

Man's Role in Modifying Tropical and Subtropical Polynesian Ecosystems

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Some years ago, Raymond Fosberg asserted that 'perhaps the thing that most distinguishes islands, at least oceanic islands, . . . is their extreme vulnerability, or susceptibility to disturbance' (1963:55). Within Polynesia, the role of prehistoric man as a major force in changing island ecosystems has long been noted for the temperate, near-continental islands of New Zealand. There, the startling discovery of extinct *moa* bones more than a century ago spurred investigations that have gradually led to a picture of human-induced landscape alteration and biotic change on a massive scale. The evidence for forest retreat under the impact of burning (Cumberland 1961; Molloy *et al.* 1963), and of the extinction — not only of the 13-odd species of *moa* — but of some 16 other endemic species of ducks, geese, crow, eagle, coot and so forth (Cassels, *ms.*), are well documented in the New Zealand literature.

For the myriad tropical and subtropical islands of Polynesia, there has, in contrast, been relatively little intensive research on prehistoric man's role in altering indigenous biota and landscapes. This situation is, however, rapidly changing, with recent investigations in several island groups demonstrating that vulnerable Polynesian ecosystems underwent often drastic transformations following upon human colonization.

In assessing evidence for human-induced changes in Polynesian ecosystems, we may speak of three major processes contributing to environmental transformation. First is the introduction by man to the naturally isolated, remote Pacific Islands, of a variety of adventive species. Such adventives included not only the domestic triumvirate of pig, dog, and fowl, along with a score or more cultigens, but a range of inadvertent synanthropic or anthropophilic 'stowaways' (rats, terrestrial snails, cockroaches,

mites, skinks, geckos, and weeds). Direct archaeological evidence of domestic animals (and indirect evidence for the crop plants) has long been available from a number of early Polynesian sites. Only recently have such items as gecko bones, terrestrial land snails (Christensen and Kirch 1981a; Hunt 1980; Christensen 1981), and the seeds of weedy plants (Allen 1981) provided direct testimony to man's larger role as a 'transporter of landscapes' (Anderson 1952). To anyone familiar with Pacific Island biogeography and evolution, the significance of these prehistoric biotic introductions is evident. The barrier of isolation having been breached by man, the largely endemic and vulnerable biotas of the Polynesian islands were placed in competition with, or were preyed upon by, a host of new (and generally highly competitive) adventives.

The second major process leading to ecosystem change was that of direct displacement of pre-human indigenous biota by man's actions, in particular forest clearance and exploitation of wild food resources. Prior to Polynesian colonization, most (if not all) tropical and subtropical oceanic islands appear to have been heavily forested, so that the large tracts of *Gleichenia*-fern and grassland savannah noted at European contact were the result of human action. Take, for example, the case of Easter Island, whose treeless landscape the botanist Skottsberg once thought to represent a unique 'oceanic steppe' (1956:422). Flenley's pollen cores from several crater lakes (1979, 1981), along with the evidence of root molds underlying the megalithic *ahu* (Mulloy and Figueroa 1978:22), have now indicated that Easter Island was formerly cloaked in a scrubby rainforest. Though all the results are not yet in, it is man who is most strongly implicated in the conversion of this forest to savannah (Flenley 1979; McCoy

1976). Such massive habitat alteration and destruction, combined with direct predation, doubtless affected many native animal populations as well, sometimes to the point of extinction.

Third, we may distinguish processes of modification of the physical landscape or landforms, in particular erosion and deposition (as well as the rearrangement of landscapes through construction of terraces, field systems, fishponds, and so forth). To the extent that such changes depend upon the removal of vegetation, they overlap with the second category discussed above. As archaeologists in Polynesia have widened the scope of their investigations from particular sites to whole settlement landscapes, they have begun to marshal direct evidence of such landform modification. In Futuna, for example, up to 3.5 metres of stratified alluvium and slopewash capping Lapita deposits (Kirch 1981) testify to the efficacy of even early Polynesian populations in initiating the movement of large quantities of soil and earth. The work of Hughes and others (1979) on Lakeba provides a similar picture.

Keeping in mind the three general processes of human-induced ecosystem change discussed above, we may now turn to the specific evidence recently obtained from two Polynesian localities. The first to be considered, Tikopia, is one of the smallest of Polynesian islands, although it has a lengthy occupation sequence. For contrast, the evidence from Hawaii, one of the largest of Polynesian archipelagoes with a relatively short occupation sequence, will also be considered. Together, these two case studies demonstrate something of the potential of prehistoric island populations to modify their local ecosystems.

Tikopia

Archaeological investigation of ethnographically - famed Tikopia (Firth 1936) revealed an unbroken, 3000-year long cultural sequence mirroring several major epochs of southwestern Pacific prehistory. The cultural sequence has been analyzed in full elsewhere (Kirch and Yen 1982), and here I shall focus solely on the evidence for transformation of the island's

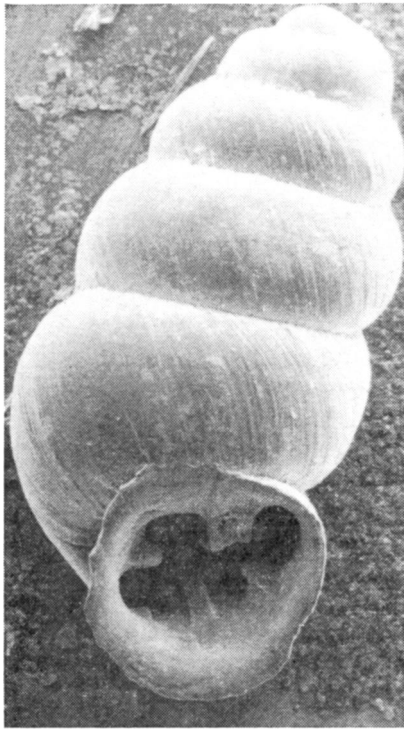


Figure 1. SEM enlargement of the anthropophilic snail *Gastrocopta pediculus*, one of several species transported throughout the inner Pacific by the Oceanic peoples. Length of shell 2.6mm. (Photo courtesy C. Christensen.)

landscape and biota. It is worth noting that the sequence of local environmental change is *not* necessarily synchronized with that of culture history as indicated by traditional material culture.

The faunal content of Site TK-4, a small hamlet settled ca. 900 BC, provides a record of the initial phase of modification of the island's biota, after colonization by a Lapitoid pottery-producing group of settlers. The usual Austronesian pattern of introducing domesticates is attested by the skeletal remains of pigs, dogs and fowl, and the presence of cultigens can be inferred from a range of evidence. Doubtless, however, the variety of adventives introduced to Tikopia by the first human settlers went beyond these purposefully transferred species. Three anthropophilic land-snails, *Lamellidea pusilia*, *Gastrocopta pediculus* (Fig. 1), and *Lamellaxis gracilis*, have been recovered from the Site TK-4 sediments, and attest to the transport of plants and edaphic media (Christensen and Kirch 1981a). The Pacific rat, *Rattus exulans*, and a larger species of Melanesian rat (possibly *Rattus ruber*, or a species

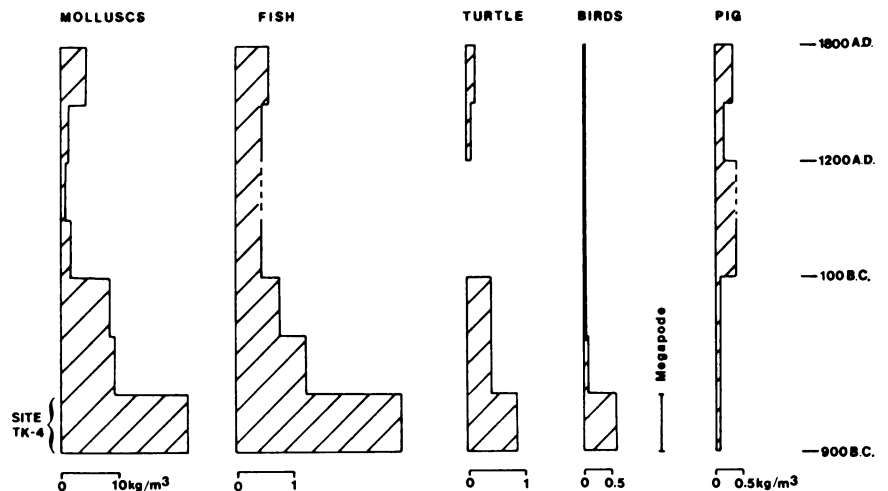


Figure 2. Change in the Tikopia faunal sequence from ca. 900 BC to AD 1800, illustrating the great reduction in wild animal resources following initial human colonization. The graph reflects estimated usable meat per cubic meter of archaeological deposit. The bottom component of the graph represents the initial colonization phase (Site TK-4).

of *Uromys* or *Melomys*) can also be counted among the early, probably inadvertent, introductions. The transference of biotic elements from neighbouring islands to Tikopia was not confined to the initial settlement period, and the cosmopolitan mixture of Melanesian and Polynesian plants on Tikopia reflects a lengthy tradition of adventive arrivals which continues today.

Against this picture of the addition of new species to the island's biota, we have the evidence of drastic reductions in the populations of indigenous species, in a few instances leading to local extinction (Fig. 2). In a pattern common to many early Oceanic sites, the initial settlers of Tikopia relied heavily upon the exploitation of wild birds, turtles, fish, and shellfish, as reflected in the faunal record of massive reductions in usable meat over time. In the case of the molluscs the large size range of individual species in the early TK-4 site is never again matched in later archaeological deposits. Most heavily affected by human exploitation were the wild birds (both land birds and nesting populations of seabirds). Among these, a species of megapode (probably *Megapodius freycinet*), and possibly an indigenous rail (*Rallus* or *Porzana*), were exploited to the point of local extinction.

The net result of these biotic introductions and of heavy exploitative pressure on indigenous species was the creation, on Tikopia, of a thoroughly anthropogenic commu-

nity. This is especially evident in the island's vegetation, where the only remnant of an original Eastern Solomons-New Hebrides rainforest clings precariously to cliff-like slopes of the crater rim. All else is some form of managed vegetation.

Even more striking than the evidence for biotic change on Tikopia is that relating to transformation of the island's physical landscape. Here we must distinguish between shoreline processes and those of terrestrial erosion and deposition. Shoreline changes in Tikopia have been particularly dramatic, including progradation of coastal dunes, the creation of a large freshwater swamp, and the closure of a former salt-water bay, creating the brackish lake, Te Roto. Quantitatively, these shoreline alterations amounted to a 40% increase in land area, and a concomitant loss of 41% in reef flat area, since the period of human settlement (Fig. 3).

To what causal mechanisms should these changes in coastal geomorphology be ascribed? The immediate answer might appear to be that such modifications are simply the reflection of the environmental initiative of the Holocene, particularly the rapid increase in global sea levels. One might also invoke local tectonic movement on the Torres-Vitiaz subplate (Hughes 1978). While such geologic forces were doubtless initiating variables of some import in the transformation of the Tikopia coastline, I doubt if they are sufficient to ac-

count totally for these changes. Rather, I believe that the net gain in land over reef on Tikopia must be explained as a combination of geologic and *cultural* actions. Such cultural practices of shoreline conservation were witnessed in the archaeological record as frequent retaining walls of coral cobbles now buried in fossil dune ridges. Ethnographically, the evidence for conservation of dunes is richer,

including such practices as seawall construction, the physical transport of sand from beach front to dune crest, the purposive in-filling of the lakeshore for land reclamation, and the planting of *Calophyllum* stands to stabilize dune surfaces (Kirch and Yen 1982). In short, while the Tikopia shoreline would probably have undergone some form of aggradation even if man had not colonized the island, I doubt that the same pronounced gain in land area over reef would have been achieved without the input from human actions.

Of equal, if not greater importance for Tikopia man-land relationships has been the alteration of the terrestrial, volcanic landscape. Here the dominant processes have been erosion of the 80,000 year-old volcanic crater, and mass transport of soil, earth, and rock from the higher volcanic slopes to the lower colluvium that forms an interface between volcanic and calcareous edaphic environments. The adaptive significance of such deposition should not be underestimated, for this colluvium is counted as the most productive agricultural land on the island, including the intensively gardened Rakisu tract (Firth 1936:Plan IV). A series of excavations undertaken in Rakisu by my colleague, Douglas Yen, yielded evidence that the rate of colluvial deposition was significantly increased in the period following human colonization, and that forest clearance with burning was a primary cause of the increased erosion on the higher slopes (Kirch and Yen 1982:147-160). The scale of erosion and deposition on Tikopia is difficult to translate into quantitative terms, but a conservative estimate of the volume of transported soil and earth that mantles the Rakisu zone stands at something greater than 100,000 cubic meters. On an island of only 4.6 km², such mass transport is indeed impressive.

We thus see from the evidence of island Tikopia, that the ability of the Polynesians to extensively modify physical landscapes was considerable, and that the use of fire in forest clearance was a major initiator of transformation. From a wider comparative viewpoint, the Tikopia evidence thus joins that of Golson and Hughes (1980) for the Kuk Swamp site in Highland New

Guinea, of Hughes and Sullivan (1981) for the impact of bushfires in Australia, and of Spriggs (1981) for valley infilling in southern New Hebrides. In Tikopia, however, the positive repercussions of erosion and deposition for intensive agriculture cannot be overly stressed.

On a small island such as Tikopia, the environmental consequences of human land utilization might expectably be rather dramatic, and the evidence relatively easy to obtain through archaeological and geomorphological investigations. What then, of a large archipelago such as Hawaii, with a land area not only exceeding that of Tikopia by a factor of 3,600 times, but with the sequence of Polynesian settlement only half as long as the Tikopian? Until recently, the accepted view appeared to be that the Hawaiian ecosystem had undergone only relatively minor transformation due to Polynesian habitation. New evidence, mostly obtained during the past decade, and much of it not yet widely published, has now caused us to drastically reconsider this viewpoint (Kirch 1982a, 1982b).

The Hawaiian Islands

As with Tikopia, we now have abundant direct evidence from Hawaii for the introduction by prehistoric Polynesians of a considerable range of exotic species. Aside from the usual domesticates and cultigens, these again include the Pacific rat (*Rattus exulans*), several species of landsnails, geckos, and skinks. In her work on the archaeobotany of the Mauna Kea Adz Quarry sites, S. Allen (1981) has recovered the carbonized seeds of several weedy plants transported by the Polynesians, including *Oxalis corniculata*, *Daucus* sp., *Solanum nigrum*, and *Adenostema lavenia*. These discoveries add time depth to St. John's (1978) analysis of the first botanical collections in Hawaii (by David Nelson, on Cook's third voyage in 1778-9), which demonstrated the importance of exotic weeds in the lowland vegetation, even at initial European contact.

The most exciting new developments in Hawaiian prehistory and paleo-environment are not, however, these records of Polynesian introductions to the Hawaiian biota. Rather it is the striking discovery over the past decade (and

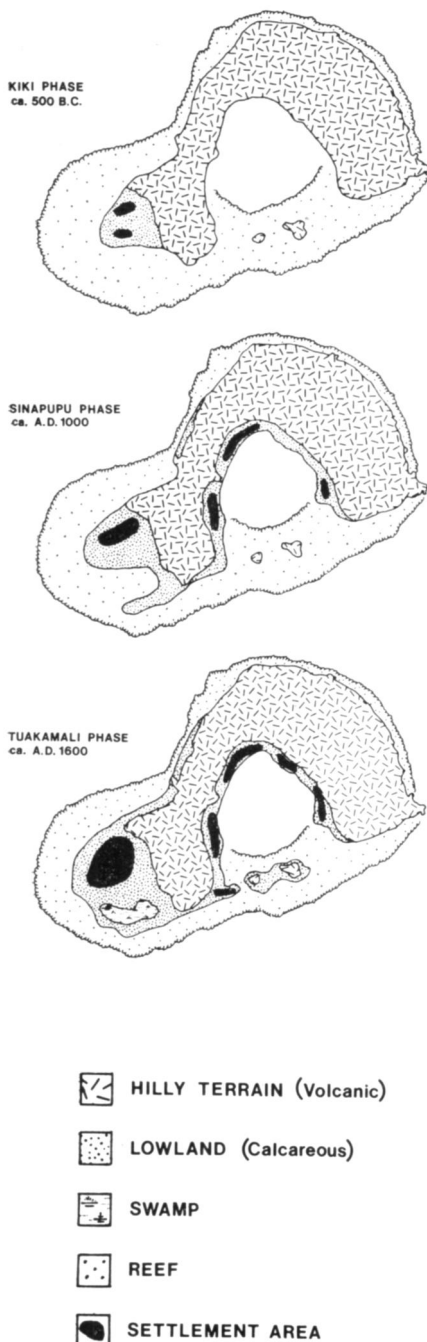


Figure 3. Paleogeographic reconstructions of Tikopia at three points in time, showing the evolution of the island's landscape and distribution of prehistoric settlements. After AD 1600, the central bay became a closed, brackish lake.

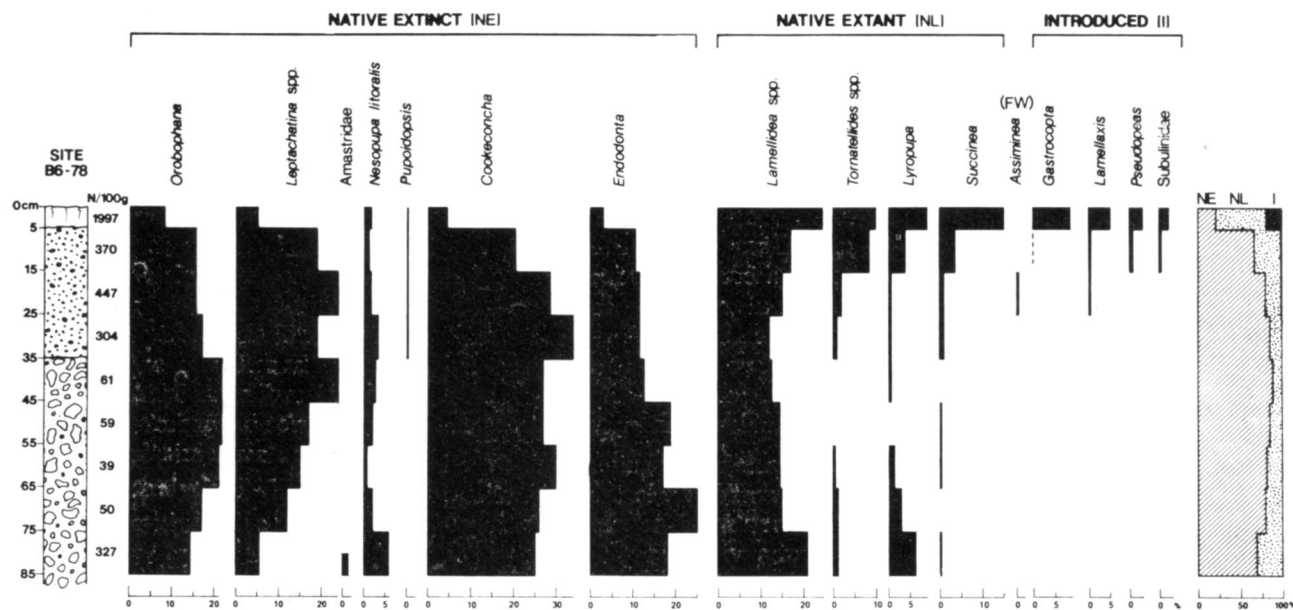


Figure 4. Stratigraphic column through the sediments in Site OA-D6-78, a limestone sink at Barbers Point, Oahu, Hawaii, showing the sequence of change in nonmarine molluscs. Layer II, from 5-35cm, contains large numbers of fossil bird bones, and represents a phase of rapid decrease in the frequency of several native snail genera (now extinct), as well as an increase in certain genera preadapted to disturbed conditions. Layer II is also marked by the presence of the anthropophilic snail *Lamellaxis gracilis*.

especially since 1978) that a large and hitherto unsuspected number of endemic bird species formerly existed in the main islands of the archipelago, and that many of these became extinct only within the period of Polynesian tenure. (As well, we now know that many species of landsnails also became extinct within the same period; see below.) Amongst students of island life and evolution, the Hawaiian Islands have long been noted for their endemic avifauna; the honeycreepers, especially, with 22 species in 9 genera, are considered a textbook example of adaptive radiation (Amadon 1950). Whilst some 40% of the historically-known endemic Hawaiian bird species are now extinct, it has commonly been assumed that such extinctions occurred largely after European contact (e.g., Berger 1972:18-20). The destruction of large tracts of native forest in the 19th century is generally cited as the primary cause.

The first hints that a number of previously unknown species of birds might have gone extinct prior to European contact came with the discovery in the early 1970s of a flightless ibis (*Apteribis glenos*) and of a large flightless goose (*Thamnetochon chauliodous*), the latter from Pleistocene deposits on Molokai Island (Olson and Wetmore 1976; Stearns 1973). Subsequently, exca-

vations by A. Sinoto (1978) in limestone sinks at Barbers Point, Oahu Island yielded large quantities of bones of extinct birds, including more than 20 species. The question of prehistoric man's role in the extinction of this diverse faunal assemblage was suddenly brought to the fore.

The deposits containing extinct bird bone at Barbers Point were also notable for their high frequency of endemic landsnails, again including many extinct species. Recognizing that terrestrial snails are potentially good indicators of paleoenvironment, Carl Christensen and I undertook a paleomalacological analysis of stratigraphic columns from several limestone sinks and open habitation sites (Kirch and Christensen 1980; Christensen and Kirch 1981b). The sequence from Site B6-78, illustrated in Figure 4, is representative of those from the Barbers Point area. The site, a small limestone sinkhole, has three stratigraphic units: Layer I, a thin overburden; Layer II (30cm thick), consisting of a mixture of decomposed limestone mixed with aeolian soil particles, contains the majority of the extinct and locally extirpated avifauna; and Layer III, a limestone breccia with scattered bird bones. Clearly, Layer II represents a period of rapid deposition, and a period just prior to the birds' extinction. It

is significant that Layer II also reflects major changes in the terrestrial snail fauna, with significant reductions in certain endemic taxa (*Orobophana*, *Leptachatina*, *Cookeconcha*, and *Endodonta*), and with relative increases in certain other taxa preadapted to disturbed conditions (*Lamellidea*, *Tornatellides*, *Lyropupa*, and *Succinea*). We interpret these changes in the snail fauna as reflecting modifications in the local Barbers Point environment, particularly in the local vegetation. That these changes are coterminous with the period of rapid deposition of the extinct bird bones furthermore suggests that the extinction process was closely linked to habitat change.

That prehistoric man was the cause, directly or indirectly, of these habitat changes, is indicated by the presence in Layer II of four of the anthropophilic animals introduced by the Polynesians to Hawaii: (1) the Pacific rat; (2) geckos; (3) skinks; and (4) the adventive snail, *Lamellaxis gracilis*. Since our paleomalacological studies were undertaken, further investigations at a very large sink (B6-22) by P. C. McCoy have yielded more direct evidence of the associations between extinct birds and man. These include the bones of a large goose in a hearth feature, radiocarbon dated to the thirteenth century AD. Further field studies, in progress at

this time, are aimed at further elucidating the role of man in the extinction of the Barbers Point avifauna.

The remains of extinct, and often large, flightless species of endemic birds are by no means confined to the Barbers Point area. Faunal material from the Kuliouou rock-shelter site, excavated by Emory in the early 1950's (Emory and Sinoto 1961), proved — upon re-examination by Dr Storrs Olson (pers. comm.) of the Smithsonian Institution — to contain skeletal parts from several extinct species, including a flightless goose. From the Kawela Mound site on leeward Molokai, we now have evidence that the *nene* (*Branta sandwicensis*), an endemic goose known during the historic period only from Hawaii Island, persisted until as late as AD 1500 (Weisler and Kirch 1982). Similarly, a refuge cave near Kailua, Kona on Hawaii, recently excavated by Rose Schilt of the Bishop Museum, has yielded the remains of yet another new species of very large, and probably flightless, endemic goose, along with those of a possible new species of rail, and of the locally extirpated petrel.

These few examples, selected from amongst a range of new evidence, leave little room for doubt that the period of prehistoric Polynesian occupation of the Hawaiian chain saw the rapid extinction of several tens of endemic bird species. Storrs Olson and Helen James (1982), who have studied much of this new material from a taxonomic viewpoint, believe that the main cause of extinction was the radical alteration of the lowland dry-forest habitats by the Polynesians, an interpretation with which I completely concur. Thus, the Hawaiian case must now be counted with that of New Zealand with regard to avifaunal extinctions. (Amazingly, the evidence for these extinctions in Hawaii remained unrecognized during nearly 30 years of intensive archaeological excavations!)

The impact of the prehistoric Polynesians on the Hawaiian ecosystem was certainly not confined to the introduction of exotic species and to the extinction of endemic birds and landsnails. As I have noted, the faunal extinctions themselves mirror major modifications

of the lowland habitats. In particular, recent evidence suggests that considerable tracts of lowland dry-forest or parkland were converted, largely through the use of fire, to open grassland or savannahs. Analyses of pollen, opal-phytoliths, wood charcoal, and landsnails from sites in the Waimea-Kawaihae area of Hawaii Island (Clark and Kirch 1983) have suggested precisely such a vegetative transition over the last few hundred years of the Hawaiian sequence.

Evidence for local erosion resulting from the firing of native vegetation has been obtained from several islands. In the Halawa Valley, on Molokai, a series of stratified colluvial beds containing abundant charcoal and endemic landsnails indicate burning of the valley slopes, and consequent erosion, beginning by AD 1200 (Kirch and Kelly 1975:55-64, 180-183). In the upper Makaha Valley, Oahu, a local slumping of colluvium, believed to have been initiated by shifting cultivation, resulted in the burial of a taro irrigation system (Yen *et al.* 1972). More dramatic evidence comes from the dry, leeward island of Kahoolawe, where 'burn layers' containing charcoal and extinct landsnails, dated to the 16th century AD, mark the beginning of a phase of island-wide erosion (Hammatt 1978, Hommon 1980).

It is only within the past few years that Hawaiian archaeologists have begun to look explicitly for the evidence of environmental change during the period of Polynesian tenure. The advances in our knowledge, made in such a short time, hint that further studies of prehistoric man-land relationships, now in progress, will indeed be rewarding.

Conclusion

To sum up, I wish to return briefly to the general theme of this symposium, the disentangling of human and climatic influences in the changing environments of Australia and the Pacific Islands. I have focused above on the evidence for environmental change from two Polynesian localities, both settled relatively late in the overall time frame of man in the Pacific region. Though the cultural sequence for Hawaii spans at most a mere mil-

lennium and a half, we have seen that time itself was not a determinant of the degree to which humans were capable of initiating major ecological change. More important, it would seem, was the fragility and vulnerability of the remote, insular biota of the inner Pacific Islands. Once the barrier of isolation was broken by seafaring Polynesians, it was possible for drastic transformations of biota and of landscape to occur, on a time scale measurable in centuries rather than millennia.

Based on the evidence from Tikopia and Hawaii, it would clearly seem that the dominant agent of environmental change — during the period that man has occupied the islands — was man himself. This does not imply that climatic change may not have played some role, but simply that whatever environmental shifts were owed to climatic initiative, these were significantly overshadowed by man's own actions.

The investigation of man's role in modifying tropical and sub-tropical Polynesian ecosystems would appear to be of value not only for prehistory, but for the study of island evolution and biogeography as well. We cannot assume that the biota of the Pacific Islands, as known to the first European explorers, represented anything like an original pre-human biota. Such uncritical assumptions have, however, underlain much of the work in island biogeography, such as the correlation of island size and species diversity (e.g. McArthur and Wilson 1967). Clearly, the data of prehistory may be of inestimable value in reconstructing the nature of Oceanic ecosystems prior to man's arrival, and of establishing a baseline upon which more sophisticated models of insular evolution may be constructed. Our recent efforts in Hawaii have certainly revealed the reciprocal gains possible through close interdisciplinary work. Prospects for the future are no less exciting.

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