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Article

ʻĀina Momona, Honua Au Loli

Productive Lands, Changing World

Combining models of the human ecological footprint with traditional knowledge to inform future sustainability in Hawaiʻi

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Abstract: Pre-Western contact Hawaiʻi 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

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1. Introduction

E Kāne-au-loli-ka-honua
Honu neʻe 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,

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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].

Native Habitat	Remaining Extent as of 2015
Montane Mesic	77%
Montane Dry	59%
Lowland Wet	46%
Lowland Mesic	31%
Lowland Dry	29%

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

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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).

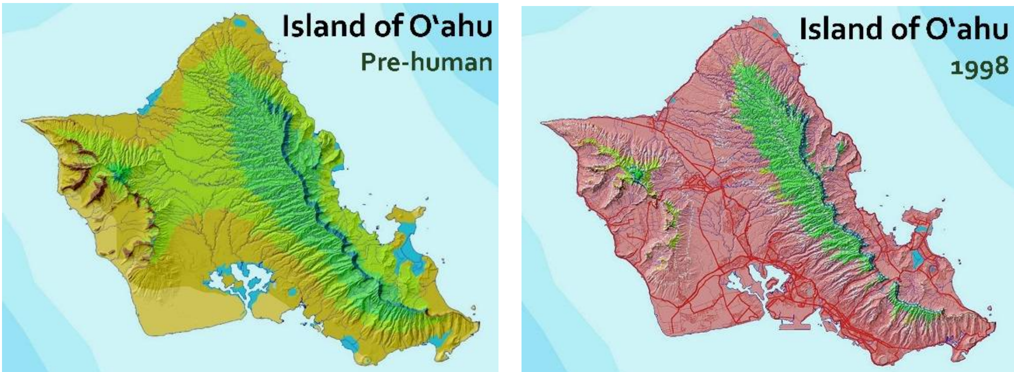

Figure 1. a) O‘ahu before humans. b) O‘ahu landcover in 1998 (via [10]). 85% of native habitat had been lost.

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, tyically 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

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staple crops in Hawaiʻi (*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 Hawaiʻi, Maui, Oʻahu and Kauaʻi. 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 Hawaiʻi 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* (storied localities), terrestrial trail systems, religious sites, including *heiau* (temples) and *koʻa* (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 *ahupuaʻa* 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 Hawaiʻi.

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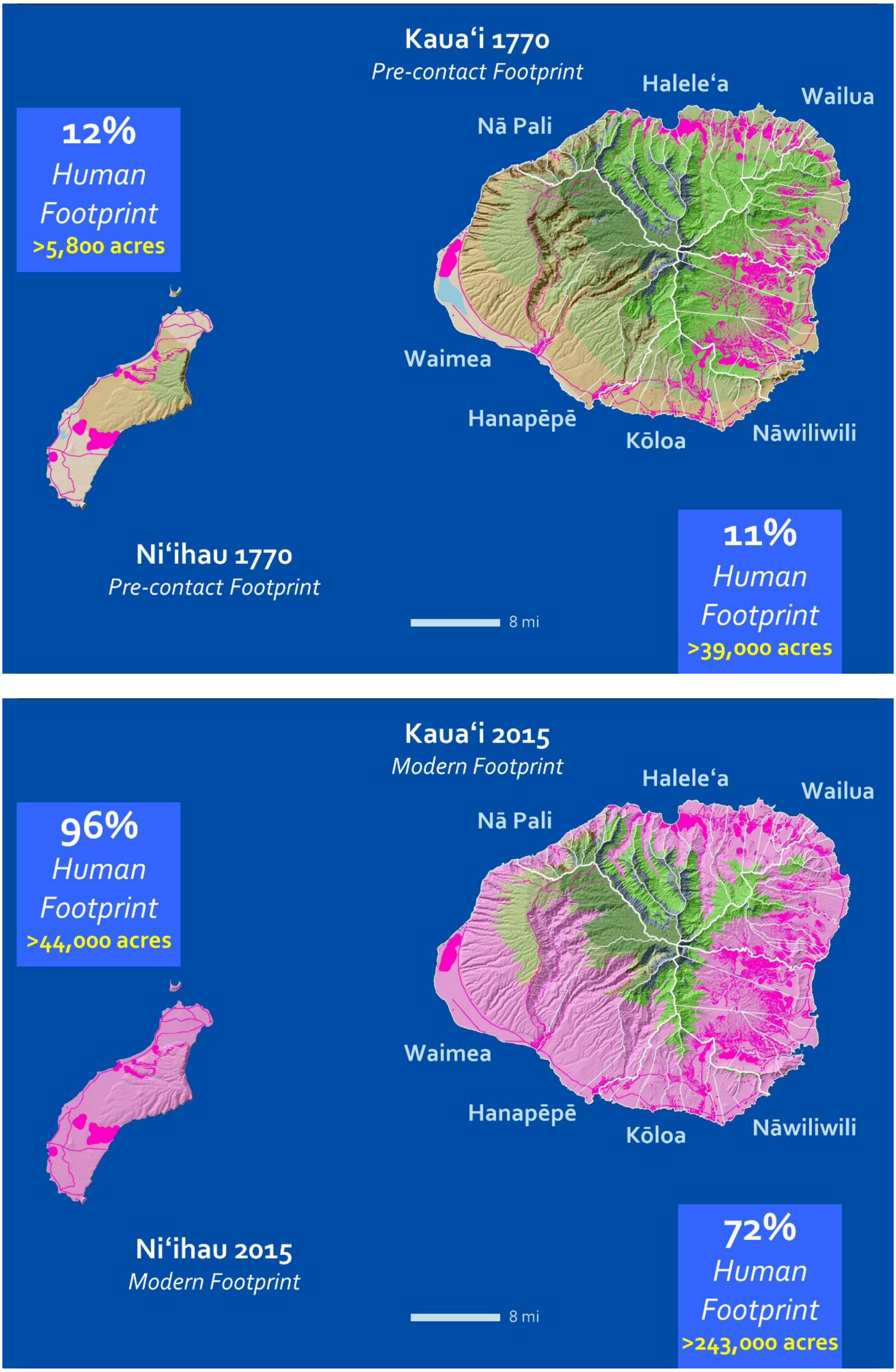

Figure 2. A) Hawaiian footprint, prior to Western contact, resulted in <12% native habitat loss on the islands of Kauaʻi and Niʻihau. B) Modern footprint resulted in 72% and 96% native habitat loss, respectively. Key: pink = human footprint; white line = *moku*, districts; colored basemap = major native vegetation zones.

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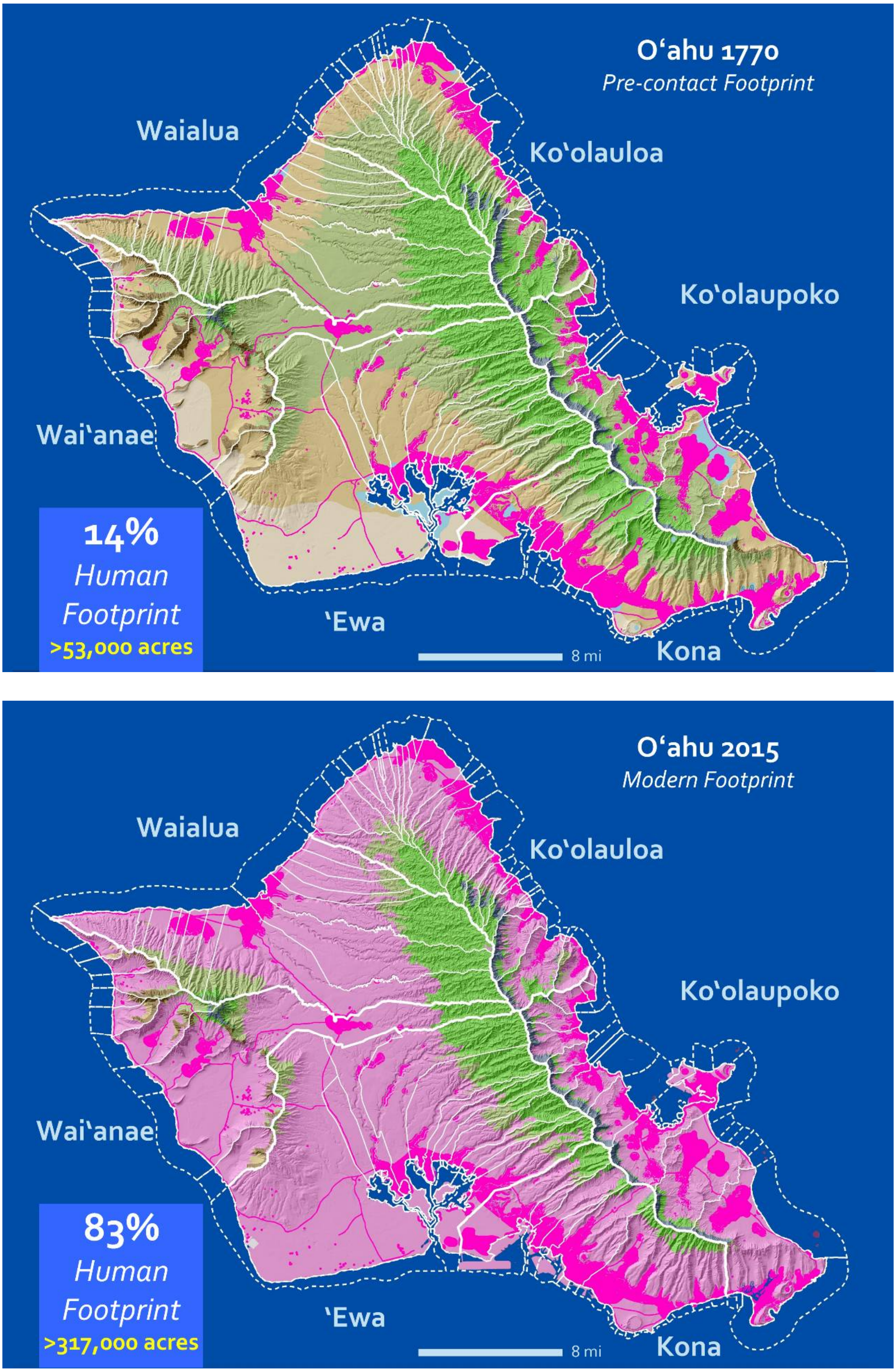

Figure 3. A) Hawaiian footprint, prior to Western contact, resulted in 14% native habitat loss on the island of O'ahu. B) Modern footprint resulted in 83% native habitat loss. Key: pink = human footprint; white line = *moku* (districts) and *ahupua'a*; dotted white line = historical nearshore fisheries, makai part of *ahupua'a*; colored basemap = major native vegetation zones.

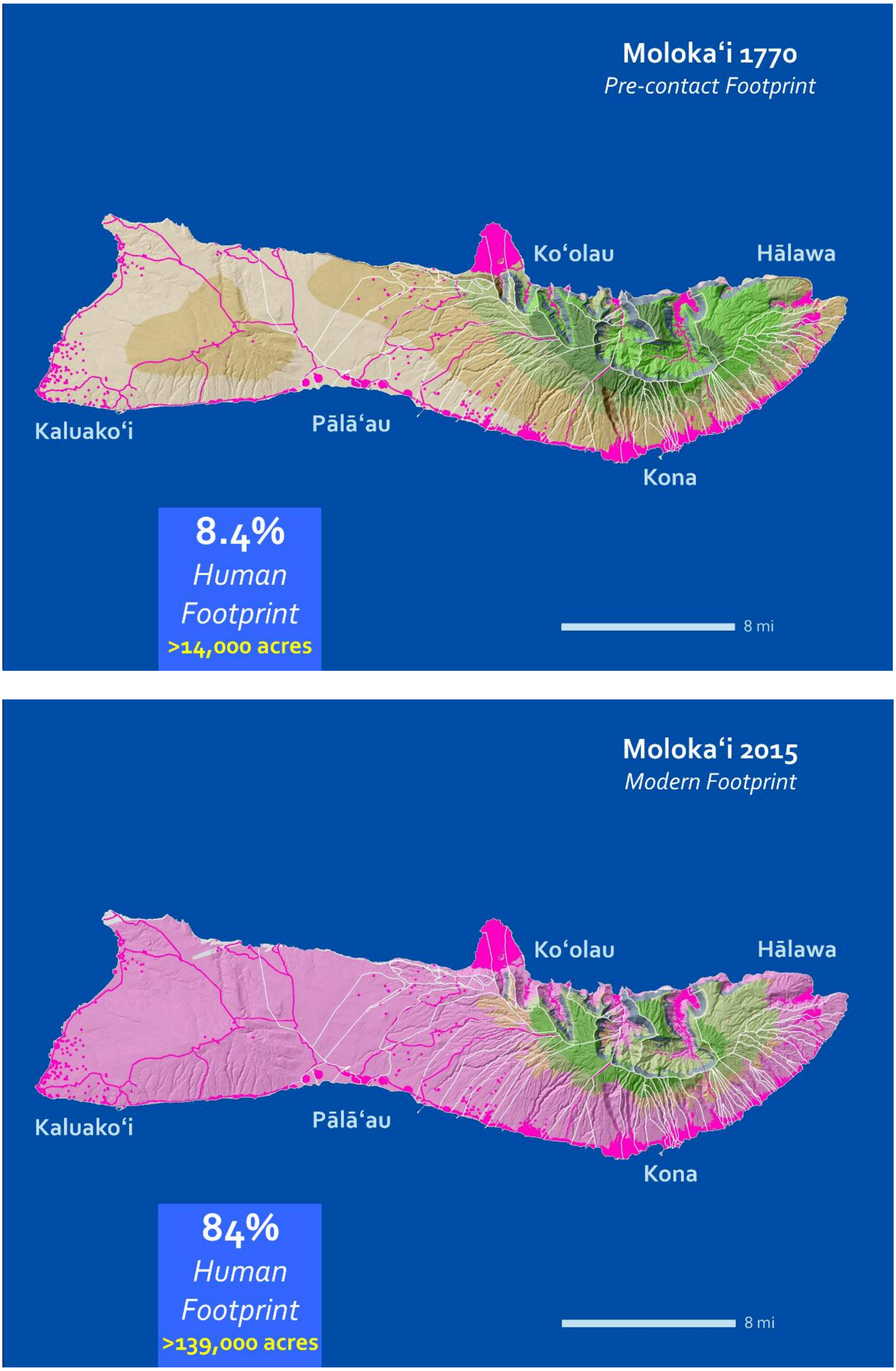

Figure 4. A) Hawaiian footprint, prior to Western contact, resulted in <9% native habitat loss on the island of Moloka'i. B) Modern footprint resulted in 84% native habitat loss. Key: pink = human footprint; white line = *ahupua'a*; colored basemap = major native vegetation zones.

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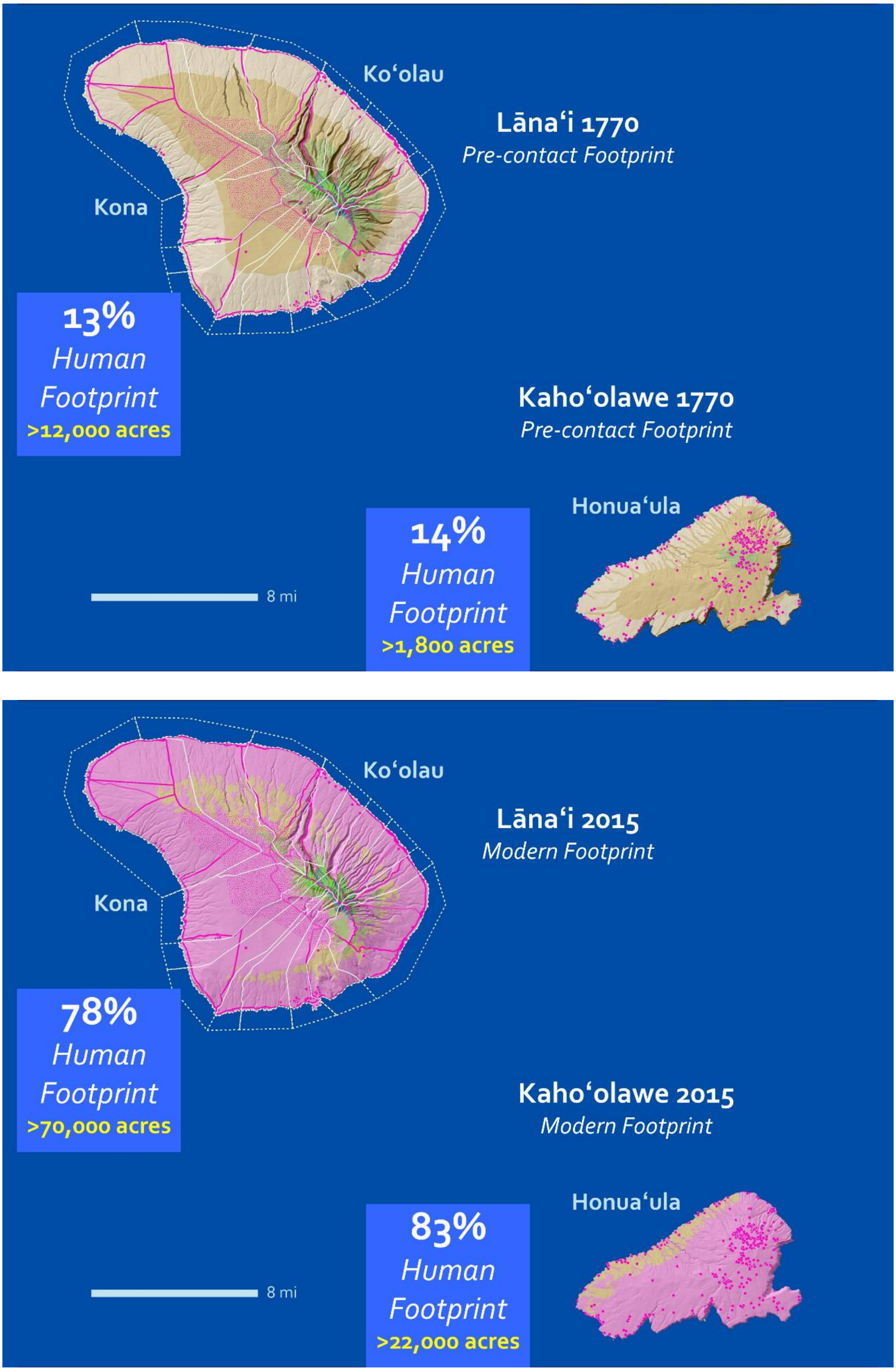

Figure 5. A) Hawaiian footprint, prior to Western contact, resulted in <14% native habitat loss on the islands of Lāna‘i and Kaho‘olawe. B) Modern footprint resulted in >78% native habitat loss. Key: pink = human footprint; white line = *ahupua‘a*; dotted white line = historical nearshore fisheries, makai part of *ahupua‘a*; colored basemap = major native vegetation zones.

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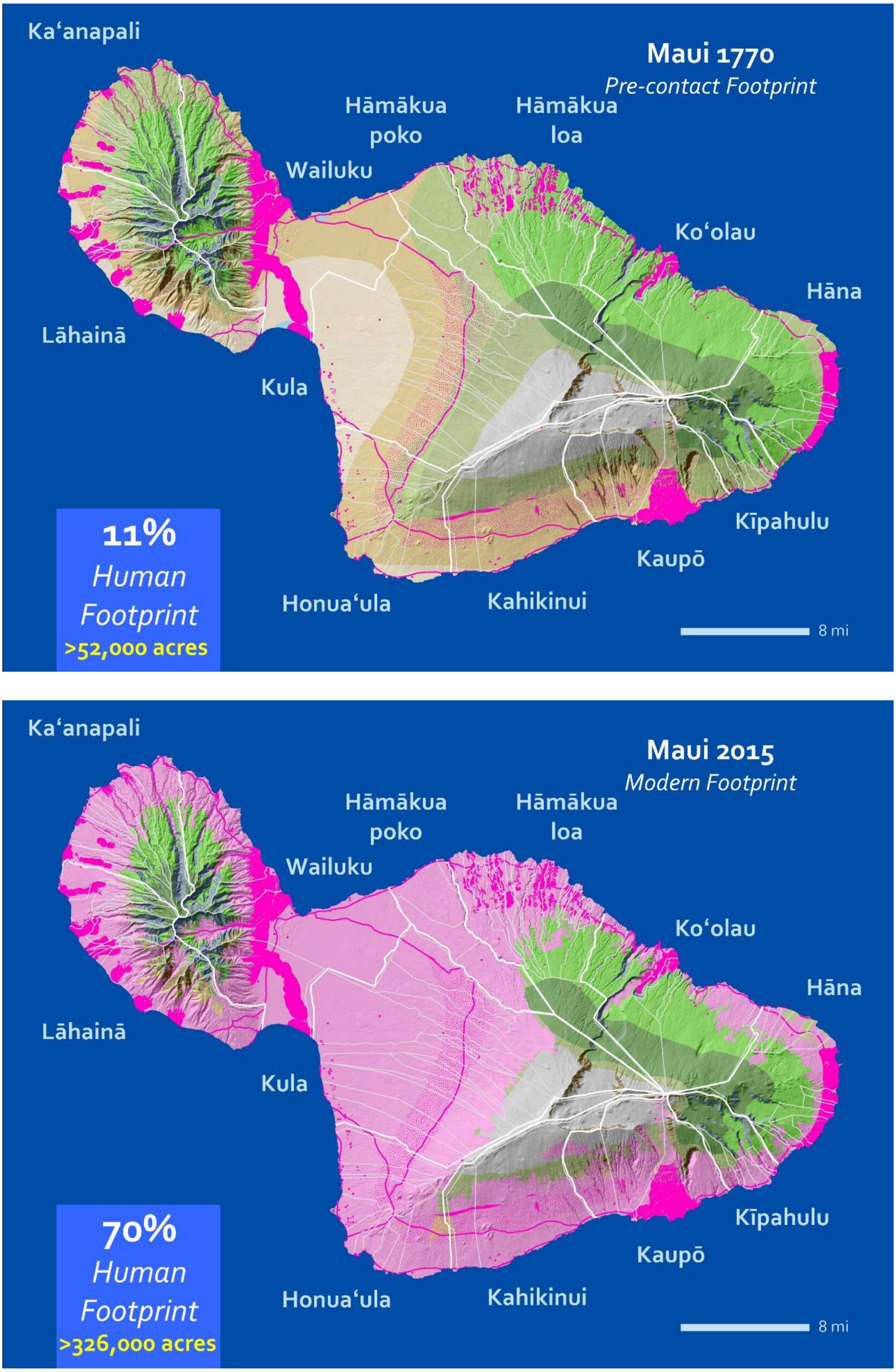

Figure 6. A) Hawaiian footprint, prior to Western contact, resulted in 11% native habitat loss on the island of Maui. B) Modern footprint resulted in 70% native habitat loss. Key: pink = human footprint; white line = *moku* (districts) and *ahupua'a*; colored basemap = major native vegetation zones.

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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.

Native Habitat Loss	1770 (acres)	% lost	1870 (acres)	% lost	2015 (acres)	% lost
Lowland Mesic	35,000	21%	73,000	44%	118,000	71%
Lowland Dry	104,000	19%	230,000	43%	371,000	69%
Lowland Wet	51,000	9%	68,000	12%	303,000	54%
Montane Dry	5,000	1.4%	137,000	37%	151,000	41%
Montane Mesic	2,000	1%	31,000	17%	43,000	23%
Alpine/Subalpine	3,300	1%	33,000	6%	33,000	6%

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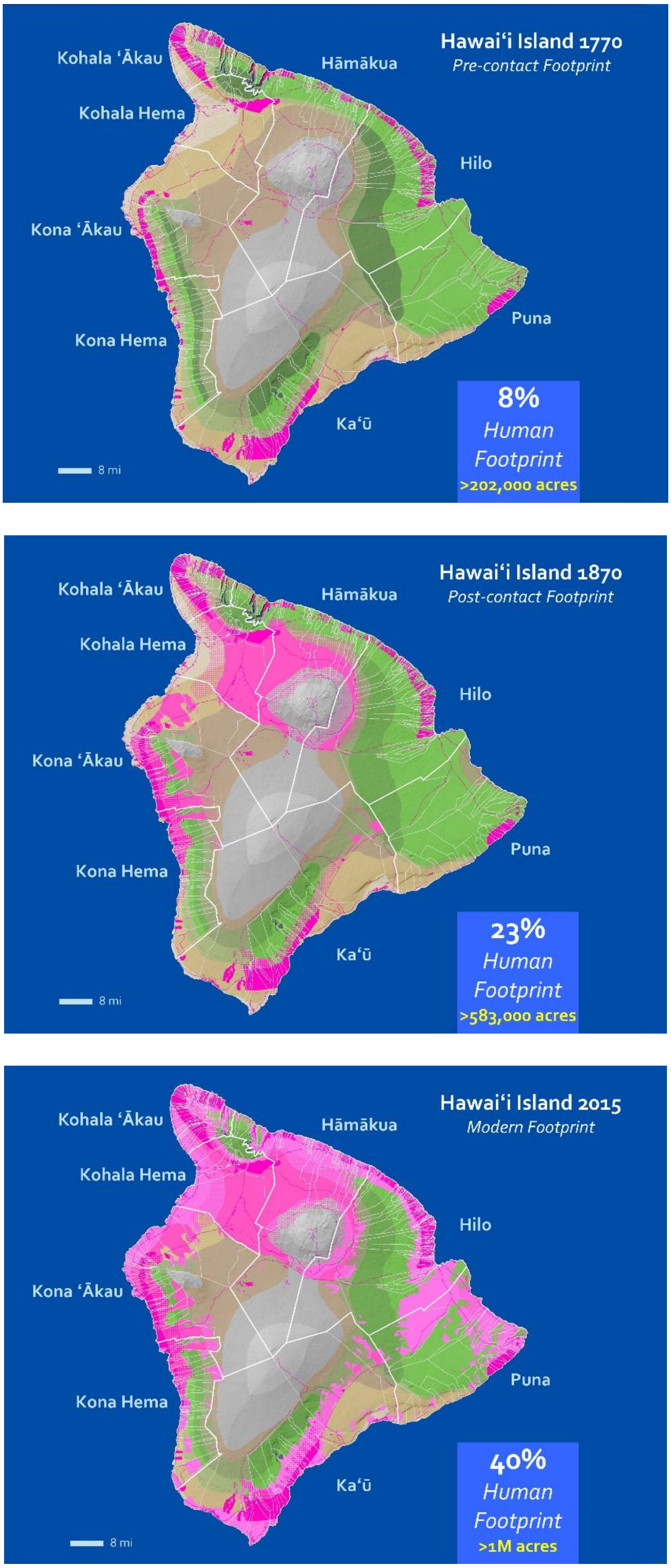

Figure 7. A) Hawaiian footprint, prior to Western contact, resulted in 8% native habitat loss on the island of Hawaiʻi. B) The human footprint tripled 100 years after Western contact. C) Modern footprint resulted in 40% native habitat loss. Social-ecological change over two centuries reflects the affect of commodification of land and resources, and loss of pre-contact biocultural relationships. Key:

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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]

Hawaiian name	Notes	Status	Scientific name
kou	wood, *lei*	Polynesian introduction	*Cordia subcordata*
kamani	*lei*, wood	Polynesian introduction	*Calophyllum inophyllum*
'uala	staple crop	Polynesian introduction	*Ipomoea batatas*
ipu	containers, music	Polynesian introduction	*Lageneria siceraria*
kukui	oil, medicinal, wood, *lei*, relish, dye	Polynesian introduction	*Aleurites moluccana*
'auhuhu	fish poison	Polynesian introduction	*Tephrosia purpurea*
'ulu	staple food crop, medicinal, sap, wood	Polynesian introduction	*Artocarpus altilis*
wauke	fiber, clothing	Polynesian introduction	*Broussonetia papyrifera*
'ōhi'a 'ai	fruit	Polynesian introduction	*Syzygium malaccense*
'awa	ritual drink, medicinal	Polynesian introduction	*Piper methysticum*
noni	medicinal, dye	Polynesian introduction	*Morinda citrifolia*
kī	food, medicinal, ritual	Polynesian introduction	*Cordyline fruticosa*
'ape	famine food	Polynesian introduction	*Alocasia macrorrhiza*
kalo	mainstay food crop	Polynesian introduction	*Colocasia esculenta*
niu	food, wood, fiber	Polynesian introduction	*Cocos nucifera*
uhi	secondary crop, not naturalized	Polynesian introduction	*Dioscorea alata*
hoi	famine food, naturalized	Polynesian introduction	*Dioscorea bulbifera*
pi'a	famine food, naturalized	Polynesian introduction	*Dioscorea pentaphylla*
mai'a hē'ī	wild food source	Polynesian introduction	*Musa troglodytarum*
mai'a (varieties)	staple crop	Polynesian introduction	*Musa x paradisiaca*
kō	food	Polynesian introduction	*Saccharium officinarum*
pia	food	Polynesian introduction	*Tacca leontopetaloides*
'ōlena	dye, medicinal, ritual	Polynesian introduction	*Curcuma longa*
'awapuhi	medicinal	Polynesian introduction	*Zingiber zerumbet*
pā'ihi'ihi	uncommon medicinal, accidental?	Polynesian introduction?	*Rorippa sarmentosa*
kāmole	wetland, accidental w/*kalo*?	Polynesian introduction?	*Ludwigia octovalvis*
'ihi	medicinal; indig? seeds in pre-contact sites	Polynesian introduction?	*Oxalis corniculata*
---	cultiv. central Pac, 3 records from HI	Polynesian introduction?	*Solanum viride*
'ohe Kahiki	tools, wood, music, container; indig?	Polynesian introduction?	*Schizostachyum*
---	seeds in pre-contact sites; indig NA, SA	naturalized?	*Daucus pusillus*
pohe	indig NA; pre 1871 HI records	naturalized?	*Hydrocotyle verticillata*
koali 'ai	famine food, poss indig?	naturalized?	*Ipomoea cairica*
koali kuahulu	pantropical, indig?	naturalized?	*Merremia aegyptia*
kākalaioa	indig/early intro; also *hihikolo*	naturalized?	*Caesalpinia major*
maunaloa	indig Honduras; 1st record HI 1825	naturalized?	*Dioclea wilsonii*
pāpapa	native to tropical Asia? edible	naturalized?	*Lablab purpureus*
---	pantropical weed	naturalized?	*Sida rhombifolia*
kāmole	accidental w/*kalo*?	naturalized?	*Polygonum glabrum*
pōniu	also *haleakai'a*; medicinal	naturalized?	*Cardiospermum halicacabum*
'aka'akai	also *kaluhā*, indigenous to NA & SA	naturalized?	*Schoenoplectus californicus*
---	cosmop., accidental on *kalo*?	naturalized?	*Lemna aequinoctialis*
---	cosmop., accidental on *kalo*?	naturalized?	*Spirodela polyrrhiza*
---	indig Asia, Malesia; 1st HI coll pre 1871	naturalized?	*Garnotia acutigluma*
'ili'ohu	once noted nr *kalo* fields; extinct?	indigenous?	*Cleome spinosa*

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---	widespread in the S. Pacific	indigenous?	*Ipomoea littoralis*
kākalaioa	indig/early intro; *lei*, medicinal	indigenous?	*Caesalpinea bonduc*
---	widesp trop Indo-Pac, but 1st HI rec 1920	indigenous?	*Entada phaseoloides*
pakaha	indig NA, pretty flowers, no descr uses.	indigenous?	*Lepechinia hastata*
pūkāmole	1st HI record 1794; medicinal	indigenous?	*Lythrum maritimum*
maʻo	indigenous NA;	indigenous?	*Abutilon incanum*
hau	wood, fiber, medicinal	indigenous?	*Hibiscus tiliaceus*
milo	wood	indigenous?	*Thespesia populnea*
pōpolo	medicinal, dye, food	indigenous?	*Solanum americanum*
uhaloa	medicinal	indigenous?	*Waltheria indica*
ʻahuʻawa	fiber, plaiting	indigenous?	*Mariscus javanicus*
---	prob indigenous	indigenous?	*Carex thunbergii*
kohekohe	low elev marshes	indigenous?	*Eleocharis calva*
hala	brought, but also indigenous; plaiting,	indigenous?	*Pandanus tectorius*
mānienie ʻula	1st HI record 1819, widespread	indigenous?	*Chrysopogon aciculatus*
pili	thatch	indigenous?	*Heteropogon contortus*
mauʻu laiki	no rec uses; post-contact Hawn name	indigenous?	*Paspalum scrobiculatum*
---	accidental w/ *kalo*? leafy pondweed	indigenous?	*Potamogeton foliosus*
---	accidental w/ *kalo*? long-leaved pondweed	indigenous?	*Potamogeton nodosus*

Key: **Hawaiian name** (--- = no known Hawaiian name); **Notes** (Hawaiian uses, other salient info); **Status** (indigenous? = possibly indigenous; naturalized? = possibly early naturalized post-contact introduction).

Two-hundred and fifty years of plant introductions since Western contact have completely changed that picture and disrupted the process of vegetation succession in Hawaiʻi. Perhaps 15,000 or more taxa of vascular plants had been introduced to Hawaiʻi [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 *loʻi 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 Hawaiʻi 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 *ʻuala* are sensitive to precipitation (*ʻuala* particularly so), the archeology of sweet potato agriculture on Maui already demonstrates a mismatch: archeological complexes associated with seasonal *ʻuala* 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.

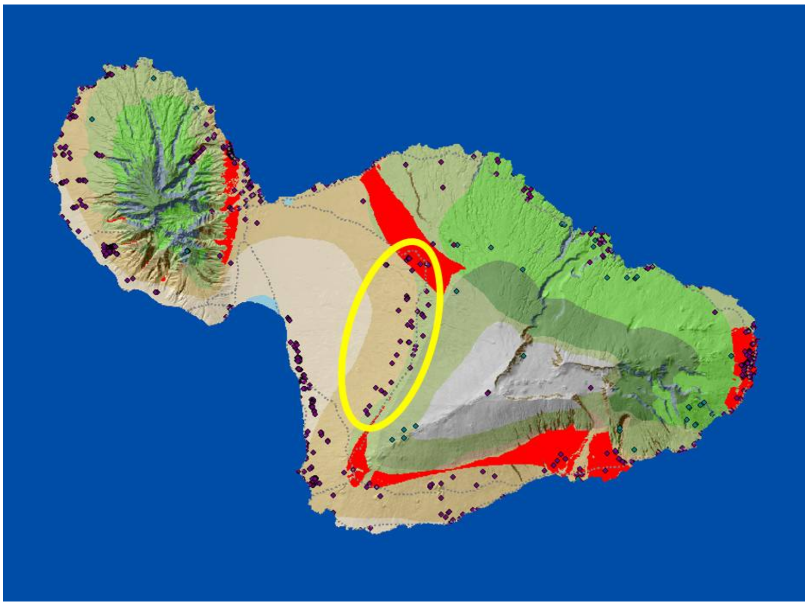

Figure 8. Map showing mismatch of *'uala* agricultural model prediction (red) with archeological complexes (dots) on the west flank of East Maui (yellow oval).

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:

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