ʻĀina Momona, Honua Au Loli

Productive Lands, Changing World

Combining models of the human ecological footprint with traditional knowledge to inform future sustainability in Hawai‘i

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Abstract: Pre-Western contact Hawai‘i stands as a quintessential sustainability example of a large human population that practiced intensive agriculture, yet minimally displaced native habitats that comprised the foundation of its vitality. An explicit geospatial footprint of human-transformed areas across the pre-contact Hawaiian archipelago comprised less than 15% of total land area, yet provided 100% of human needs, supporting a thriving Polynesian society. A post-contact history of disruption of traditional Hawaiian land-use and its supplanting by Western land tenure and agriculture based on ranching, sugarcane, and pineapple, culminated in a landscape, in which over 50% of native habitats have been lost, while self-sufficiency has plummeted to 15% or less. Recapturing the ʻāina momona (productive lands) of ancient times can be accomplished through study of pre-contact agriculture, assessment of biological and ecological changes imposed on Hawaiian social-ecological systems, and conscious planned efforts to increase self-sufficiency and reduce importation. Impediments include the current tourism-based economy, competition from habitat-modifying introduced species, a suite of agricultural pests severely limiting traditional agriculture, and changes in climate rendering some pre-contact agricultural centers suboptimal. Modified agricultural methods will be required to counteract these limitations, and diversified agriculture to broaden the production base, without contributing to further degradation of native habitats.

Keywords: human ecological footprint; traditional ecological knowledge; biocultural restoration; social-ecological system; Hawaiian Islands

1. Introduction

E Kāne-au-loli-ka-honua
Honu ne’e pū ka ʻāina

O Kāne-who transforms-the-world
Like a sea-turtle crawling, so the land [changes]

The opening lines out of a traditional pule [prayer] for cultivation evokes a Hawaiian god who transforms the world, an acknowledgement of the dynamic nature of ecosystems. The second line is evocative of the nature of changes; occurring slowly over the course of generations, but, as a sea turtle’s surges of movement upward from the shore towards her nesting site, sometimes more abrupt,
noticeable, dramatic. The wisdom incorporated within oral traditions in Hawai‘i (and elsewhere in the world) may be, at first blush, obscure and incomprehensible, but ultimately a huge wealth of information pertinent to today’s challenges can be found within them. This paper describes how an effort to combine biological monitoring, archeological databases, and oral traditions created the first geospatially explicit rendering of the human ecological footprint in the Hawaiian archipelago. While this footprint allowed for a variety of very useful extrapolations, including better estimates of the pre-contact human population in Hawai‘i, not only for the entire archipelago, but per island, it also offers a milestone in the story of landscape changes in Hawai‘i from those times to present, and can inform future sustainability strategies.

1.1. The rich ecological setting in the Hawaiian Islands

A variety of sources have documented the biotic richness of the Hawaiian Archipelago, recognizing it as a unique Biogeographic Ecoregion whose isolation has generated extremely high levels of endemism in both terrestrial and marine realms (e.g., ~90% endemism of native flowering plants; >98% endemism of native terrestrial invertebrates; 25% endemism of native reef fishes) [1, 2]. An estimated 15,000 species are found nowhere else [3]. When a Holdridge Lifezone analysis [4] was conducted for the Hawaiian Islands by the U.S. Forest Service [5], it revealed that of the 38 lifezones defined in a system designed to cover the full range of terrestrial ecosystems on Earth, 27 could be found in the 17,400 sq km land area of the Hawaiian archipelago, making the archipelago the single most ecosystem-rich known on the planet [6].

1.2. The current loss of major terrestrial native habitats in Hawai‘i

Recent mappings of the remaining native-dominated vegetation in Hawai‘i have been conducted (e.g., Figure 1), and largely agree on the areal extent of remaining native-dominated habitats [7-10]. They point to major losses of certain broad categories of natural communities, such as the Lowland Dry Communities, which have been almost entirely lost on smaller islands, and have been reduced to 31% of their original extent on the largest island of Hawai‘i. In contrast, certain zones, in large part much less suitable for human occupation or uses, have retained much larger percentages of their original cover (see Table 1). Geospatial documentation of the remaining native-dominated areas have guided conservation efforts of both public (Federal and State) as well as private agencies and organizations, focusing efforts on the maintenance of intact areas, augmented by restoration of damaged or destroyed ecosystems [11].

<table>
<thead>
<tr>
<th>Native Habitat</th>
<th>Remaining Extent as of 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montane Mesic</td>
<td>77%</td>
</tr>
<tr>
<td>Montane Dry</td>
<td>59%</td>
</tr>
<tr>
<td>Lowland Wet</td>
<td>46%</td>
</tr>
<tr>
<td>Lowland Mesic</td>
<td>31%</td>
</tr>
<tr>
<td>Lowland Dry</td>
<td>29%</td>
</tr>
</tbody>
</table>

Table 1. Example remaining native habitat on Hawai‘i Island, the largest island in Hawaiian archipelago.

It is apparent that the elevation and moisture zones most compatible with human residence and uses, such as agriculture, have resulted in a bias toward loss of lowland native ecosystems. With few exceptions, areas below 2000 feet elevation have been almost entirely displaced by a growing human ecological footprint, and by that of the non-native plant and animal introductions that have naturalized and spread, further displacing native species habitats [12].

The history of social-ecological landscape change in Hawai‘i occurred over the course of about 1000 years, beginning with the initial migration of Polynesians from the nearest archipelagoes of Oceania, those of the Marquesas and Tahiti. For centuries, the human population grew and spread across the Hawaiian archipelago and developed a unique indigenous Hawaiian culture, marked by
an epistemology that regarded the surrounding biotic community as familial and ancestral, thereby establishing a strongly biocultural society [13-16].

Another major milestone occurred in 1778 when the Hawaiian Islands was encountered by Captain James Cook and this initial contact with the Western World resulted in increasing presence and influence of Western culture and land uses in the islands, establishing a different social-ecological context based on commodification of land and natural resources, culminating in the footprint of the early 21st Century. Although there have been discussions of the pre-contact and post-contact impacts of humans on the native biota and ecosystems of Hawai‘i [17], there had been no geospatially-explicit reconstructions of landscape change offered specifically focusing on native habitat loss. Many of those early observations by Westerners were made from the ocean with limited geographic view plane and often by those with no familiarity with Hawaiian vegetation. Instead, we had only the reconstructions of the pre-human extent of terrestrial native-dominated vegetation zones in Hawai‘i [18] to compare against the current extent (see example for Island of O‘ahu below).

![Figure 1. a) O‘ahu before humans. b) O‘ahu landcover in 1998 (via [10]). 85% of native habitat had been lost.](image)

However, for every "before and after" situation that spans centuries of time, it is instructive to provide intermediate stages that speak to the human factors, such as population, changes in land tenure, and key introductions of both species and activities that influenced the trajectory, rate and intensity of social-ecological change.

2. Materials and Methods

2.1. Mapping of the human ecological footprint in pre-contact Hawai‘i

Models of pre-Western contact agriculture in Hawai‘i combined with archeological and oral tradition created an explicit geospatial footprint of human-occupied and transformed areas across the pre-contact Hawaiian archipelago.

One of the most important milestones for historical landscape change is the thousand years of presence and activities of pre-contact indigenous Hawaiians. The Hawaiian social-ecological system of land management has been described elsewhere as the ahupua‘a system [19,20], based on units of land and sea that typically included a cross section of ecosystems from the summit of an island to the coast, and outward to include nearshore marine habitats. Integration of human society and its processes with the endemic biota and a small set of transported Polynesian plant and animal introductions created a system in which biological resources were deeply woven via explicit genealogical ties, rendering them as biocultural relationships [21]. Based on current knowledge of Hawaiian management of ahupua‘a in the pre-contact era, it appears that minimization of the human footprint was in large part realized by delineating portions of the landscape as wao kanaka (realm of human influence, typically in coastal and lowland areas) and designating sacred (typically upland) habitats as wao akua (realm of deities) [22].

Pertinent to the impacts of intensive agriculture on this social-ecological system, Ladefoged et al [23] created a geospatial model expressing the optimal conditions for the cultivation of the two major
staple crops in Hawai‘i (kalo [taro] Colocasia esculenta, and ʻuala [sweet potato] Ipomoea batatas). It was
tested and refined via comparison to known archeological complexes associated with agriculture [24].
One conclusion was that practically all of the lands of greatest potential for agriculture had been
developed for agriculture, and that formulae for deriving human population estimates from
agricultural acreage suggested a pre-contact Hawaiian population from 400,000 to 800,000, with
largest populations on the islands of Hawai‘i, Maui, O‘ahu and Kaua‘i. This was further discussed
in Kirch 2011 [25] in terms of the population basis of the great Hawaiian chiefdoms of those four
islands, supported by their exceptional agricultural and biocultural potential. Such highly productive
agricultural lands, the basis for not only political power but cultural proliferation, were called ʻāina
momona, sweet/productive lands [26,27]—the most important lands for maintaining biocultural
vitality in those times, and an important focus for restoration of social-ecological systems and
biocultural revitalization today.

From 2009 to 2012, working in cooperation with the research staff of the Office of Hawaiian
Affairs (OHA), we expanded on the agricultural model by mapping known loko iʻa (estuarine walled
fishponds, a major source of protein foods), and continuing the reviews of archeological geospatial
databases compiled by the State of Hawai‘i Historic Preservation Division (SHPD) [24] of the
Department of Land and Natural Resources (DLNR), as well as historical maps from Department of
Accounting and General Services (DAGS).

Major compilations of oral history out of a variety of sources in both English and Hawaiian were
gleaned for further information on wahi pana (storiied localities), terrestrial trail systems, religious
sites, including heiau (temples) and ko‘a (shrines), to set against the emerging geospatial depiction of
areas of habitation, agriculture, or other traditional uses (see Appendix A). Because the oral
traditional accounts were extremely place-specific, and because current land boundaries retained the
ahupua‘a designations and boundaries largely intact from pre-contact times, descriptions of places in
oral accounts were readily placed geospatially, to corroborate models and archeological mappings.
It is becoming apparent that in terms of indigenous knowledge archives in written form, the millions
of pages of Hawaiian language newspapers represent the single largest of such first-peoples archives
known in the world [28]. Appendix A offers an overview of some of the sources that were consulted.

3. Results

What emerged from this multidisciplinary combination of sources was the first geospatially
explicit footprint of pre-contact human activity that displaced the original native terrestrial habitats
in the Hawaiian Islands (Figure 2-7). It was coined the Hawaiian Footprint Project. This process was
applied to all of the eight main Hawaiian Islands, and an example is available as for public scrutiny
online (http://kipukadatabase.com/apps/footprint%20molokai/), with GIS layers provided by request
via The Nature Conservancy of Hawai‘i.
Figure 2. A) Hawaiian footprint, prior to Western contact, resulted in <12% native habitat loss on the islands of Kaua‘i and Ni‘ihau. B) Modern footprint resulted in 72% and 96% native habitat loss, respectively. Key: pink = human footprint; white line = moku, districts; colored basemap = major native vegetation zones.
Figure 3. A) Hawaiian footprint, prior to Western contact, resulted in 14% native habitat loss on the island of O‘ahu. B) Modern footprint resulted in 83% native habitat loss. Key: pink = human footprint; white line = moku (districts) and ahupua‘a; dotted white line = historical nearshore fisheries, makai part of ahupua‘a; colored basemap = major native vegetation zones.
Figure 4. A) Hawaiian footprint, prior to Western contact, resulted in <9% native habitat loss on the island of Moloka‘i. B) Modern footprint resulted in 84% native habitat loss. Key: pink = human footprint; white line = ʻahu‘ula; colored basemap = major native vegetation zones.
Figure 5. A) Hawaiian footprint, prior to Western contact, resulted in <14% native habitat loss on the islands of Lāna‘i and Kaho‘olawe. B) Modern footprint resulted in >78% native habitat loss. Key: pink = human footprint; white line = ʻahupuaʻa; dotted white line = historical nearshore fisheries, makai part of ʻahupuaʻa; colored basemap = major native vegetation zones.
Figure 6. A) Hawaiian footprint, prior to Western contact, resulted in 11% native habitat loss on the island of Maui. B) Modern footprint resulted in 70% native habitat loss. Key: pink = human footprint; white line = moku (districts) and ahupua‘a; colored basemap = major native vegetation zones.
A similar analysis of land uses one century later, applied to the Island of Hawai‘i, documented greatly increased disruption of native ecosystems [27]. Table 2 lists selected extents of ecosystems displaced by the 1870 human footprint and their current status. The geospatial depiction comparing these same pre- and post-contact situations (Figure 7) clearly demonstrates the greatly accelerated rate of social-ecological disruption and loss of the original biocultural landscape.

Table 2. Extensive native habitat loss in the first 100 years after Western contact was driven primarily by ranching and sugarcane mono-culture.

<table>
<thead>
<tr>
<th>Native Habitat</th>
<th>1770 (acres)</th>
<th>% lost</th>
<th>1870 (acres)</th>
<th>% lost</th>
<th>2015 (acres)</th>
<th>% lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowland Mesic</td>
<td>35,000</td>
<td>21%</td>
<td>73,000</td>
<td>44%</td>
<td>118,000</td>
<td>71%</td>
</tr>
<tr>
<td>Lowland Dry</td>
<td>104,000</td>
<td>19%</td>
<td>230,000</td>
<td>43%</td>
<td>371,000</td>
<td>69%</td>
</tr>
<tr>
<td>Lowland Wet</td>
<td>51,000</td>
<td>9%</td>
<td>68,000</td>
<td>12%</td>
<td>303,000</td>
<td>54%</td>
</tr>
<tr>
<td>Montane Dry</td>
<td>5,000</td>
<td>1.4%</td>
<td>137,000</td>
<td>37%</td>
<td>151,000</td>
<td>41%</td>
</tr>
<tr>
<td>Montane Mesic</td>
<td>2,000</td>
<td>1%</td>
<td>31,000</td>
<td>17%</td>
<td>43,000</td>
<td>23%</td>
</tr>
<tr>
<td>Alpine/Subalpine</td>
<td>3,300</td>
<td>1%</td>
<td>33,000</td>
<td>6%</td>
<td>33,000</td>
<td>6%</td>
</tr>
</tbody>
</table>
Figure 7. A) Hawaiian footprint, prior to Western contact, resulted in 8% native habitat loss on the island of Hawai‘i. B) The human footprint tripled 100 years after Western contact. C) Modern footprint resulted in 40% native habitat loss. Social-ecological change over two centuries reflects the affect of commodification of land and resources, and loss of pre-contact biocultural relationships. Key:
pink = human footprint; white line = moku (districts) and ahupua’a; colored basemap = major native vegetation zones.

4. Discussion

4.1. The Hawaiian social-ecological system as a model of sustainability and self-sufficiency

The two major conclusions of the Hawaiian Footprint Project were that prior to Western contact in 1778, a substantial human population in the Hawaiian archipelago (estimated at 600,000 – 800,000 people) had displaced less than 15% of the original area of native terrestrial ecosystems, and was necessarily 100% self-sufficient, that is, did not rely on any significant external inputs from the rest of global humanity. Thus pre-contact Hawai'i stands as a quintessential example of a large human population that practiced intensive agriculture, yet minimally displaced the native habitat that was the foundation of its vitality and development. This baseline of human sustainability in a finite (but extremely rich) high island setting, can be used to compare with footprints of other historical milestones, as well as the current situation.

4.2. Using pre-contact models of sustainability in transformed landscapes

When the models for pre-contact agriculture were published and made publicly available, it generated many inquiries regarding the use of the mapped extent of pre-contact agriculture as guidance for revitalization of current biocultural restorations. To the extent that areas of pre-contact agriculture remain available for agricultural use in our times, it stands to reason that the model could indicate areas of greatest potential for successful social-ecological revitalization of Hawaiian traditional agriculture.

4.3. Post-contact changes to the social-ecological landscape of Hawai‘i

In the 250 years that followed contact with the Western world, much has changed in both the social-ecological setting and the biocultural setting of Hawai‘i. Several different reviews of these changes point to the imposition of Western worldviews that viewed land and natural resources as commodities to be exploited to feed capitalist economies, leading to practices such as ranching and mono-crop agriculture that supplanted multi-crop and semi-wild systems of the pre-contact Polynesian social-ecological system and induced wholesale erasure of native biodiversity across tens of thousands of acres. [28-30]. Our recent geospatially explicit review of land use changes on Hawai‘i island between 1770 (pre-contact) and 1870 (one century after contact), demonstrated that the human footprint had more than tripled in size. These changes entirely transformed lowland social-ecological landscapes, and extended high into the montane zones on the highest islands of Maui and Hawai‘i, displacing biocultural resources there. This is a trend that has continued into the 21st Century, resulting in the modern human footprint that is more than 5 times larger than the pre-contact Hawaiian Footprint on the Island of Hawai‘i. Self-sufficiency, expressed as importation of goods, has plummeted from 100% in pre-contact times to 15% or less in the 21st century [31,32]. Growing human populations, (1.4 million permanent residents, augmented by a transient but significant visitor population that amounts to 7-9 million additional people per year in Hawai‘i) not only extends beyond the carrying capacity of the islands’ agricultural areas, but has created a growing urbanization in many areas that were once prime agricultural lands, further limiting efforts to increase self-sufficiency and sustainability [32].

4.4. Non-native Species

During the 1000 years of the pre-contact period perhaps 50-60 species of plants had been introduced into the highly endemic Hawaiian Islands terrestrial flora, summarized here in Table 3 [33]. The majority of these Polynesian Introductions were agricultural crops, plants used in cordage and plaiting, other ethnobotanical species, and a handful of agricultural weeds inadvertently introduced. All but one of these, kukui (Aleurites moluccana) were largely confined to agricultural
settings, and did not naturalize readily into surrounding native vegetation. Kukui is the exception and has naturalized readily and frequently is a canopy dominant in lowland riparian situations on all of the larger islands [33]. The otherwise non-invasive nature of the majority of the Polynesian Introductions meant that even in areas completely converted to croplands, any fallow areas would have converted back into native successional communities. Even in those areas dominated by kukui, native subcanopy and groundcover diversity would have remained, and a mixed forest with strong native composition would still be present.

Table 3. Polynesian Introductions in the Hawaiian Archipelago [33]

<table>
<thead>
<tr>
<th>Hawaiian name</th>
<th>Notes</th>
<th>Status</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>'ohe</td>
<td>food, medicinal</td>
<td>Polynesian introduction</td>
<td>Cordyline fruticosa</td>
</tr>
<tr>
<td>'ōlina</td>
<td>medicinal, dy</td>
<td>Polynesian introduction</td>
<td>Alaisrenia macrorhiza</td>
</tr>
<tr>
<td>koa</td>
<td>mainstay food crop</td>
<td>Polynesian introduction</td>
<td>Colocasia esculenta</td>
</tr>
<tr>
<td>niu</td>
<td>food, wood, tr</td>
<td>Polynesian introduction</td>
<td>Cocos nucifera</td>
</tr>
<tr>
<td>ohi</td>
<td>secondary crop, not naturalized</td>
<td>Polynesian introduction</td>
<td>Dioscorea alata</td>
</tr>
<tr>
<td>poi</td>
<td>famine food, naturalized</td>
<td>Polynesian introduction</td>
<td>Dioscorea bulbifera</td>
</tr>
<tr>
<td>'a'apane</td>
<td>famine food, naturalized</td>
<td>Polynesian introduction</td>
<td>Dioscorea pentaphylla</td>
</tr>
<tr>
<td>'o'e</td>
<td>staple crop</td>
<td>Polynesian introduction</td>
<td>Musa x paradisiaca</td>
</tr>
<tr>
<td>'ole'elena</td>
<td>food</td>
<td>Polynesian introduction</td>
<td>Saccharum officinarum</td>
</tr>
<tr>
<td>'a'apapuhi</td>
<td>medicinal</td>
<td>Polynesian introduction</td>
<td>Curcuma longa</td>
</tr>
<tr>
<td>'uhi 'ilii 'iku'iki</td>
<td>uncomnon medicinal, accidental?</td>
<td>Polynesian introduction?</td>
<td>Koptopa sarmentosa</td>
</tr>
<tr>
<td>kāmoku</td>
<td>wetland, accidental w/kalo?</td>
<td>Polynesian introduction?</td>
<td>Ludwigia octovalis</td>
</tr>
<tr>
<td>'ihi</td>
<td>medicinal; indig? seeds in pre-contact sites</td>
<td>Polynesian introduction?</td>
<td>Oxalis corniculata</td>
</tr>
<tr>
<td>---</td>
<td>cultiv. central Pac, 3 records from HI</td>
<td>Polynesian introduction?</td>
<td>Solanum viride</td>
</tr>
<tr>
<td>'ōhe Kahiki</td>
<td>tools, wood, music, container; indig?</td>
<td>Polynesian introduction?</td>
<td>Schizostachyum</td>
</tr>
<tr>
<td>---</td>
<td>seeds in pre-contact sites; indig NA, SA</td>
<td>naturalized?</td>
<td>Daucus pusillus</td>
</tr>
<tr>
<td>pohe</td>
<td>indig NA; pre 1871 HI records</td>
<td>naturalized?</td>
<td>Hydrocotyle verticillata</td>
</tr>
<tr>
<td>ko'ai 'ai</td>
<td>famine food, poss indig?</td>
<td>naturalized?</td>
<td>Ipomoea carica</td>
</tr>
<tr>
<td>ko'ai kualulu</td>
<td>pantropical, indig</td>
<td>naturalized?</td>
<td>Merremia aegyptia</td>
</tr>
<tr>
<td>kākalaua</td>
<td>indig/early intro; also kūhikolo</td>
<td>naturalized?</td>
<td>Caesalpinia major</td>
</tr>
<tr>
<td>mauaolu</td>
<td>indig Honduras; 1st record HI 1825</td>
<td>naturalized?</td>
<td>Dielea wilsonii</td>
</tr>
<tr>
<td>pāpapa</td>
<td>native to tropical Asia? edible</td>
<td>naturalized?</td>
<td>Lablab purpureus</td>
</tr>
<tr>
<td>---</td>
<td>pantropical weed</td>
<td>naturalized?</td>
<td>Sida rhombifolia</td>
</tr>
<tr>
<td>kāmoku</td>
<td>accidental w/kalo?</td>
<td>naturalized?</td>
<td>Polygonum glabrum</td>
</tr>
<tr>
<td>pōniu</td>
<td>also haleakai 'a; medicinal</td>
<td>naturalized?</td>
<td>Cardiospermum halicacabum</td>
</tr>
<tr>
<td>'a'aka'akai</td>
<td>also kalula, indigenous to NA &amp; SA</td>
<td>naturalized?</td>
<td>Schoenoplectus californicus</td>
</tr>
<tr>
<td>---</td>
<td>cosmp., accidental on kalo?</td>
<td>naturalized?</td>
<td>Lenina aquinaxialis</td>
</tr>
<tr>
<td>---</td>
<td>cosmp., accidental on kalo?</td>
<td>naturalized?</td>
<td>Spindola polyrrhiza</td>
</tr>
<tr>
<td>---</td>
<td>indig Asia, Maleasia; 1st HI coll pre 1871</td>
<td>naturalized?</td>
<td>Gnetum acutifolium</td>
</tr>
<tr>
<td>'ōli'o'ohu</td>
<td>once noted nr kalo fields; extinct?</td>
<td>indigenous?</td>
<td>Cleome spinosa</td>
</tr>
</tbody>
</table>
Two-hundred and fifty years of plant introductions since Western contact have completely changed that picture and disrupted the process of vegetation succession in Hawai‘i. Perhaps 15,000 or more taxa of vascular plants had been introduced to Hawai‘i [34] Among these are hundreds of habitat-modifying species that not only degrade native vegetation composition and structure, but can disrupt traditional agriculture and greatly increase the labor required to remove aggressive weeds and successfully grow desired crops. Introduced animals, including wetland invertebrates such as Apple snails (Pomacea canaliculata) and crayfish (Procambarus clarkii) damage both the plants and the traditional infrastructure of lo‘i kalo (taro terraces), adding further impediments to restoring traditional agriculture. Introduced bacterial and fungal diseases are another major challenge to kalo and other traditional crops [35].

4.5. Climate Change

In an era of increasing climate change, predicted effects on precipitation and temperature could conceivably affect the potential for biocultural restoration. The high islands of Hawai‘i exhibit elevation zonation in both temperature and moisture (see Figure 7) and it is anticipated that zones will shift in their placement, and that novel zones currently not present will come into being [36] Because the models for both kalo and ‘uala are sensitive to precipitation (‘uala particularly so), the archeology of sweet potato agriculture on Maui already demonstrates a mismatch: archeological complexes associated with seasonal ‘uala agriculture on the western slope of Haleakalā extend into areas with annual precipitation that is currently insufficient for the crop (see Figure 8). It is a clear indication that over 250 years ago, slopes that are currently too hot and dry for growing sweet potatoes were seasonally worked for that crop. This means that in the decades to come, with warming and drying trends predicted for the lowlands of the Hawaiian Islands, the model generated for the pre-contact Hawaiian footprint will have to be adjusted in various ways to track the optimal rainfall conditions of the future.
Figure 8. Map showing mismatch of ‘uala agricultural model prediction (red) with archeological complexes (dots) on the west flank of East Maui (yellow oval).

In a somewhat less direct manner, drying trends may convert streams that are currently continuous and perennial (and therefore suitable for kalo) into intermittent streams that may provide insufficient water for the crop. If the predicted trends are for warming and drying, this likely means an overall reduction in the potential area for wet lo‘i kalo production.

In similar manner, each of the traditional crops of Hawai‘i, and indeed all future potential crops should be assessed for their optimal climate envelopes, and plans made to shift the areas designated for those crops according to shifting climate patterns in the decades to come. A similar analysis was already conducted for every native flowering plant in Hawai‘i [37], and this tool is already being promulgated and applied in conservation efforts involving assisted migration of rare plants out of habitat that is becoming climatically suboptimal.

4.6. Diversification

One of the major advantages of the broad range of life zones in Hawai‘i is the great potential for diversification of agriculture. While the models for the pre-contact footprint were based on the optimal range of the two major staple crops of those times, modern agriculture in Hawai‘i has already seen an expansion to include a wide variety of agricultural products, including coffee, macadamia nuts, tropical fruit, ornamentals, and vegetable crops that were not available in pre-contact times. While we should likely never again consider a large-scale monoculture approach that was the signature of the sugarcane and pineapple eras of agriculture in Hawai‘i, the future offers a broad range of possibilities. It may be feasible to develop agroforestry models such as those used traditionally and successfully in other island nations (e.g. Pohnpei) and gain both agricultural diversity as well as the benefits of ecosystem functions that derive from maintaining forest cover and diverse understory structure. These include minimal erosion and sedimentation of our streams and nearshore marine habitats, increasing their viability and potential for food production.

5. Conclusions

Reconstructions of pre-contact agricultural hotspots are instructive in demonstrating the potential for a closed island social-ecological system to sustainably support a large human population in an entirely self-sufficient manner while creating a relative small ecological footprint that allows for maintenance of strong native biological diversity and vital ecosystem processes and services. While it might be desirable to recapture that ancient situation, several factors have imposed themselves over the last 240 years of post-contact history and greatly complicate any simple schemes to restore that
pre-contact state. One is the presence of thousands of non-native plants and animals that impose their
own ecological influences that impede agricultural success via competition, predation, and
pathologies that did not exist in pre-contact times. Another is the irreversible land developments that
have displaced many areas of formerly rich agricultural production. A third is the effect of sheer
numbers of people present in the islands, far exceeding the estimated 600,000 - 800,000 Hawaiians
that comprised the archipelagic human population prior to contact. Finally, the anticipated changes
in climate, including temperature and precipitation, will require adjustments of the models of
optimal agricultural output, and may render some of the original areas unusable, while other areas
may emerge as optimal in the future. Knowing these limitations is a vital step toward addressing and
surmounting them. While we may not be able to turn the clock back, we are more able than ever to
take intelligent action to frame our future.

More importantly however, is the lesson of the thousand years of pre-contact Hawaiian
presence, and the social-ecological system that developed as a result of a worldview with a strong
foundation of biocultural relationships. These regarded the natural world as family in a reciprocal
and caring relationship wherein human health and welfare was viewed as one with the health and
welfare of the surrounding living community. In such a context, humans stand not intrinsically apart
from nature, and not a threat to nature, but acknowledge that we are a force of nature with potential
to damage or to repair. The consequences of shifting from this social-ecological system into one of
land and resources as economic commodities has clearly resulted in a post-contact history of loss of
native habitats, sustainability, and self-sufficiency.

In our analyses of pre-contact Hawai‘i we see that it is possible to support a thriving human
population, practice intensive sustainable agriculture, and establish a social-ecological system that
maintained the native habitat that was the foundation of ‘āina momona. It becomes clear that a future
shift that strives to recapture the best of the pre-contact social-ecological system is sorely needed in
Hawai‘i and by extension, Planet Earth. Achieving this will take the best of indigenous values
combined with the best of 21st Century knowledge to realize.

Appendix A

Some major sources of Hawaiian oral tradition consulted and incorporated into the Hawaiian
Footprint Project:

2. Cordy, R. An Ancient History of Wai‘anae – Ka Moku o Wai‘anae: He Mo‘olelo o ka Wā Kahiko; Mutual
4. Ellis, W. A Narrative of an 1823 Tour Through Hawaii‘i or Owhyhee, with remarks on the History, Traditions,
Manners, Customs and Language of the inhabitants of the Sandwich Islands; Mutual Publishing: Honolulu, HI.
USA, 1825 (1994); ISBN 9781406725537.
[reprinted in 2013, includes text of hundreds of chants in original Hawaiian, with translations and
discussion in English.]
of the Hawaiian People to the Times of Kamehameha I. Vol. II. Trubner, London.
Bernice Pauahi Bishop Museum, Vols. 4-6. Honolulu. [in original Hawaiian and English translation.]
Kalākaua I. Dynastic Chants, Ancestral Chants, and Personal Chants of King Kalākaua I. Hawaiian
Language Reprint Series, Honolulu.
Honolulu.


18. Multiple authors. 1856-1885. He Lei No Emmalani: Chants for Queen Emma Kaleoleonalani. [200+ Hawaiian chants and songs composed by as many authors, compiled, translated and edited by Mary Kawena Pukui, Theodore Kelsey, and M. Puakea Nogelmeier, in original Hawaiian language with English translations.]


29. Ulukau.org [Hawaiian Electronic Library, a Hawaiian language compilation site, searched for numerous Hawaiian language newspaper articles too numerous to list (nupepa.org), providing descriptions of the biocultural geography of pre-contact and early post-contact Hawai‘i]. Maintained by Alu Like, Inc., Hale Kuamo‘o, and the Bishop Museum, Honolulu.]

References


5. Tosi, J.A.J.; Watson, V.; Bolaños, R. Life zone maps: Hawai‘i, Guam, American Samoa, Northern Mariana Islands, Palau, and the Federated States of Micronesia; Tropical Science Center and the Institute of Pacific Islands Forestry, USDA Forest Service: San Jose, Costa Rica and Hilo, Hawaii, USA, 2002.


