

A RETROSPECTIVE EXPLORATION INTO MA'OHĪ ARBORICULTURE: THE LEGACY OF PREHISTORIC LAND USE ON THE SPATIAL DISTRIBUTION OF THREE TREE SPECIES ON MO'OREA, FRENCH POLYNESIA

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Abstract. Tree community composition was compared across areas of different types of land use within an abandoned *Ma'ohi* settlement in the 'Opunohu valley of Mo'orea, French Polynesia. Focusing on three tree species (*Inocarpus fagifer*, *Aleurites moluccana*, *Neonauclea forsteri*), differences in tree communities on seven archaeological complexes were used to make retrospective inferences about the arboricultural practices of pre-European *Ma'ohi* culture. Differences in community were quantified with density, diameter, and distribution relative to archaeological structures.

Data from this study suggest that different types of prehistoric land use in the 'Opunohu valley have left distinct and lasting impacts on forest composition on a small scale, and imply the following about *Ma'ohi* arboricultural practice: 1) *Inocarpus* cultivation was associated with residential areas; 2) *Aleurites* and *Neonauclea* were cultivated or preserved in ritual complexes and areas dedicated to craft production; 3) *Aleurites* and *Neonauclea* were not cultivated in areas dedicated to agriculture. These results indicate that modern biological communities have the potential to provide insight into pre-European land use patterns even after long periods of succession, which plays into a larger argument calling for the further integration between archaeological and ecological disciplines.

Key words: *prehistoric land use; Inocarpus; Neonauclea; Aleurites; tree communities; Mo'orea, French Polynesia; Ma'ohi*

INTRODUCTION

Archaeological research has shown that ancient peoples have had major, long-lasting impacts on ecosystems around the world. In the United States, semi-desert environments were created in New Mexico by the Anasazi's overharvesting of juniper and pine trees. These harvests occurred 800-1000 years ago, but the ecosystem is just now beginning to recover and return to woodland (Swetnam et al. 1999). Ancient people in southern and southwest Turkey have also caused major shifts in forest location and composition through clearance for agriculture and the accelerated erosion that accompanied it (Roberts 1990). In Oceania, the modern grassland on Easter Island is a result of massive deforestation from intensive land use by prehistoric Polynesian people (Flenley 1991).

Research has also shown that land use can also leave distinctive legacies on a smaller scale. Motzkin et al. (1999a, 1999b) have shown that different types of land use have left different legacies on species composition at the stand level in New England forests. In Puerto Rico, localized land use such as

charcoal production has created patches of distinctive vegetation in a tropical forest (Thompson et al. 2002). From such cases, we know that past land use leaves distinct legacies on the modern landscape on a large and small scale. In addition to explaining modern vegetational patterns using information about past land use, we can reverse the flow of knowledge to travel in the opposite direction. That is, modern patterns in vegetation can also be used to provide information about how land was used by prehistoric people in the past.

Archaeological research has been integrated with accounts from ethnohistoric sources to recreate the nature of the native Society Island (*Ma'ohi*) culture prior to European influence. As a result, much is known about land use patterns by the *Ma'ohi*, including the importance of particular tree species (Whistler 1991, Lepofsky 1999, Fosberg 1991, Kirch 1991, Brown 1931, Butaud 2008). However, there are many gaps in our knowledge about specific cultivation patterns of these trees because references to *Ma'ohi* arboriculture are very sparse in ethnohistoric sources, as well as being relatively neglected in archaeological research (Lepofsky 1994).

The 'Opunohu valley on the island of Mo'orea, French Polynesia (Fig. 1) provides an excellent opportunity for retrospective research into *Ma'ohi* tree cultivation practices. Stratigraphic analysis by Lepofsky et al. (1996) has shown that a large prehistoric settlement

these small areas of different land use have left different legacies on the modern community of three culturally important tree species and, in turn, what that legacy can tell us about where and how these trees were used by pre-European Polynesian people.

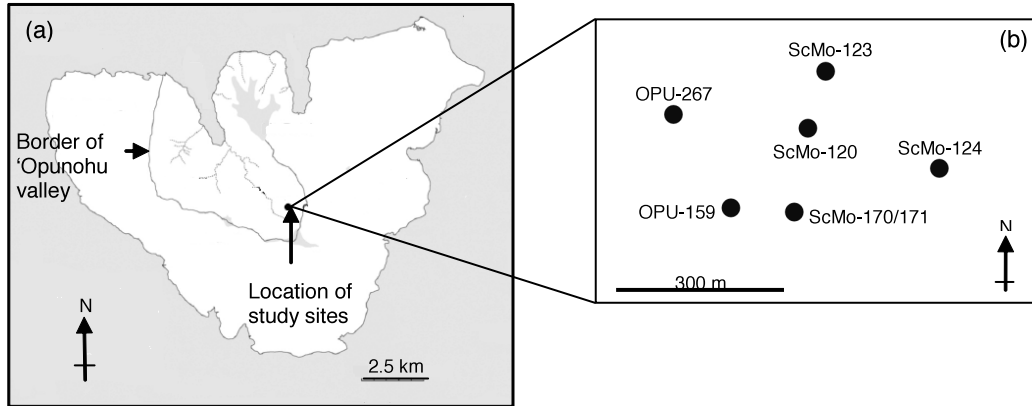


FIG. 1. (a) A map of Mo'orea, French Polynesia showing the 'Opunohu valley and the general location of study sites (Map source: Kahn and Kirch 2011); and (b) The relative locations of all study sites (Q GIS 1.7.1) [Coordinates (06 K UTM, WGS 84 grid): OPU-267 (199521 8059080), ScMo-120 (199768 8059055), ScMo-123 (199800 8059158), OPU-159 (199626 8058910), ScMo-170/171 (199743 8058903), ScMo-124 (200009 8058982)]

in the valley caused a major shift from native forest to vegetation dominated by anthropogenic species by 1200-1300 AD. The modern forest, characterized by a similar composition of species found in charcoal samples from the protohistoric period (Lepofsky et al. 1996), is the result of relatively undisturbed succession after the settlement was abandoned in the early nineteenth century (Green et al. 1967a). This suggests that the composition of the forest in the 'Opunohu valley today is directly related to pre-European patterns of land use in the valley.

Today, evidence of land use within this pre-European 'Opunohu settlement can be found in a widespread and highly diverse patchwork of stone structures that spans a large portion of the valley (Green 1961). Surveys and excavations of these stone structures (Green 1961, Green et al. 1967, Green and Descantes 1989, Lepofsky 1994, Kahn 2003, Kahn and Kirch 2011) have shown that small pockets of different land use were integrated together within the settlement, creating an amalgamation of agricultural, ceremonial, and residential areas in the valley. This settlement pattern has been likened to a 'mosaic' and is typical of pre-European *Ma'ohi* settlements (Lepofsky 1999). This study was designed in order to explore whether or not

BACKGROUND

'Opunohu valley

The 'Opunohu valley (Fig. 1) is the largest valley on the island of Mo'orea, French Polynesia. Much of the land in the lower valley is dedicated to agriculture and livestock grazing. However, the upper valley is nearly entirely covered by dense secondary forest. The forest is dominated by Tahitian Chesnut (*Inocarpus fagiferus*) and *Hibiscus tiliaceus* throughout. Other tree species frequently found in the forest, though much less dominant than these two species, are candlenut (*Aleurites moluccana*), mara (*Neonauclea forsteri*), breadfruit (*Artocarpus altilis*), and malay apple (*Syzygium malaccense*).

Stratigraphic analysis has dated pre-European occupation of the 'Opunohu valley as beginning as early as 600 AD (Lepofsky et al. 1996). Archaeological surveys and excavations of structures in the valley established that the area was a locus of dense habitation and extensive agricultural activity dating long before European contact, with most of the valley floor in use by the 11th-13th centuries (Green 1961, Green et al. 1967, Lepofsky et al. 1996). Excavated charcoal samples from the protohistoric period show

that anthropogenic vegetation was well established by 1200-1300 AD as a result of extensive human disturbance (Lepofsky et al. 1996).

The large and socially complex settlement in the upper valley was abandoned sometime between 1805 and 1815, shortly after contact with Europeans, as a result of rapidly declining population (Green 1967).

Ma'ohi arboriculture

Ma'ohi people practiced an extensive and intensive agricultural system comprised of several cropping subsystems which included arboriculture (Lepofsky 1999, Kirch 1991). Dwellings were placed in order to be near groves and gardens of principal food crops (Oliver 1974:175). Households congregated into neighborhoods were separated from each other by gardens and orchards (Oliver 1974:44). Tree crops were often a dominant part of house gardens (Lepofsky 1999).

Trees were also integrated into areas dedicated to religious ritual. A standard element of most temples (*marae*) was the sacred trees growing within and nearby the *marae* enclosure (Green 1967, Oliver 1974:102). Only certain trees were considered sacred or noble enough to shade the *marae*. Trees specifically mentioned in ethnohistoric sources to grow on and around *marae* are Ironwood (*Calophyllum inophyllum*), miro (*Thespesia populnea*) (Emory 1933, Oliver 1974), and Candlenut (*Aleurites moluccana*) (Bligh 1789, cited in Oliver 1974:102). Emory (1933) also notes that coconut palms and banana plants were also sometimes found within *marae* enclosures. Sacred trees were also involved with religious rituals because of their use for material for production of ritual objects. Only the wood from trees considered sacred or noble were considered worthy of use for production of certain ritual objects (de Bovis 1980) and were, in turn, planted within and around *marae*.

Study Species

Inocarpus fagifer: This tree was introduced and cultivated throughout Polynesia by original Polynesian settlers for its large seeds which are eaten roasted or boiled (Whistler 1991, Thaman et al. 2000). While *Inocarpus* was widely cultivated in many areas of Polynesia, there is no direct evidence that this

tree was cultivated in the Society Islands (Lepofsky 1994). *Inocarpus* was present in protohistoric charcoal samples in the 'Opunohu valley from the 11th-13th centuries, but was underrepresented in comparison to its current dominance (Lepofsky et al. 1996). Lepofsky et al. (1996) argue that this underrepresentation may indicate that *Inocarpus* was more restricted to garden plots at that time, and that its current extent is due to natural dispersal out from these gardens as well as from wild trees.

Aleurites moluccana

Aleurites is also a Polynesian introduction cultivated for its oily nut, which was burned for illumination (Whistler 1991) in homes for everyday night-time activities, as well as to illuminate after-dark entertainment (Oliver 1974:127,916). The tree was also utilized for various other purposes. The soot collected from burnt nuts was used to make ink for tattooing, and the bark was a source of a reddish-brown dye used to color cloth (*tapa*) (Brown 1931). *Aleurites* is usually found in cultivation, but is also frequently found in naturalized secondary forests as a relict of former cultivation (Whistler 1991, Fosberg 1991). This tree is also directly referred to in William Bligh's 1789 journal (Bligh 1789, cited in Oliver 1974:102) as a sacred tree standing over a *marae*. *Aleurites* charcoal was also present in protohistoric sediment samples taken from the 'Opunohu valley (Lepofsky et al. 1996).

Neonauclea forsteri

Neonauclea is indigenous to the Society Islands (Mueller-Dombois and Fosberg 1998). It is relatively frequent in the forest, but stands appear to be associated with archaeological sites (Kahn 2003, personal observation). Very large individuals are often found growing on and near archaeological structures, especially *marae*. This tree was used as a carving wood for the production of canoes, *tapa* beaters, handles of axes and adzes, and temple drums (*pahu* and *to'ere*) (Butaud 2008). This species was not present in charcoal samples excavated by Lepofsky et al. (1996).

HYPOTHESES

Based on current knowledge that exists about land use and specific uses of these three tree species by pre-European Polynesian

cultures, the *Ma'ohi* in particular, several hypotheses were formed about specific cultivation patterns of these tree species.

Inocarpus

Because of this tree's importance as a food crop (Whistler 1991), in combination with ethnohistoric accounts of multi-storied house gardens (Lepofsky 1999) and orchards separating households within neighborhoods (Oliver 1974:44) in *Ma'ohi* settlements, I hypothesize that *Inocarpus* was cultivated in association with residential areas.

Aleurites

Although *Aleurites* was not cultivated as a food crop, I hypothesize that cultivation of this tree was integrated into residential areas due to its common use for everyday illumination of people's homes (Oliver 1974:127). In addition, based on ethnohistorical references to *Aleurites* as a sacred tree associated with a *marae* (Bligh 1789, cited in Oliver 1974:102) I also hypothesize that *Aleurites* was cultivated or preserved in ritual areas, particularly in association with *marae*.

Neonauclea



Because this tree was primarily used as a material for the production of various wooden objects (Butaud 2008), I hypothesize that *Neonauclea* was cultivated or preserved in areas dedicated to craft production. Its use for the production of ritual drums (Butaud 2008) implies that *Neonauclea* was considered noble or sacred to some degree. Because of this, I hypothesize that this tree would be planted or preserved in areas dedicated to ritual, associated with *marae* in particular.

METHODS

Study design

To test these hypotheses, community composition of the three focal species (*Inocarpus fagifer*, *Aleurites moluccana*, *Neonauclea forsteri*) was compared across seven archaeological complexes categorized by land use background (Table 1). Each focal species was chosen because it was important in pre-contact *Ma'ohi* society, in addition to being

relatively frequent in the 'Opunohu valley forest.

In order to test for general association of each species with complexes of different land uses, the tree community on each complex was characterized by the density and diameter of trees present in each complex. High density indicates past association between a particular tree species and that complex and/or complex type. Relative diameter is a proxy for relative age. Therefore, the presence of large trees in a particular area indicates its possible connection to relict stands of that species. In addition, the largest trees could potentially be original trees that were growing on this settlement before its abandonment.

Specific associations between *Neonauclea* and *Aleurites* with structural types were tested for by analyzing which types of structures these trees are closest to on average. A lower mean distance to a particular structural type may indicate that the original trees that the modern community is derived from were also associated with those structures.

Study sites

Categorization of archaeological complexes: A comprehensive survey of the stone structures

TABLE 1. Categorization of archaeological complexes by land use type

Complex Type	Complex
Ceremonial	ScMo-124 OPU-159c
Agricultural	OPU-267 OPU-159a
Domestic	ScMo-170/171
Specialized Domestic	ScMo-120 ScMo-123

Notes Complex 159c and 159a are part of the same archaeological complex as defined by Lepofsky (1994) and Green and Descantes (1989). Based on excavations by Lepofsky (1994), there are two distinct portions of the complex. The upper portion of the complex, containing a *marae* and several terraces with no evidence of agricultural activity, was dedicated to ceremonial purposes. The terraces on the lower portion of the complex show evidence of agricultural activity. For the purposes of this study, these two areas were placed in different land use categories and treated as two separate complexes.

in the 'Opunohu valley was carried out in the 1960s under the direction of Roger C. Green (Green 1961, Green et al. 1967, Green and Descantes 1989). Hundreds of stone remains were found, mapped, and grouped into functional and architectural categories which have been further refined by recent archaeological excavation (e.g. Kahn 2003, Lepofsky 1994, Kahn and Kirch 2011). Groups of structures that are spatially and functionally related to each other have been grouped into archaeological complexes which are identified by a unique number.

Seven archaeological complexes were chosen for comparison in this study (Table 1). All seven complexes are located in the Tupauruuru sector of the 'Opunohu valley (Fig.1), a maximum of approximately 500 meters apart. There is very minimal variation in abiotic conditions between study sites.

Each complex was grouped into one of four land use categories (ceremonial, agricultural, domestic, specialized domestic) based on interpretation of overall function by archaeologists (Table 1). All of the complexes (except the agricultural land use type) were originally surveyed, mapped, and classified during Green's survey of the valley (Green and Descantes 1989) and have been further interpreted based on recent archaeological excavations (Kahn 1992, 2003, Kahn and Kirch 2011, Lepofsky 1994, Lepofsky and Kahn 2011). "Ceremonial" complexes were dedicated to ritual functions and are composed of *marae* and other ceremonial and specialized structures (Kahn and Kirch 2011, Lepofsky 1994). "Agricultural" complexes consist of agricultural terraces and were dedicated to cultivation of crops (Lepofsky 1994). "Domestic" complexes are areas dedicated to everyday residence and were centers of domestic activities like cooking (Kahn 1992, 2003). Specialized domestic complexes contain domestic-type structures such as rectangular houses (*fare haupape*) and round-ended houses (*fare pote'e*) but were used for specialized functions rather than everyday habitation (Kahn 1992, 2003).

Categorization of structures: Each archaeological complex is comprised of an aggregation of two or more archaeological structures. Because the architecture and function of the stone structures included within these complexes was widely diverse, each individual structure was also grouped into one of four functional categories:

Ceremonial, domestic, agricultural, or special (Table 2).

Sampling methods

Sampling area: For each complex, a rectangular sampling area was defined which included all structures included within the complex and extended approximately five meters beyond the outermost structures. Complex 124 was the one exception; because this complex is so large, rather than sampling over its entire area, the complex was divided into ten different sampling zones (Appendix A). These ten sampling zones included all of the major structures on the complex but did not encompass the entire complex area. Approximately 65% of the total complex area

TABLE 2. Categorization of stone structures by functional category

Structure Type (Functional category)	Structures (Specific type)
Ceremonial	Shrines <i>Marae</i> Ceremonial terraces
Agricultural	Agricultural terraces
Domestic	Round-ended houses (<i>fare pote'e</i>) Rectangular houses (<i>fare haupape</i>) Domestic terraces
Special	Stone platforms Workshops

Notes: Functional types are modeled after structural categories outlined by Green and Descantes (1989)

was sampled. The approximate area of each complex was calculated using maps produced by excavating archaeologists: Complex 120, 123, 170/171 (Kahn 2003); Complex 267, 159 (Lepofsky 1994); Complex 124 (courtesy of Patrick Kirch).

Density and DBH: Data was collected on every individual of the three focal species included within each sampling area. The diameter at 1.3 meters (DBH) was recorded for every individual of the three focal species with a diameter ≥ 10 cm.

Distribution of Neonauclea and Aleurites: A GPS (Garmin 72H, 06K UTM on WGS 84 grid) was used to mark the location of every

individual *Aleurites* and *Neonauclea* within the sampling area, as well as the center of every stone structure included in the complex. The distance between each tree and every structure within the sampling area was calculated using the UTM coordinates of each point. Then the mean distance from each species to each functional structure group was calculated. In addition, each tree's approximate location on the complex was marked on a map of the complex to create a visual representation of their distribution in relationship to the spatial arrangement of structures within the complex (Appendices A-C).

Analysis

Density: Because sample size was too small on each complex type (N=1 or 2), statistical tests were not performed for density data. Instead, average density on each complex type was calculated and analyzed by observing qualitative trends.

DBH: The distribution of trees in the 80th percentile of DBH was tested for uniformity with Chi-square test across complex types and across individual complexes. The mean DBH was compared with one-way Analysis of Variance (ANOVA) in conjunction with the Tukey-Kramer test as post-hoc analysis.

Distribution: The mean distance of *Aleurites* and *Neonauclea* to each structural type was analyzed with a one-way ANOVA in conjunction with the Tukey-Kramer test as post-hoc analysis. Pearson's t-test was used to compare the mean distances to *marae* to the mean distance to other structural types.

All statistical tests were performed using JMP 7.0.0 (JMP)

RESULTS

Inocarpus

DBH: The distribution of trees in the 80th

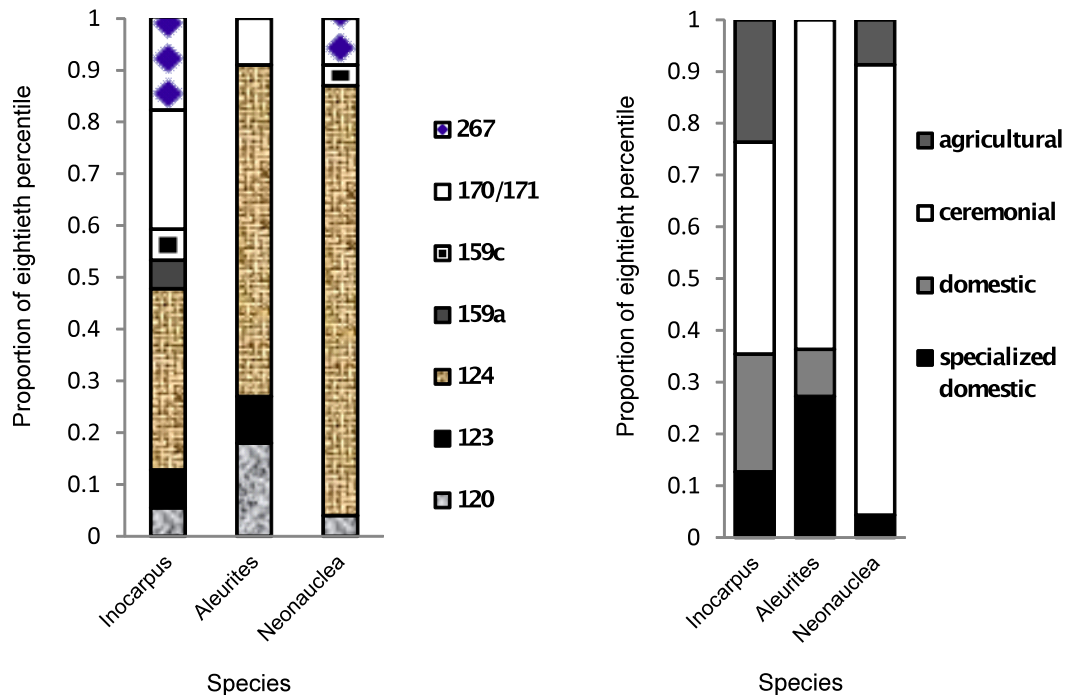


FIG. 2. The proportion of trees included within the eightieth percentile of DBH for *Inocarpus fagifer*, *Aleurites moulunensis*, and *Neonauclea forsteri* across seven archaeological complexes in the 'Opunohu valley, Mo'orea. The largest trees of all three species were unevenly distributed (Chi-square test, $p < 0.0001^*$; $p = 0.0005^*$; $p < 0.001^*$ respectively), and (b) across land use types. The largest trees of all species were unevenly distributed across land use types (Chi-square test, $p = 0.0057^*$; $p = 0.015^*$; $p < 0.0001^*$ respectively).

percentile of DBH was unequal across complex types and individual complexes. Ceremonial complexes were more likely to contain trees in the 80th percentile of DBH than expected assuming equal distribution across complex types (Chi-square test, $\chi^2=12.56$, $df=3$, $p=.0057$) (Fig. 2). Complexes 124, 170/171, and 267 contained more trees in the 80th percentile than expected assuming equal distribution across all complexes (Chi-square test, $\chi^2=44.76$, $df=6$, $p<.0001$) (Fig. 2)).

Density: The average density of *Inocarpus* was high and relatively constant on all complex types except on the domestic complex, which was the highest by far (Fig. 3).

Aleurites

DBH: The trees in the 80th percentile of DBH were distributed unequally across complex types (Chi-square test, $\chi^2=10.45$, $df=3$, $p=.015$). Ceremonial and specialized domestic complexes were more likely to contain trees in this percentile than expected, while agricultural and domestic complexes were less likely (Fig. 2).

All of the trees located on ceremonial complexes were found on complex 124. Complexes 124 and 120 both contained more trees in the 80th percentile of DBH than expected assuming equal distribution (Chi-square test, $\chi^2=24$, $df=6$, $p=.0005$) (Fig. 2).

Density: Average density of *Aleurites* was highest by far on specialized domestic complexes and zero on agricultural complexes. Domestic and ceremonial complexes had approximately equal average densities (Fig. 3). Within the specialized domestic category, the density of *Aleurites* was much higher on complex 120 than complex 123 (Fig. 4). In the ceremonial category, density was zero on complex 159c but relatively high on complex 124 (Fig. 4).

Distribution: *Aleurites* trees are significantly closer to *marae* than other ceremonial structures (Pearson's t test, $t_{67} = -3.1$, $p=.003$). Overall, the mean distance from *Aleurites* to ceremonial structures is significantly lower than the mean distance to domestic structures but not significantly different from the distance to special structures (ANOVA, $F_{2,257}=10.67$, $p<.0001$) (Fig. 5).

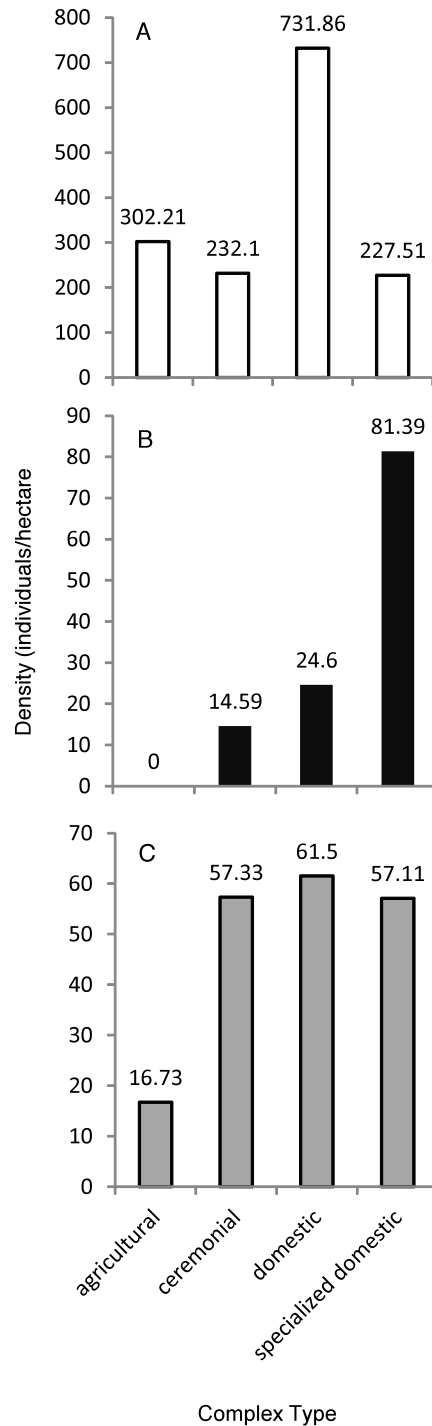


FIG. 3. The average density of (a) *Neonauclea forsteri*, (b) *Aleurites*, and (c) *Inocarpus fagifer* across complex types. Data shown is average density (individuals/hectare).

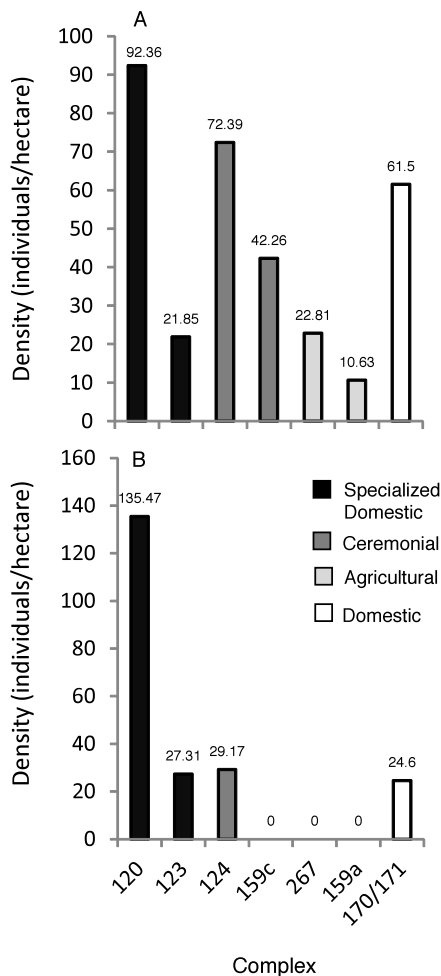


FIG. 4. The density of (a) *Neonauclea* for: and (b) *Aleurites moluccanum* at archaeological complexes. Complexes are color coded by land use type. Data shown is density (individuals/hectare).

Neonauclea

DBH: Trees in the 80th percentile of DBH were distributed unequally across complexes (Chi-square test, $X^2=29.83$, $df=2$, $p<.0001$). Ceremonial complexes account for the highest proportion of trees in the 80th percentile (Fig. 2). The 80th percentile of DBH was also unevenly distributed across individual complexes (Chi-square test, $X^2=40.83$, $df=3$, $p<.0001$). Complex 124 contains the highest

proportion of trees in the 80th percentile over all other complexes (Fig. 2).

On complex 124, sampling zone IJ contained the most trees from the 80th percentile with all but one of these trees located inside or within one meter of a *marae* (Appendix A). On this sampling zone, trees on within the 80th percentile account for six out of the eight trees of this species sampled.

Density: Domestic, ceremonial, and specialized domestic complexes have approximately equal densities of *Neonauclea* while the average density on agricultural complexes is much lower (Fig. 3).

There is discrepancy in the density of *Neonauclea* on some complexes of the same type (Fig. 4). Specialized domestic complexes were the most different from one another, with complex 120 having a density of *Neonauclea* about three times the density on complex 123. On agricultural complexes, complex 267 had a density about twice that on complex 159a. Ceremonial complexes, too, are different from one another; the density on complex 124 is about one and half times as high as the density on 159c.

Distribution: There are significant differences in mean distance to different structure types. The mean distance to *marae* is lower on average than the mean distance to other ceremonial structures, but the difference is not significant (Pearson's t-test, $t_{261}=-1.19$, $p=.1172$). Overall, however, *Neonauclea* are significantly closer to ceremonial structures than both domestic and agricultural structures (ANOVA, $F_{3,546}=19.96$, $p<.0001^*$) (Fig. 5).

DISCUSSION

Inocarpus

Data on DBH and density support the hypothesis that *Inocarpus* was associated with ancient domestic complexes. There is a relatively high proportion of trees from the 80th percentile located on complex 170/171 (Fig. 2), suggesting that these trees may be descended from a relict stand of *Inocarpus* in this area. In addition, the density of trees on domestic complexes is much higher than on any other complex type (Fig. 3). This implies that *Inocarpus* is more highly associated with domestic areas over any other land use type. The strong association with domestic land use provides evidence that the cultivation of

Inocarpus was centered on residential areas, possibly as an upper story of house gardens or as a part of arboricultural plantations between houses.

Ceremonial complexes, too, accounted for a high proportion of the trees in the 80th percentile of DBH (Fig. 2). Complex 124 in particular contained several of these largest trees. These data suggest a possible historical association of *Inocarpus* with ceremonial areas, especially complex 124. However, the density data do not support this trend.

The data collected during this study on the density and DBH of *Inocarpus* may not be useful for making inferences about pre-contact land use patterns. *Inocarpus* charcoal is present in sediment samples from the valley dating back to the 12th and 13th centuries, including from agricultural sites (Lepofsky et al. 1996). A modern agroforestry text (Pakau 2006 in Elevitch 2006) recommends that *Inocarpus* not to be planted in conjunction with herbaceous crops such as taro and sweet potato due to the shade created by its dense canopy. The presence of these trees on agricultural areas is, therefore, unlikely to be due to deliberate planting on agricultural terraces. Rather, Lepofsky et al. (1996) argue that the presence of *Inocarpus* charcoal from agricultural areas in this time period is probably due to slash and burn clearance of the forest to prepare the land for planting. This shows that, if *Inocarpus* was being cultivated in the valley, it had already escaped garden plots and begun to spread via natural distribution. *Inocarpus* propagates prolifically in the modern forest; other than ferns, *Inocarpus* seedlings are the most common plant in the understory. By the time the valley settlement was abandoned in the early 19th century (Green 1967), naturalized *Inocarpus* was probably dominant in pockets of unused land as a result of natural spread from areas where the trees were originally planted. Therefore, the modern distribution of these trees is probably less likely to be directly reflective of past land use than other trees in the forest that propagate less aggressively.

Aleurites

A past association of *Aleurites* with ceremonial complexes, complex 124 in particular, is supported by the unequal distribution of trees in the 80th percentile of DBH. Ceremonial complexes account for the highest proportion of trees in the 80th percentile (Fig. 2). Therefore, the *Aleurites*

growing on ceremonial complexes are the most likely to be connected to relict stands of these trees. Of the two ceremonial complexes sampled, complex 124 in particular seems to have been associated with a historical population of *Aleurites*. The density of *Aleurites* as well as the proportion of trees from the 80th percentile was both much higher on complex 124 than complex 159c (Fig. 4).

This discrepancy is likely due to the level of importance of these two ceremonial areas indicated by differences in size, complexity, and location of the two complexes. Complex 124, in conjunction with another ceremonial *marae* complex just adjacent and upslope (complex 125) is the largest and on one of the most important aggregate ceremonial complexes in the entire 'Opunohu valley (Kahn and Kirch 2011, Kahn 2003). Complex 124 alone contains twelve *marae* of various types as well as many other structures (Kahn and Kirch 2011). In contrast, complex 159c consists of a single *marae* and several terraces (Lepofsky 1994) and is nestled between a residential area (complex 170/171) and areas dedicated to agriculture (complex 159a and other agricultural terrace complexes). This suggests that *Aleurites* was planted or preserved in ceremonial areas preferentially based on status or overall function of the complex. In addition, trees that shaded *marae* were considered sacred (Oliver 1974:102). Because of this, the strong association of *Aleurites* with complex 124, a large and important ritual center for the valley settlement, supports the hypothesis that *Aleurites* was considered a sacred tree by *Ma'ohi* people.

The argument that *Aleurites* was a sacred tree planted or preserved in ceremonial areas is strengthened by data that show these trees are closest to ceremonial structures compared to other structural types (Fig. 5). Further, *Aleurites* are significantly closer to *marae* than other ceremonial structures. This suggests that this species was preferentially planted or preserved in the direct proximity of *marae*. This is consistent with the account from William Bligh's 1789 journal that describes *Aleurites* as a sacred tree shading a *marae* (Bligh 1789, cited in Oliver 1974:102).

The distribution of the largest *Aleurites* trees in addition to average density across complex types suggest that *Aleurites* was associated with areas of a specialized function (Fig. 3). When the two specialized domestic complexes are considered separately, however, the data associating *Aleurites* with

complex 120 is much stronger than the association with complex 123; Complex 120 has a much higher density of *Aleurites* as well as a larger proportion of the trees in the 80th percentile (Fig. 3, Fig. 2). This is most likely due to the difference in overall function of the two complexes. Both complexes are located just downslope of complex 124. Because of their location and their interpreted functions, they both most likely served a purpose somehow related to the large ceremonial complex 124 (Kahn 1992, 2003). However, these complexes served very different functional purposes (Kahn 1992, 2003). Complex 120 has been interpreted as an area dedicated to the production of ritual objects for use on complex 124-125, while complex 123 likely served a ritual function and, tentatively, as a temporary residence for visiting priests (Kahn 1992, 2003). The association of *Aleurites* with complex 120 over 123 suggests that this tree was associated with areas dedicated to production of ritual objects—either as a source of material for production of these objects, or simply as a source of illumination. In addition, the location of the two trees on complex 120 included in the 80th percentile of DBH supports the hypothesis that *Aleurites* on this complex served a functional purpose because they are not growing in proximity to the *marae* (Appendix C).

Surprisingly, data on the average density across complex types implies that *Aleurites* was not cultivated in residential areas (Fig. 3), supported by data on the mean distance from *Aleurites* to different structural types which suggest a lack of association with domestic structures (Fig. 5). However, the distribution of large *Aleurites* on complex 170/171 indicates that the trees there may be connected to a deliberately placed relict stand (Appendix B).

The location of this potential relict stand, if it was indeed deliberately planted, suggests that common groves of *Aleurites* were cultivated in residential areas in the vicinity of high-ranking community members. There is one tree on complex 170/171 that is included in the 80th percentile and two that are included in the 70th percentile. All three of these trees were found growing just beyond the front face of structure 170 (Appendix B), a *fare pote'e* interpreted as the residence of a low-ranking chief who served as the head of the group that resided in complex 170/171 (Kahn 1992). Control over resources and production was an important source of political power for *ma'ohi*

elites (Kahn 2003:13). In addition, according to Lepofsky's (1994) "Reconstruction of *Ma'ohi* Land Tenure, Resource Control, and Settlement Patterns," related households part of the same neighborhood held land and gardens in common, and the chief of that group was responsible for allocating natural resources to group members. A plantation of *Aleurites* around an elite residence could have served as an indication of power and status, especially if the neighborhood depended on a common plantation for access to nuts for use as lamps. In addition, it is interesting to note that this *fare pote'e* is also associated with a small structure interpreted as an adze-production workshop (structure 170WS, Kahn 2003) (Appendix B). The clustering of *Aleurites* in this area supports the data from specialized domestic complexes that indicate an association of *Aleurites* with areas dedicated to craft production.

The complete lack of *Aleurites* on either agricultural complex supports the hypothesis that *Aleurites* was not planted or allowed to grow on terraced areas dedicated to cultivation of crops.

Neonauclea

The distribution of the largest *Neonauclea* points to an association with ceremonial complexes (Fig. 2). These trees were closest, on average, to ceremonial structures over domestic and agricultural structures (Fig. 5), strengthening the argument for an association with sacred sites. These trees were not significantly closer on average to *marae* than other structures. However, looking at the qualitative distribution of the largest trees, were located on or in direct proximity to *marae* (complex 120, complex 124 zones IJ and QD) (Appendix A). The location of these trees suggests that *Neonauclea* may have been deliberately planted or preserved as a sacred tree in conjunction with *marae*.

Given the discrepancy in the proportion of the largest trees and overall density of *Neonauclea* between the two ceremonial complexes a past association of *Neonauclea* with complex 124 seems much stronger than the association with complex 159c. Complex 124 had a much higher proportion of the largest trees, as well as having a much higher density of *Neonauclea* than complex 159c (Fig. 3, Fig. 4). This provides further evidence for the possibility of *Neonauclea* being planted on ceremonial areas as a sacred tree because of

complex 124's importance as a hub for ritual activity in the valley (Kahn 2003).

Overall, evidence from this study does not suggest an association with specialized domestic areas in general. The density of *Neonauclea* on complex 120, however, is much higher than on complex 123 (Fig. 4). In addition to its high density on this complex, the areas just up and down slope of complex 120 were dominated by groves of large *Neonauclea*. This, in addition to the relatively high density of *Neonauclea* on complex 120, suggests a historical association of *Neonauclea* with areas dedicated to production of ritual wooden objects, rather than an association with specialized domestic complexes in general. This relationship is consistent with the use of *Neonauclea* as a carving wood by *ma'ohi* people, including as a material for the production of temple drums (Butaud et al. 2008).

Data suggest, as hypothesized, that *Neonauclea* was not associated with residential areas in the past. There were no trees on complex 170/171 that were included in the 80th percentile of DBH, although overall density was relatively high compared to other complexes (Fig. 2, Fig. 4). However, most of the trees located on this complex were relatively small and do not imply a connection to relict stands. In addition, *Neonauclea* were farthest from domestic structures overall, which further implies a lack of association of these trees with residential areas.

Data suggest, as hypothesized, that *Neonauclea* was not associated with areas dedicated to agriculture because the density of *Neonauclea* was low on agricultural complexes compared to other complex types (Fig. 3). In addition, there were very few trees included in the 80th percentile of DBH that occurred on agricultural complexes (Fig. 2). The two of the largest trees that were found on an agricultural complex were found on complex 267, which is directly adjacent to a large, complex *marae* (OPU-129) which is part of a larger ceremonial complex (Green and Descantes 1989) and may account for the presence of large *Neonauclea*, given previous evidence that suggests the association of *Neonauclea* with ceremonial areas. Complex 159a, in contrast, is adjacent to more agricultural terracing and a small, isolated *marae* (159c) and only contains two very small *Neonauclea*.

CONCLUSION

Modern communities of *Inocarpus fagifer*, *Aleurites moluccana*, and *Neonauclea forsteri* in the 'Opunohu valley show that different types of land use by protohistoric *Ma'ohi* likely play a major role in defining small-scale variations in forest composition, even after hundreds of years of succession.

As a result, small-scale patterns in tree communities have the potential to provide evidence about specific land use practices in pre-European cultures. These variations have led to several inferences about *Ma'ohi* practices of arboricultural cultivation: 1) cultivation of *Inocarpus* was most likely practiced in residential areas; 2) *Aleurites* and *Neonauclea* were cultivated or preserved in ceremonial areas and areas dedicated to craft production; 3) *Aleurites* and *Neonauclea* were not cultivated or allowed to grow in areas dedicated to intensive agricultural production; 4) *Aleurites* may have been cultivated in residential areas in association with residences of high-ranking individuals.

This study plays into a larger argument for the further integration of archaeology and ecology. Not only can ecologists' exploration of modern ecosystems benefit from perspectives about the past provided by archaeologists; Archaeologists can also benefit from the perspectives into ancient peoples provided by modern ecosystems. This, in turn, adds credence to the argument for conservation of secondary forests: First, because of their potential as a source of knowledge about pre-European cultures, and second, because they represent a part of the cultural legacy of native peoples.

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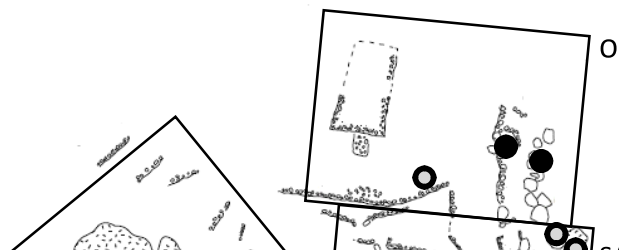
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APPENDIX A

Overall map of complex ScMo-124 showing lettered sampling zones and the distribution of *Neonauclea* and *Aleurites* in the 80th percentile of DBH.



APPENDIX B

APPENDIX B

Overall map of complex ScMo-170/171 showing stone structures and distribution of *Aleurites* and *Neonauclea*

170-WS

170



APPENDIX C

Overall map of complex ScMo-120 showing stone structures and distribution of *Neonauclea* and *Aleurites*

