Baseline and Projected Future Carbon Storage and Carbon Fluxes in Ecosystems of Hawai‘i
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Chapter 2. Baseline Land Cover

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2.1. Highlights

- The land-cover map used for the carbon assessment of Hawai‘i was developed by integrating mapped components from several recent land-use and land-cover maps and the mapped units were updated using very high resolution imagery, as needed.
- The resulting land-cover map has a hierarchical classification scheme that groups the mapped units into 48 detailed units, 27 general units, 13 biome units, and 7 major land-cover units.
- Although the detailed units more clearly depict the current vegetation composition of the area, we used the general units for calculating aboveground carbon stocks and the biome units were used as a basis for projecting vegetation distribution to 2100 based on climate change projections as reported in Fortini and others (this volume, chap. 3).
- An updated map depicting the current status of habitats on the main Hawaiian Islands was also produced. This habitat map identifies the vegetation in a given area as native dominated, a mix of native and alien species, heavily disturbed (agriculture, urban development) with few native species, or sparse to barren (recent lava flows or bare ground).

2.2. Introduction

The flora of the Hawaiian Islands is unique to the world, displaying some of the highest rates of species endemism for a major land area (Wagner and others, 1999; Ziegler, 2002). A primary factor leading to the development of the unique native flora and vegetation of Hawai‘i is the extreme isolation of this island archipelago; the closest continental area is North America, more than 3,200 km away (Juvik, 1998). The vast distances to other biological regions has dramatically restricted the number of species that have been able to successfully disperse across the Pacific Ocean and establish on these volcanic islands. The unique composition, structure, and species dynamics (such as disturbance history, species invasion, and succession) of the vegetation in Hawai‘i, in addition to land-use and land-cover changes, make this tropical island archipelago an essential addition to the overall carbon assessment of the United States.

The currently documented native Hawaiian flora is estimated to have resulted from just 258 successful colonizing species (Price and Wagner, 2011), which Juvik (1998) equates to species getting established in these islands at an average rate of one species every 98,000 years. Successfully colonizing species generally have small seeds that can be blown over the ocean by winds or dispersed by birds. Many of the ancestral species that ultimately became established in Hawai‘i were subsequently able to radiate into a myriad of new endemic species (Wagner and Funk, 1995). One other important result of this isolation was that only a few tree species could become naturally established in Hawai‘i and the resulting plant community composition and structure reflects the disharmonic nature of these few successfully colonizing taxa. This is clearly seen with ‘ohi‘a (*Metrosideros polymorpha*), which is the most abundant tree species in most native Hawaiian plant communities. ‘Ohi‘a is the dominant species forming the tree canopy in habitats that range from sea level to tree line, and it also dominates the vegetation from the wettest areas to very dry zones (Wagner and others, 1999; Mueller-Dombois and others, 2013). Perhaps the most remarkable feature of ‘ohi‘a is the fact that it displays most of the characteristics of a pioneer species and is able to quickly colonize new or disturbed sites through dispersal of its very small, wind-blown seeds. Additionally, ‘ohi‘a is relatively shade intolerant, another pioneer species characteristic. In most continental ecosystems, pioneer species are the first colonizers of a new or disturbed site but are eventually replaced by more typical climax species that are best adapted to getting established as secondary species in more mature habitats and are able to retain their dominance since they can regenerate even in dense understory shade conditions.

Within this backdrop of the disharmonic Hawaiian flora filtered by isolation, the vegetation on the main Hawaiian Islands is influenced by a combination of abiotic and biotic factors.

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Moisture availability, temperature, and substrate type and age are primary factors that determine the composition, structure, and distribution of plant species and communities across the archipelago (Pratt and Gon, 1998; Price and others, 2012). However, human changes to the original landscape (for example, agriculture and development of urban areas) (Cuddihy and Stone, 1990; Warshauer, 1998), as well as impacts from a multitude of introduced invasive plant and animal species (Staples and Cowie, 2001), have dramatically altered the composition and distribution of many of the plant communities currently found in Hawai‘i, particularly in lower elevation areas.

The northeast trade winds that blow in this region of the Pacific Ocean more than 75 percent of the time generally result in wet windward habitats and dry leeward habitats on all of the main Hawaiian Islands (Giambelluca and others, 2013). The only exceptions to this pattern are seen on the tall volcanoes on the islands of Hawai‘i and Maui, where the habitat becomes arid in the subalpine and alpine zones that lie above the trade-wind inversion layer (Giambelluca and others, 2013). Additionally the western (Kona) side of the Island of Hawai‘i is in the wind shadow of the two large volcanoes, Mauna Loa and Mauna Kea. As a result, the weather pattern in this area is not driven by the trade winds but by a daily convection-circulation system that results in a pattern of onshore winds during the daytime that allows for the development of much wetter conditions at mid-elevations, even in this leeward part of the island (Giambelluca and Schroeder, 1998). Price and others (2012) produced a map showing the distribution of seven moisture zones across the main Hawaiian Islands and it clearly depicts these two anomalous conditions (fig. 2.1).

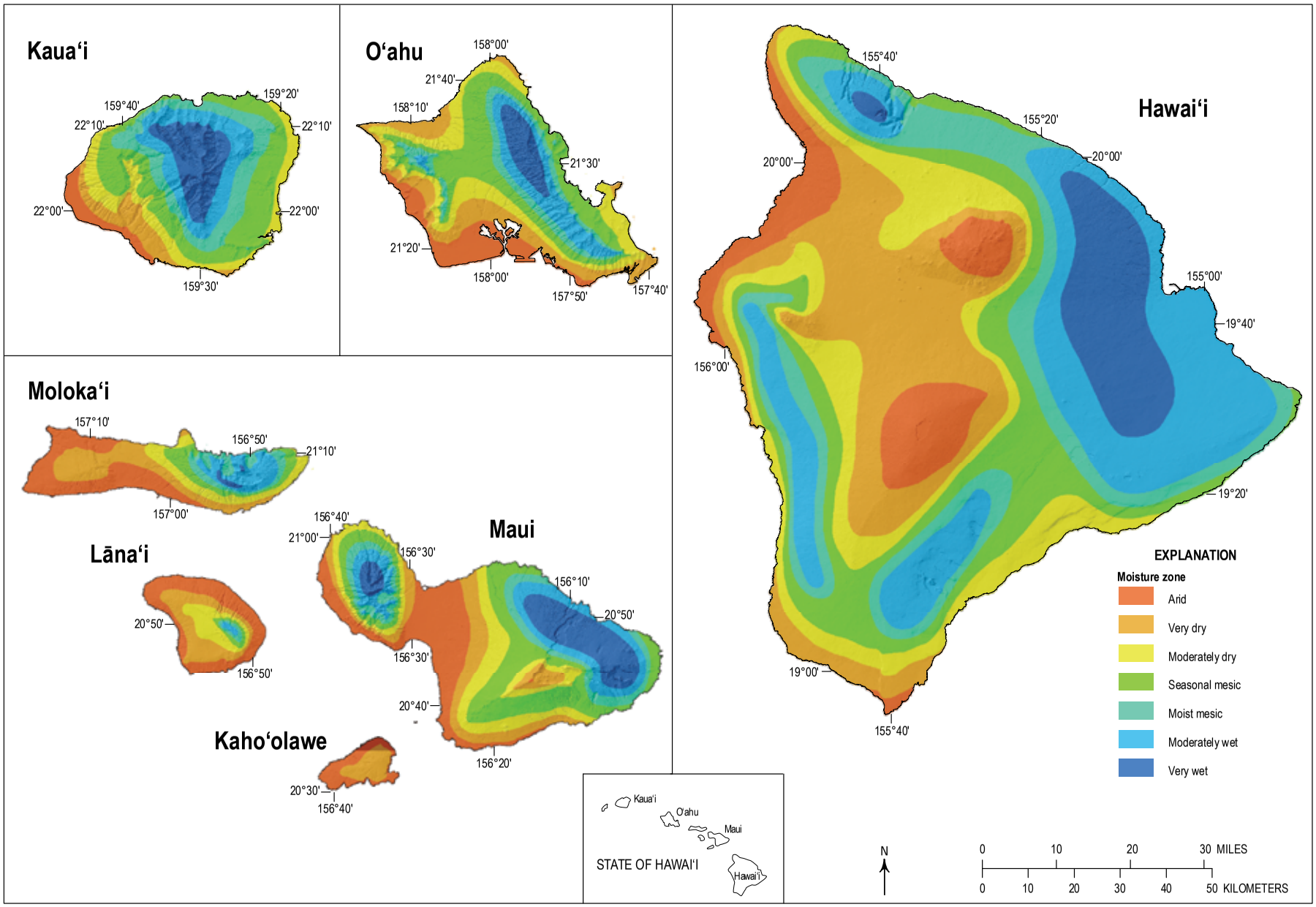
Although there have been many maps produced that depict vegetation for the State of Hawai‘i, only a few of these display land cover for all of the main Hawaiian Islands, and most of those that were created before the year 2000 have very generalized units or are somewhat inaccurate as a result of more recent land-use changes or poor resolution (both spatial and spectral) in the imagery that was used to produce the map. Some of the more detailed and accurate maps include the Hawai‘i GAP Analysis (HIGAP) land cover map (Gon and others, 2006), the NOAA C-CAP land cover map (NOAA National Ocean Service Coastal Services Center, 2012), and the more recently released Hawai‘i LANDFIRE EVT land cover map (U.S. Geological Survey, 2009). However, all of these maps as originally produced were not considered to be detailed enough or current enough, or they had other classification issues that would not allow them to be used as the primary base for the carbon assessment for Hawai‘i (CAH).

For the CAH we integrated components from several of these previously mentioned land-use and land-cover mapping efforts and combined them into a single new land-cover map (CAH land cover) that was further updated using very high resolution imagery. The hierarchical classification system of the CAH land cover map allows for grouping the mapped units into different configurations, ranging from very detailed plant communities reflecting current conditions to very generalized major land-cover units and biomes that represent land use and potential vegetation zones, respectively. Additionally, we created an updated habitat status map based on the original version described in Price and others (2012). This map (CAH habitat status) depicts the distribution of plant communities that are (1) dominated by native species, (2) mixed native and alien species, (3) heavily disturbed areas with few native species, and (4) areas with less than 5 percent vegetation cover.

2.3. Input Data and Methods

The land-cover map used for the CAH was created by updating and combining spatial units from several previously produced maps using Esri ArcGIS ver. 10.2. Although the original maps were developed using imagery from various dates between 2000 and 2012, we considered them to represent “current” (about 2014) conditions. Base maps for this newly compiled CAH land-cover map included vegetation units and boundaries from the HIGAP land cover map (Gon and others, 2006), land-use units from the 2005 NOAA C-CAP map (NOAA National Ocean Service Coastal Services Center, 2012), the “bare” (<5 percent vegetation cover) map unit from the Hawai‘i LANDFIRE map (Rollins, 2009; U.S. Geological Survey, 2009), and data on the distribution of managed tree plantations for the main Hawaiian Islands on both state lands (Yoshiko Akashi, Hawai‘i Division of Forestry and Wildlife, unpublished data) and private lands (Nicholas Koch, Forest Solutions Inc., unpublished data). All spatial files were projected in UTM Zone 4 using the NAD83 datum. The HIGAP, NOAA C-CAP, and LANDFIRE maps were all based on LANDSAT TM imagery with 30 by 30 m (900 m^2) pixels. The tree-plantation maps were originally produced as polygon feature layers so they were converted to raster format and aligned to the same 30 m grid system that was used for the other maps and for the final CAH land-cover map.

Each land-use or land-cover data layer was reviewed for accuracy of its selected units by comparing the mapped units to more recent high-resolution WorldView 2 (WV2) digital satellite imagery collected by DigitalGlobe in 2010 (<2-m pixel size; https://www.digitalglobe.com) and very high resolution imagery from Pictometry Online (POL; Pictometery International, 2014), which were also projected in UTM Zone 4 NAD 83. Where differences were found between the original mapped land-use and land-cover units and the high-resolution imagery, corrections were made to the original raster maps by reclassifying pixels to their correct values using the raster editing program Grid Editor developed by ARIS B.V. (2014). The HIGAP land cover layer needed the greatest amount of modification; these changes included (1) manually correcting misclassified pixels based on current high-resolution imagery, (2) combining similar or redundant mapping units with different names, (3) reclassifying some of the ambiguous HIGAP units (for example, “uncharacterized forest”) into other mapped units, and (4) separating several of the HIGAP units (for example, “ohi‘a forest”, “koa forest”) into subunits based on moisture zones described and mapped by Price and others (2012). The updated map layers were then combined into a single raster map (CAH land-cover), which also has 30-m pixel resolution, using the



Shaded-relief base modified from U.S. Geological Survey National Elevation Dataset, 2015.

Figure 2.1. Distribution maps of moisture zones on the main Hawaiian Islands (adapted from Price and others, 2012).

ArcGIS Mosaic tool. For this final map the updated HIGAP land cover map was used as the base map, with values from the NOAA C-CAP, LANDFIRE, and tree plantation maps replacing the HIGAP raster values that they overlaid.

The mapped units for the CAH land-cover map are linked to the alliance and association levels of the revised National Vegetation Classification (rUSNVC) which is based on the National Vegetation Classification Standard that was formally adopted by the Federal Geographic Data Committee (FGDC) in 2008 (FGDC, 2008). These units also correspond with NatureServe's Terrestrial Ecological Systems Classification (NatureServe, 2010, 2011). However, one major difference between the various CAH land-cover classification levels and the rUSNVC classification is that in the CAH land-cover map we did not separate the units into lowland, montane, and alpine units.

The CAH habitat status map was developed by modifying the original Habitat Quality map produced by Price and others (2012) using several more recent land-use and land-cover maps and imagery. This map was revised by combining mapped agriculture and land use, as well as the "bare" categories from the NOAA C-CAP 2005 map (NOAA National Ocean Service Coastal Services Center, 2012), and adding road corridors to the heavily disturbed category based on the Tiger Roads layer (U.S. Census Bureau, 2014). Additionally, corrections were made to this new version of the map by visually inspecting previously mapped units and comparing them to recent high-resolution imagery including WorldView 2 multi-spectral imagery and to very high resolution imagery obtained from Pictometry Online. Where needed, specific changes to pixels were reclassified using the ARIS GRID Editor. Because the CAH habitat status map was revised directly from a previous map, there are slight differences in the area calculations reported here for this map relative to areas reported for the CAH land-cover map, which was clipped by a different island polygon.

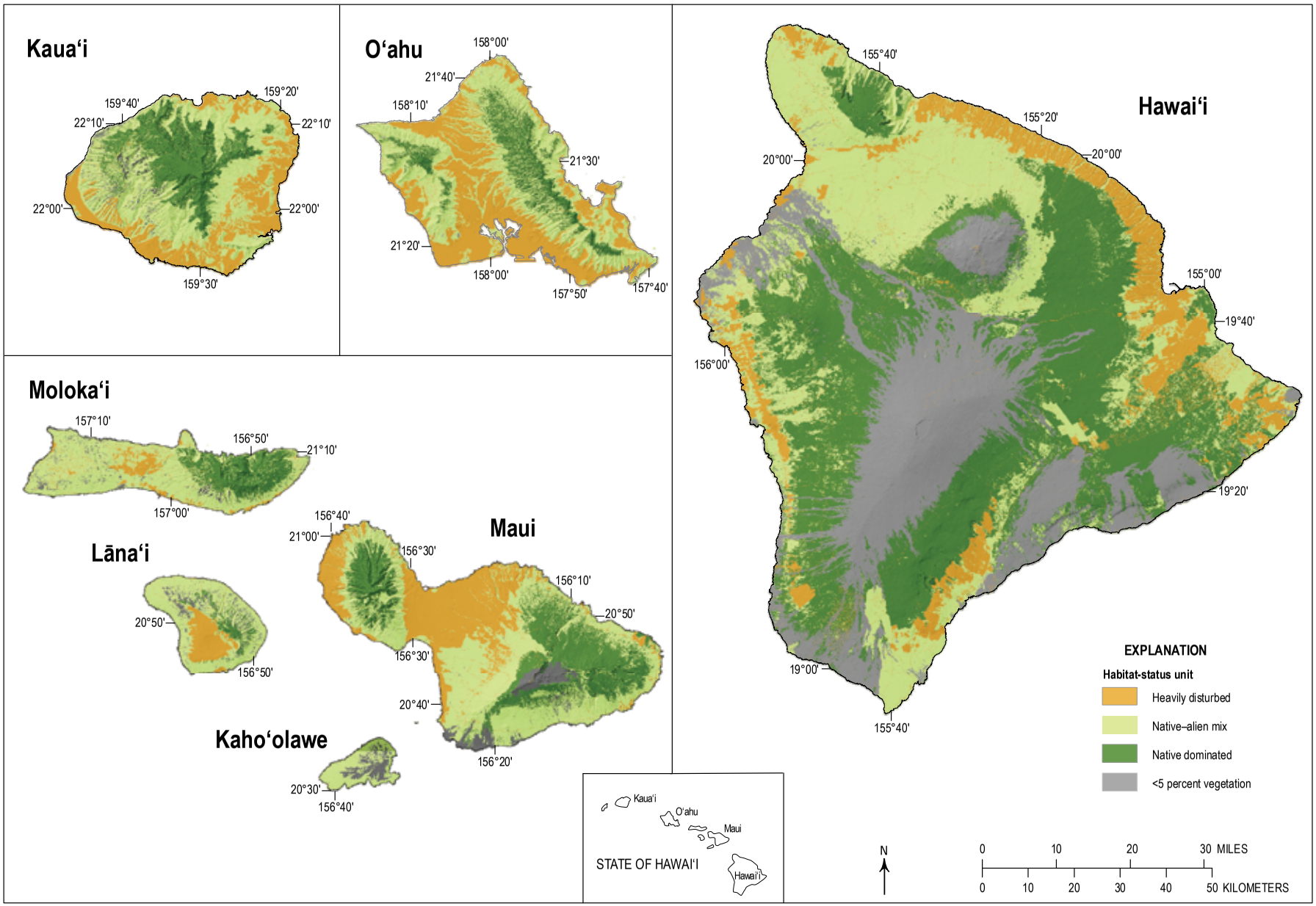
2.4. Summary of Habitats and Land-Cover Units

The CAH land-cover classification is hierarchical with 48 CAH Detailed land-cover units, which can be grouped into 27 CAH general land-cover units, 13 CAH biome units, and 7 CAH major land-cover units (Appendix 1). The CAH detailed land-cover units generally correspond to the rUSNVC association level, the CAH general land-cover units correspond to the rUSNVC group level, and the CAH biome units correspond to the rUSNVC subclass level. Although the CAH detailed land-cover units more clearly depict the current vegetation of the area, we used the CAH general land-cover units for calculating aboveground carbon stocks (Hawbaker and others, this volume, chap. 5), and the CAH biome units were used as a starting point for projecting vegetation distribution in 2100 (see Fortini and others, this volume, chap. 3).

Based on our revised CAH habitat status map, more than 16 percent of the landscape on the main Hawaiian Islands has been heavily impacted by agriculture, urban development, and resort development (fig. 2.2; table 2.1). Approximately 31 percent of the islands are still dominated by native vegetation and 36 percent of the area has habitats that are somewhat disturbed, with a mix of native and alien plant species. The remaining area, 16 percent,

Table 2.1. Summary of coverage of the carbon assessment for Hawai‘i habitat status map units for the main Hawaiian Islands.

Habitat-status unit	Island							Total
	Kaua‘i	O‘ahu	Moloka‘i	Lāna‘i	Maui	Kaho‘olawe	Hawai‘i	
	Area in square kilometers							
Heavily disturbed	363	620	60	77	487	0	1,083	2,690
Native/Alien mix	723	729	443	238	854	85	2,875	5,947
Native dominated	324	200	149	27	464	0	3,985	5,149
<5% vegetation	27	4	23	23	84	31	2,518	2,709
Total	1,437	1,553	675	365	1,888	116	10,461	16,496
	Percent of total area							
Heavily disturbed	25.2	39.9	8.9	21.0	25.8	0.1	10.4	16.3
Native/Alien mix	50.3	46.9	65.6	65.2	45.2	73.5	27.5	36.1
Native dominated	22.6	12.9	22.0	7.4	24.6	0.0	38.1	31.2
<5% vegetation	1.9	0.2	3.4	6.3	4.4	26.5	24.1	16.4



Shaded-relief base modified from U.S. Geological Survey National Elevation Dataset, 2015.

Figure 2.2. Distribution maps of carbon assessment for Hawai‘i habitat-status units on the main Hawaiian Islands.

has less than 5 percent vegetation cover; most of this area is in the alpine zone on the islands of Hawai‘i and Maui, although some relatively large non-vegetated areas are found on recent lava flows, primarily on the Island of Hawai‘i. For the most part this non-vegetated unit can be considered to be native dominated, particularly in the alpine and subalpine zones.

From a vegetation-structure perspective, more than 35 percent of the current landscape on the main Hawaiian Islands is covered by forest, dominated variously by native tree species, alien tree species, or a mix of the two (fig. 2.3; table 2.2). Another 16 percent is mapped as shrubland and approximately 17 percent as grassland. Non-vegetated areas, primarily on Maui and Hawai‘i Island, compose almost 19 percent of the map. The remaining area was mapped as either agriculture, developed, or “other” (wetlands and bogs), which compose less than 0.2 percent of the map.

The 13 CAH biome units incorporate a combination of vegetation structure (for example, forest, shrubland, and grassland) and moisture zones from the Price and others (2012) map (fig. 2.4; table 2.3). Although this depiction of the CAH land-cover map also includes units that relate directly to modification of the landscape by human development, the basic land cover and moisture zones could be generalized across these areas to create the base for the current and future biome maps described in Fortini and others (this volume, chap. 3).

The CAH General Map units are even more detailed and display the distribution of plant communities that incorporate vegetation structure, moisture zones, and status of the dominant vegetation (native dominated, mixed native–alien communities, and alien dominated), as well as land-use units (fig. 2.5; table 2.4). This map level was used as the basis for the overall carbon assessment described in MacKenzie and others (this volume, chap. 7).

Finally, the 48 CAH detailed land-cover units bring dominant species into the unit description (Appendix 1). Although we did not use this level of detail directly in our CAH analysis, these units form the basis for the more generalized units described above. Additionally, this most detailed map level will likely be useful as a base map for other research and management applications in the main Hawaiian Islands.

Table 2.2. Summary of coverage of the carbon assessment for Hawai‘i major land-cover map units for the main Hawaiian Islands.

[CAH, carbon assessment for Hawai‘i]

CAH major land-cover unit	Island							Total
	Kaua‘i	O‘ahu	Moloka‘i	Lāna‘i	Maui	Kaho‘olawe	Hawai‘i	
	Area in square kilometers							
Forest	692	675	240	145	754	56	3,286	5,848
Shrubland	231	204	308	108	227	14	1,628	2,719
Grassland	163	110	58	91	321	21	2,024	2,789
Other	8	13	5	0	7	0	5	37
Agriculture	143	131	15	0	266	0	392	948
Developed	115	410	29	14	155	1	308	1,032
Not vegetated	85	8	18	7	155	24	2,816	3,113
Total	1,436	1,551	674	365	1,886	115	10,458	16,485
	Percent of total area							
Forest	48.2	43.5	35.7	39.7	40.0	48.3	31.4	35.5
Shrubland	16.1	13.1	45.6	29.6	12.1	12.1	15.6	16.5
Grassland	11.4	7.1	8.6	25.0	17.0	18.2	19.4	16.9
Other	0.5	0.8	0.7	0.1	0.4	0.0	0.0	0.2
Agriculture	10.0	8.5	2.3	0.1	14.1	0.0	3.7	5.7
Developed	8.0	26.4	4.4	3.7	8.2	0.5	2.9	6.3
Not vegetated	5.9	0.5	2.7	1.9	8.2	20.8	26.9	18.9

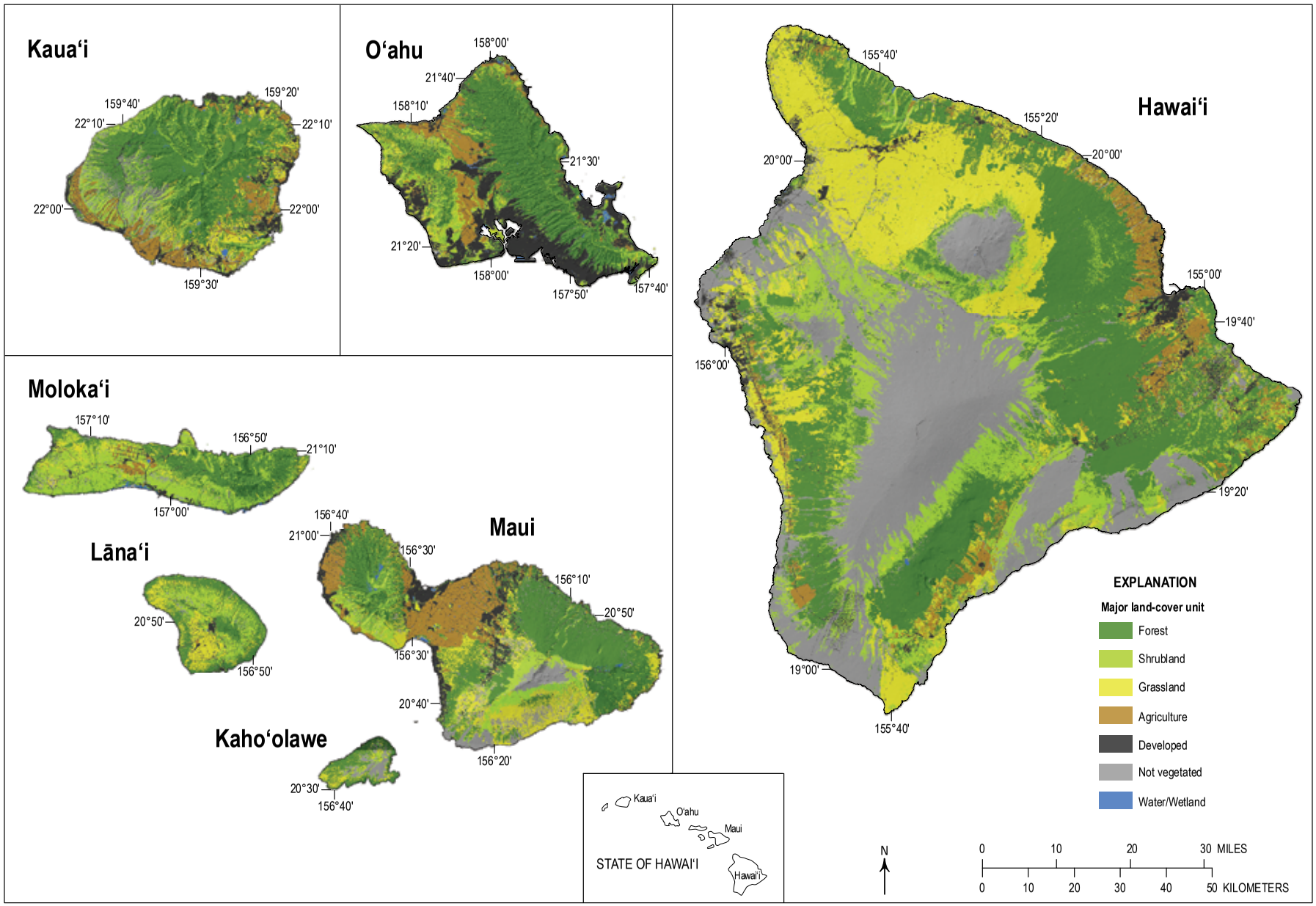


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Figure 2.3. Distribution maps of carbon assessment for Hawai‘i major land-cover units on the main Hawaiian Islands.

Table 2.3. Summary of coverage of the carbon assessment for Hawai‘i biome map units for the main Hawaiian Islands.

[CAH, carbon assessment for Hawai‘i]

CAH biome unit	Island							Total
	Kaua‘i	O‘ahu	Moloka‘i	Lāna‘i	Maui	Kaho‘olawe	Hawai‘i	
	Area in square kilometers							
Dry forest	46	97	89	128	143	56	369	927
Mesic forest	293	302	73	4	229	0	737	1,639
Wet forest	343	242	70	13	382	0	1,988	3,039
Dry shrubland	103	129	255	100	107	14	771	1,478
Mesic shrubland	71	55	31	8	70	0	606	841
Wet shrubland	57	20	22	0	50	0	251	399
Dry grassland	35	79	52	90	162	21	1,099	1,537
Mesic grassland	113	30	6	1	150	0	711	1,010
Wet grassland	16	1	1	0	9	0	214	242
Wetland	8	13	5	0	7	0	5	37
Agriculture	153	165	24	0	266	0	583	1,190
Developed	115	410	29	14	155	1	308	1,032
Not vegetated	85	8	18	7	155	24	2,816	3,113
Total	1,436	1,551	674	365	1,886	115	10,458	16,485
	Percent of total area							
Dry forest	3.2	6.3	13.1	35.1	7.6	48.3	3.5	5.6
Mesic forest	20.4	19.5	10.9	1.1	12.2	0.0	7.1	9.9
Wet forest	23.9	15.6	10.4	3.5	20.2	0.0	19.0	18.4
Dry shrubland	7.2	8.3	37.8	27.4	5.7	12.1	7.4	9.0
Mesic shrubland	5.0	3.6	4.6	2.1	3.7	0.0	5.8	5.1
Wet shrubland	3.9	1.3	3.3	0.1	2.6	0.0	2.4	2.4
Dry grassland	2.4	5.1	7.7	24.7	8.6	18.2	10.5	9.3
Mesic grassland	7.8	1.9	0.8	0.3	7.9	0.0	6.8	6.1
Wet grassland	1.1	0.1	0.1	0.0	0.5	0.0	2.0	1.5
Wetland	0.5	0.8	0.7	0.1	0.4	0.0	0.0	0.2
Agriculture	10.6	10.6	3.6	0.1	14.1	0.0	5.6	7.2
Developed	8.0	26.4	4.4	3.7	8.2	0.5	2.9	6.3
Not vegetated	5.9	0.5	2.7	1.9	8.2	20.8	26.9	18.9

Table 2.4. Summary of coverage of the carbon assessment for Hawai‘i general land-cover map units for the main Hawaiian Islands.

[CAH, carbon assessment for Hawai‘i]

CAH general land-cover map unit	Island							Total
	Kaua‘i	O‘ahu	Moloka‘i	Lāna‘i	Maui	Kaho‘olawe	Hawai‘i	
	Area in square kilometers							
Native dry forest	0	0	1	0	1	0	301	302
Native mesic forest	60	18	27	1	67	0	538	711
Native wet forest	216	127	60	13	266	0	1,755	2,437
Mixed dry forest	0	2	1	0	0	0	0	3
Mixed mesic forest	0	29	18	0	0	0	3	50
Mixed wet forest	0	4	4	0	0	0	3	11
Alien dry forest	46	95	87	128	142	56	68	622
Alien mesic forest	233	255	28	3	163	0	196	879
Alien wet forest	126	111	6	0	116	0	231	591
Alien tree plantation	10	33	9	0	0	0	191	243
Native dry shrub	8	0	2	33	54	1	728	825
Native mesic shrub	0	0	13	3	57	0	526	598
Native wet shrub	38	17	12	0	46	0	174	287
Mixed mesic shrub	0	0	2	0	0	0	0	2
Mixed wet shrub	0	0	8	0	0	0	15	23
Alien dry shrub	95	129	252	67	53	13	43	653
Alien mesic shrub	71	55	16	5	14	0	79	241
Alien wet shrub	19	2	2	0	4	0	61	89
Native mesic grassland	0	0	0	0	4	0	0	4
Alien dry grassland	35	79	52	90	162	21	1,099	1,537
Alien mesic grassland	113	30	6	1	145	0	711	1,006
Alien wet grassland	16	1	1	0	9	0	214	242
Wetland	3	4	3	0	4	0	2	16
Agriculture	143	131	15	0	266	0	392	948
Developed	115	410	29	14	155	1	308	1,032
Bare ground	85	8	18	7	155	24	2,816	3,113
Water	5	9	2	0	4	0	2	22
Total	1,436	1,551	674	365	1,886	115	10,458	16,485

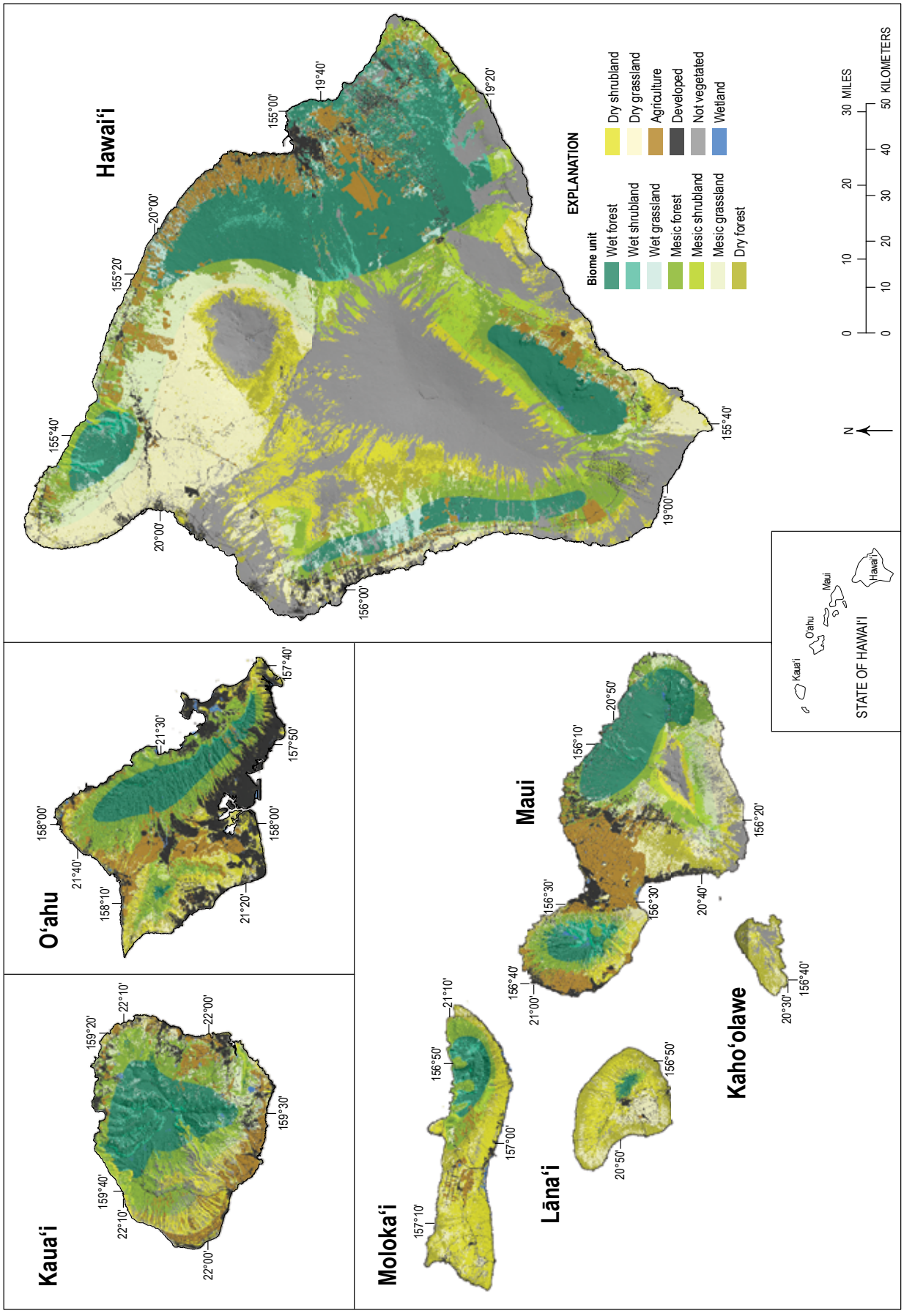
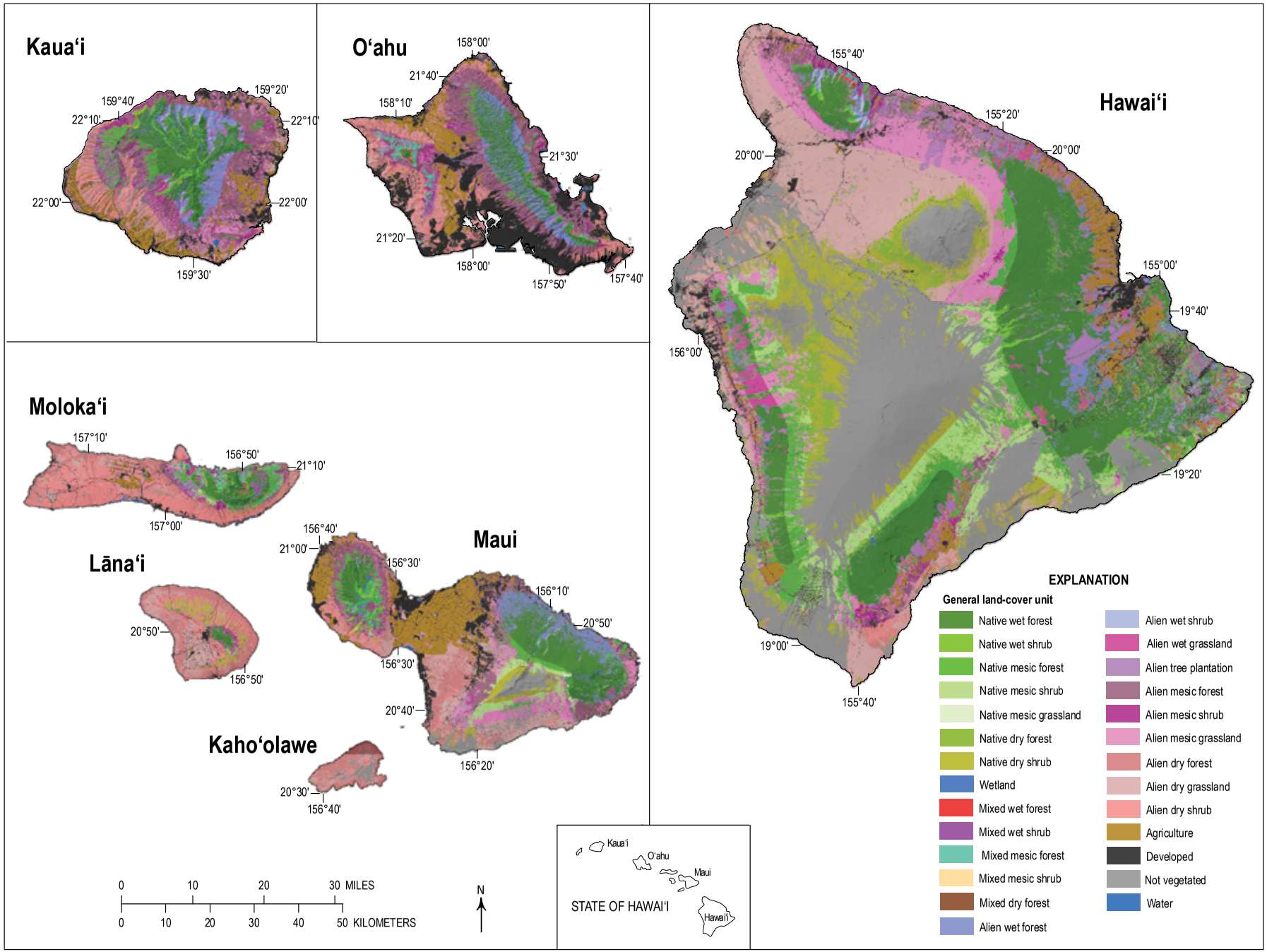


Figure 2.4. Distribution maps of carbon assessment for Hawai‘i biome units on the main Hawaiian Islands.



Shaded-relief base modified from U.S. Geological Survey National Elevation Dataset, 2015.

Figure 2.5. Distribution maps of carbon assessment for Hawai‘i general land-cover units on the main Hawaiian Islands.

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