the island by the initial human colonizers. Pig, however, is only unambiguously present in later contexts, and we are therefore uncertain as to the date of its first introduction to the island. Some of the identifiable medium mammal bone in early stratigraphic contexts may well be pig, dog, or both, so that the absence of these domesticates in early contexts is not certain. But, perhaps significantly, despite the large and well-preserved faunal sample, pig, dog, and chicken are not well represented, suggesting that they may not have been present in large numbers in prehistoric times. The Pacific Rat (*Rattus exulans*), a synanthropic species transported either inadvertently or intentionally by Polynesians, is present in the earliest cultural deposits at To'aga and throughout the rest of the sequence (total 350,000). As on many other Pacific islands, *R. exulans* appears to have arrived with the earliest human colonizers of Ofa.

Recovery of marine animals dominates the To'aga cultural deposits, with over 2,500 identified fish bones, 36 marine-turtle bones, and large quantities of mollusks and other invertebrates. Nagaoka's (1983) analysis of fish bones shows that the composition of the To'aga marine fauna changed little over time, suggesting that the level of exploitation was not severe enough for exter-
Figure 8.4  Time trends in four key variables affecting the morphodynamics of the Toaega coastal terrace.
pation or extinction of taxa. The rank-order structure of exploitation shows emphasis on a small number of taxa from the marine environment. Most fish are from inshore-reef or reef-edge habitats, taken with a variety of strategies, including netting, seineing, poisoning, and angling. When Diodontidae (42.1%) is removed from the analysis (it may bias estimations because identifiable parts are robust and distinctive), fishes from the Acantthidae (18.9%), Serranidae (17.7%), and Holocentridae (13.7%) families are most common (Nagaoa 1993:211). Other fishes, represented in lower rank-order abundances, include Scaridae (parrot fish), Carangidae (jacks), Labridae (wrasses), Lutjanidae (snappers), Muraenidae (manny eels), Balistidae (trig- gerfish), and Ostraciidae (bodfish). These, like the high-ranked taxa, are inshore-reef or reef-edge fishes. Also represented, however, albeit in small numbers, are members of the Scombridae (tunas and mackerels). These fish come from the offshore, pelagic zone and indicate the strategy of trolling.

The invertebrate fauna displays a comparable rank-order structural pattern. More than 165 kg of shellfish remains were recovered in the To'aga excavations, with more than 40 families represented. Nagaoa (1993:197) shows that more than 76% of the identified shell comes from just three families: Tur- biniidae, Trochidae, and Trygonidae. The large gastropod Turbo anthos dominates the assemblage, ranging from 29 to 40% of the total shellfish based on weight in samples from To'aga.

A relative shift from the exploitation of wild resources—such as bird, turtle, or fish—to a greater reliance on domestic resources—such as pig—has been postulated for certain island sequences (e.g., Dye and Steadman 1990). In the To'aga case, however, no clear quantitative shift is evident (Nagaoa 1993:207). While some wild resources (bird and turtle) are represented early in the sequence, but not later, they never comprised a predominant component of faunal record. Instead, a subsistence economy focused largely on marine resources, at least from the perspective of the faunal record, appears on present evidence to have been stable, in spite of the dramatic landuse changes occurring on Ofu. The stability in marine subsistence, different from many cases documented in the Pacific (e.g., Kirch and Yen 1992), may well reflect the high productivity of a living reef. Unlike other reef environments, the fringing reef of Ofu continued to grow as the island subsided (Kirch 1990b). Continuous coral growth would support a rich, diverse fish and mol- lucan fauna. The high productivity of such reef environments (Wiens 1982) could apparently sustain continued human predation without a discernible impact on the archaeofaunal record. Thus, we should anticipate variability in subsistence composition, structure, and temporal trajectory, given the unique historical and environmental factors from islands across the Pacific.
While the marine fauna shows no evidence of substantial human impact, the terrestrial avifauna from the To'aga site does reveal significant human-induced changes. The bird bones (1.39 wt%) from To'aga have been analyzed by David Steadman (1993), whose analysis proxies a striking example of human impacts on the biota of Ofu. Among the indigenous, resident species recorded from Ofu, five of 10 seabirds and one of three landbirds are extirpated on the island today. Two bones from a Megapodius sp. in the earliest dated deposits at To'aga indicate the presence of megapodes farther east than previously known. This bird—once found in later archaeological contexts at To'aga—must have been extirpated to the point of extinction early in the island's prehistory. The majority of bird bones from To'aga (62%) are of some five species of petrels or shearwaters, none of which nests on Ofu today. Indeed, Steadman (1993:226) notes a pattern of systematic butchering among the shearwaters and petrels suggested by both ends of the lumina, ulna, and tibiotarsus being broken off, implying direct predation of these birds for food. Only two of the extirpated species, Audubon's Shearwater (Puffinus lherminieri) and the Tahiti Petrel (Pterodroma rostrata), are known to nest today in American Samoa. Two of the surviving species (Sterna sp., Gallicolumba striata) exist on Ofu only in small, threatened populations. As Steadman (1993:226) concludes, "Should these [two] species be lost from Ofu, the proportion of bones of extirpated species at To'aga would increase from 85% to 93%.

The Ofu case thus joins a number of archaeologically and palaeontologically documented instances of severe avianal depletions on Polynesian islands following prehistoric human colonization (Steadman 1989a: Chapter 4). The reduction in bird populations and species diversity on Ofu and elsewhere can be attributed in large part to habitat alteration—habitat destruction for many birds—as well as direct predation of the avifauna. In many cases, birds offered a valuable, easily procured source of protein and fat, and they were widely hunted in Polynesia (see Chapter 4). Removal of large tracts of native vegetation through the creation of agricultural landscapes would also threaten birds. This sequence is one that appears to have occurred throughout the Pacific—with New Zealand one of the most dramatic examples from the region (Anderson 1969a, 1988b).

Finally, the sequence of terrestrial gastropods recovered from the To'aga deposits also informs us of the nature and degree of human-induced changes on Ofu (Kirch 1993b). These land snails are small (1–3 mm), and their presence in archaeological deposits is due not to human deposition but to their presence as natural components of the depositional environment. Land snail assemblages thus reflect vegetative conditions in the immediate vicinity at the time of deposition. Analysis of land snails has a comparatively long history in
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British and European archaeology (e.g., Evans 1972) but was neglected in Pacific archaeology until the work of Christensen and Kirch (e.g., 1984, 1987). They have shown the value of land-snail studies for documenting local environmental changes (especially in vegetation) and the introduction of exotic biota by prehistoric humans. Exotic introductions are indicated by synanthropic or anthropophilic snails closely associated with human cultivars, gardens, and habitats.

Kirch (1986b: Tables 8.1, 8.2) found that the To'aga land-snail assemblages were dominated, in early deposits, by anthropophilic rather than indigenous or endemic land-snail taxa. In the earliest sample represented, at about 2500 cal B.P., five human-introduced, anthropophilic land-snail taxa (Assemblina cf. timida, Lamellides pusilla, Gastrocoptes pellucidus, Liardetia samoensis, and Lamellariella gracilis) had already become well established on the coastal terrace. Two indigenous small taxa, Pleurophora sp. and Simplex, sp., are represented, but already in very small quantities. Kirch (1986d:118) also notes a striking trend in the distribution of small taxa across strata: "The oldest sample contains only one adventive species. This species is joined by Lamellides pusilla and Gastrocoptes pellucidus in Sample 2, and by Lamellariella gracilis and Liardetia samoensis in Sample 3. Tinax, by the time of occupation represented in Layer III, ca. 2500 cal B.P., five species had been introduced to, and become established on, the coastal terrace of Ofu Island. Because Lamellariella gracilis is particularly associated with human gardening sites, its appearance by 2500 cal B.P. is important in terms of the economic prehistory of the To'aga site."

In sum, the dominance of anthropophilic land snails supports the view of the To'aga coastal terrace as a largely modified, anthropogenic habitat occupied by gardens and human settlements. This transformation appears to have occurred within the first 500 years of occupation at To'aga, even as the land area grew through shoreline progradation that formed the coastal terrace.

Regrettably absent from our palaeoenvironmental analyses on Ofu is a sequence of vegetation change based on such evidence as pollen spectra, plant macrofossils, or woody charcoal identifications. Unfortunately, no palynological work has been done on Ofu. Taxonomic identification of wood charcoal from the archaeological deposits is possible, and the technology in the Pacific has developed dramatically in the past few years. We suspect that the vegetation history of the lower elevations of Ofu would parallel changes indicated in the land-snail and bird evidence. Probably early in the colonization of the island a large proportion of coastal land and some upland slopes were converted from native vegetation to gardens. As other Pacific Island sequences attest, Polynesians transported—that is, quickly established economic landscapes—on islands that otherwise had little to offer in the way of plant foods.
CONCLUSION

Dramatic physical and biotic changes occurred on Ofu Island over the course of its nearly 3,000-yr human occupation. Some changes, such as the propagation of the To'aga coastal terrace, cannot be attributed to human-induced changes alone. Although people have played a notable part in the physical transformation of the island, natural processes were primarily responsible. Changes in sea level, island subsidence, and related sedimentary budgets have dramatically altered Holocene shorelines. In the past, some researchers in the Pacific have conflated many of these natural and human-induced changes, placing emphasis on either the natural or the human-induced causes at the expense of an integrated perspective. We believe To'aga is instructive in this regard because it shows that it is critical to tease apart natural and human-induced processes in reconstituting paleoenvironmental change.

We have reviewed the major classes of evidence from To'aga that record dramatic landscape and biotic change, and have reconstructed the significance of the morphodynamic history of the coastal terrace. This history includes geologic processes of eustatic and net sea-level changes, island subsidence, and related sedimentation changes. Geomorphological change on the coastal terrace was also affected by human activities. Slash-and-burn forest clearance of the steep, narrow slopes above To'aga accelerated erosion of terrigenous sediments. Agricultural activities have also indubitably changed the pattern of vegetation on the island, transforming a lowland native rain forest into an agricultural, economic one. The land-use record reflects these transformations dramatically. The abundance of synanthropic taxa found early in the sequence illustrates how quickly change must have occurred on the Ofu coastal terraces. Similarly, the extirpation and extinction of avian taxa indicate the degree of human impact through predation and habitat modification (Steadman, 1993). The To'avanian vertebrate faunal record, however, suggests relative stability in the structure of subsistence. In contrast, the human population of Ofu had little significant impact on the marine environment and its abundant resources. These natural and human-induced changes documented for the past three millennia, have transformed Ofu's ecosystem from a natural landscape to an economic (or "transported") landscape where human populations can flourish.

Finally, our work in To'aga, as elsewhere in the Pacific, underscores the importance of interdisciplinary collaboration among archaeologists, geologists, geomorphologists, paleoecologists, and other natural scientists. Only through such continued interdisciplinary collaboration will we come to understand the relative contributions of natural and human agency to specific Pacific Island environmental histories.
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