



# The evolving agricultural landscape of post-plantation Hawai'i



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## ABSTRACT

Hawai'i's agricultural landscape was previously dominated by large monocrop plantations of sugar cane and pineapple, but following a sweeping series of plantation closures beginning at the end of the twentieth century, that era has concluded. The last spatial assessment of Hawai'i's agricultural footprint was completed in 1980, during the active plantation period. Here we present the results of a 2015 statewide assessment of the commercial crop footprint for Hawai'i, based on World-View 2 satellite imagery and supporting datasets. We analyzed changes relative to the 1980 baseline on both a statewide and regional basis, to better understand how Hawai'i's agricultural system has evolved in the post-plantation era. Sugar cane and pineapple saw dramatic reductions during this period, collectively losing more acres (257,000) than were planted for all crops combined (152,000) in 2015. Idle plantation lands and past plantation-era investments in irrigation and other infrastructure have created opportunities for other types of agriculture, despite rising land values, new and existing tropical diseases, and other challenges. Seed crops, primarily for genetically modified corn trials, were the second largest crop in 2015 (24,000 acres) despite having no mapped footprint in 1980. Commercial forestry, also absent in 1980, covered 23,000 acres in 2015. Macadamia nut, coffee, and diversified agriculture also all saw significant gains in their footprints, with coffee plantings increasing >250% during this period. Despite these gains, the Hawaiian Islands continue to have an extremely low degree of self-reliance for food production. The Oahu plain, adjacent to the major population center of Honolulu, has the most potential for considerably increasing the production of local produce, but without changes in consumption patterns and significant efforts to protect agricultural land from development, any increases in local food production will continue to be incremental. The post-plantation agricultural landscape in Hawaii is smaller, more diversified, and more nimble than it was in 1980, reflecting inter-island geographic differences in land use, history, and ownership. Mapping and assessing spatial changes in agricultural activity over time can provide valuable insights for decision-makers and communities as they continue to define what agriculture should look like in the post-plantation era. Our results suggest that Hawai'i's agricultural landscape and overall production capability will continue to contract without substantial changes in policy and practice.

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## 1. Introduction

An understanding of local agricultural production and capability is important for any area, but is particularly critical for Hawai'i, a remote and isolated island archipelago that by some estimates imports 85–90% of its food supply (Kim et al., 2015; Loke & Leung, 2013). Hawaiian agriculture has undergone substantial changes over the past half century, including the near disappearance of once

dominant sugar and pineapple plantations, growing numbers of diversified agriculture operations, and the rise of commercial forestry and biotechnology. These changes, and their underlying economic, social, and environmental drivers, are creating a new agricultural reality in the state. An analysis of this emerging agricultural landscape is overdue, as the last detailed statewide assessment of agricultural lands occurred over 35 years ago (Hawaii Office of Planning, 1980).

Here we report the results of a 2015 statewide assessment of the commercial agricultural crop footprint for Hawai'i based on high-resolution satellite imagery and supporting GIS, property tax, and other datasets. We then compare this footprint to a previous

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statewide assessment to better understand how Hawai'i's agricultural system has changed in the post-plantation era, focusing our analysis on change since 1980. In addition to examining state-wide trends, we highlight four different regions within Hawai'i that provide representative case studies on agricultural loss and transformative change. Finally, we discuss the opportunities and challenges facing Hawai'i's agriculture sector today and in the future.

### 1.1. Background

Located just south of the Tropic of Cancer in the Pacific Ocean, 3200 km to the southwest of the continental United States, the Hawaiian archipelago is composed of hundreds of islands in a northeast-southwest island arc (Fig. 1). The eight main islands have a total combined land area of 16,698 km<sup>2</sup> and support a population of 1.4 million people, the majority of whom (1.0 million) inhabit The City and County of Honolulu on the island of O'ahu (U.S. Census Bureau, 2010). Despite the large climatic gradients and diversity of eozones, large areas of the state are highly conducive to agriculture with year round growing conditions (Boyd, 2008; Schragger, 2014).

### 1.2. Brief history of Hawaiian agriculture

The Polynesian explorers who first settled in Hawai'i, somewhere between C.E. 800–1261, established an entirely self-sustaining civilization of approximately 400,000 by the time of western contact in 1778 (Kirch, 2007; Rieth, Hunt, Lipo, & Wilmshurst, 2011). The 'canoe plants' they brought with them, including tuber and tree crops such as taro (*Colocasia esculenta*), breadfruit (*Artocarpus ltilis*), and bananas (*Eumusa* and *Australimusa* types), provided the basis of their complex agricultural system, along with fishing and small domesticated animals. Most of the population lived in lowland areas with ample resources for high agricultural productivity (Ladefoged et al., 2009, 2011). Hawaiian society, land tenure, and highly sophisticated self-sustaining agricultural systems all went through dramatic changes following Western contact that led to the rise of a large scale plantation agriculture system in the late nineteenth century (Philipp, 1953; Suryanata, 2002).

Beginning in the 1860s and Prior to World War II, during the rise and peak of the sugar and pineapple plantation era, the Hawaiian landscape was transformed by extensive agricultural land use change and the development of major irrigation and infrastructure networks to redistribute water, goods, and people across the islands (Wilcox, 1997). In 1937, roughly 25% of the population lived in plantation settlements and 46 sugar and pineapple plantations intensively mono-cropped close to 300,000 acres across the islands (Territorial Planning Board, 1939). Following the war, the number of plantations steadily fell due to consolidation, rising labor costs, and increasing competition from overseas producers in places like Java, Australia, and the Philippines (Jones & Osgood, 2016; MacLennan, 2014). Prime agricultural lands, primarily around Honolulu, were consumed by rapid and largely uncontrolled urbanization, tourism development, and the construction of large military bases. Concern about these impacts led Hawai'i to adopt the nation's first statewide law regulating land use in 1961 (Cooper & Daws, 1985; Suryanata, 2002), which decelerated but did not stop the loss of prime agricultural lands.

In the 1970s, the number of regional sugar and pineapple operations began to decline even more sharply, and the losses continued over the next two decades. For sugar, these accelerated losses can be partially tied to the U.S. Congress Sugar Act of 1974, which eliminated domestic sugar quotas, import restrictions, and excise taxes, and increased price fluctuations (Alvarez & Polopolus, 1998). Increased consumption of competing sweeteners like high fructose corn syrup, legal and environmental challenges to plantation practices like burning and water diversions (Mnatzaganian, Pellegrin, Miyamura, Valencia, & Pang, 2015), and ever-increasing land values also contributed to declines in the number of plantation operations in Hawai'i. Modernization and efficiency efforts successfully increased crop yields but were often not enough to overcome the multitude of challenges facing the industry (Jones & Osgood, 2016). Between 1980 and 2000 the number of active sugar operations fell from sixteen to four, and by 2010 only one remained, Hawaiian Commercial & Sugar Company on the island of Maui. These shutdowns had far-ranging disruptive effects on the island communities the plantations had formerly supported, producing economic and unemployment crises and large swaths of idle land available for conversion into other uses.

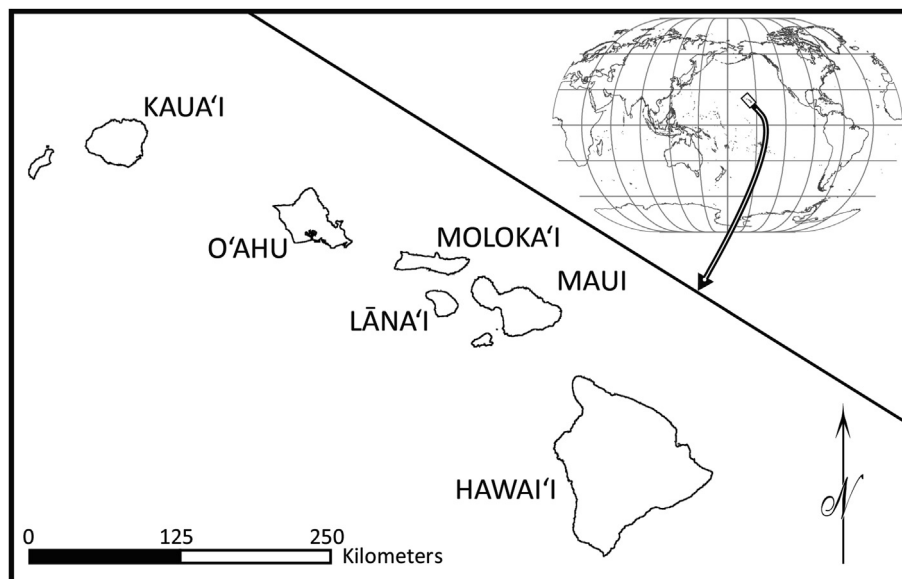


Fig. 1. Location of the main Hawaiian Islands in the Pacific Ocean.

## 2. Methods

### 2.1. Generation of the 2015 agricultural land use baseline

The 2015 agricultural land use baseline was generated from an assemblage of different datasets. Hawai'i is not part of the US Department of Agriculture (USDA) National Agricultural Imagery Program (NAIP), which provides freely-available high resolution imagery across much of the mainland United States and is the basis for many other statewide agricultural assessments (Reitsma, Clay, Clay, Dunn, & Reese, 2016). Hawai'i's tropical climate and lack of participation in NAIP or similar programs means that obtaining current, high resolution imagery that does not suffer from extensive cloud cover is challenging. The primary imagery source used in this project was half-meter spatial resolution WorldView-2 (WV2) satellite imagery from 2012 to 2014, provided by the USDA National Resource Conservation Service as cloud-free, mosaicked, and color-balanced products. Knowledge-based 'heads-up' digitization of the defined crop categories with the WV2 imagery was performed for the entire state, using a minimum mapping unit of three acres.

Although manual digitization is both tedious and somewhat subjective (Bolstad, Gessler, & Lillesand, 1990), we found that human pattern recognition of crop types and boundaries, supplemented with the ancillary datasets described below, produced better results for our study area than efforts using image segmentation or other pixel-based classification algorithms. Similar results have been reported in a number of recent studies (Ghimire, Dulin, Atchison, Goodin, & Hutchinson, 2014; Tsai, Stow, & Weeks, 2011; Wang, Johnston, Vail, Dickinson, & Putnam, 2015), and in our case is likely due in part to the loss of spectral information from the processing used to create the color-balanced mosaic. The complexity of some of Hawai'i's farming operations also contributed to difficulties with automated classification routines, particularly for farms on western Hawai'i Island producing a blended mixture of coffee and macadamia and smaller operations growing diversified crops (Fig. 2). A final reason for employing manual digitization was that the prior statewide agricultural assessment, the 1980 Agricultural Land Use Map (ALUM) layer, was also generated from manual digitizing.

Additional reference datasets used to generate the 2015 baseline include GIS layers provided by the state of Hawai'i, Office of Planning ('Agriculture and Farming,' 'Inland Water Resources,' and 'Cadastral and Land Descriptions') ([planning.hawaii.gov](http://planning.hawaii.gov)), an agricultural baseline study for Hawai'i County (Melrose & Delparte, 2012), and other spatial data layers provided by major landowners and managers in Hawai'i. Digitized crop locations and boundaries were verified through a combination of on-the-ground site visits, meetings and presentations of draft layers with agricultural stakeholders and landowners, and solicitations for public comments on draft layers through a publicly accessible online web mapping portal. Google Earth™ and other high resolution imagery sources were also used to exhaustively 'spot-check' crop boundaries. In some areas the WV2 imagery showed active commercial farming operations but landowner interviews and on-the-ground site visits in 2015 revealed cessation of agricultural activity. In those cases the apparent but now defunct agricultural lands were removed from the data layer.

County Real Property Tax and Agricultural Water Use data were also used to independently identify commercial farm operations. Data for both real property tax assessment and agricultural water use were collected from each county that provided their most recent records, generally from 2014 to 2015. Not all properties that receive County agricultural tax assessment rates or reduced water cost for agricultural uses were mapped due to the small scale of some of their operations. These data sources were used to verify mapped commercial farms and identify operations that might have been missed using the imagery alone.

### 2.2. Definition of crop categories and mapping protocols

Thirteen commercial crop types, plus pasture lands, were included in this study (Table 1). Crop categories were chosen to represent the major commercial agricultural products of Hawai'i and to allow comparison with previous statewide agricultural assessments, primarily the 1980 ALUM layer. Mapped units follow actual cropped areas as identified in WV2 satellite imagery and site visits, not property or tax parcel boundaries. Agricultural lands that did not display actual vegetation growth but appeared to be part of an active agricultural rotation (freshly tilled fields, etc.) were

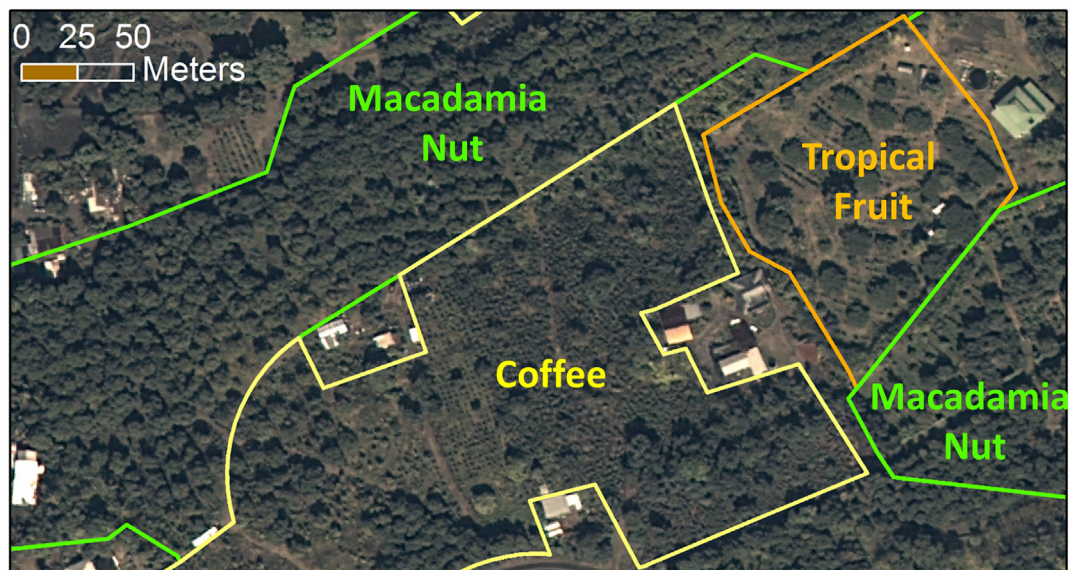


Fig. 2. Example of digitized crop boundaries from the Kona Coast on Hawai'i Island. Basemap is 0.5 m World View 2 Imagery from 2013.

**Table 1**  
Crop Category definitions.

Crop type	Description
Aquaculture	Active shrimp farms, working fishponds, algae raceways, and research/production facilities
Banana	Commercial banana fields in contiguous plantings
Coffee	Commercial coffee plantations
Commercial forestry	Short and long rotation tree crops for commercial harvesting (not forest restoration) that include eucalyptus and other species intended for timber, fiber or energy production and higher value hardwoods like koa and mahogany
Dairy	Core milking and on-farm processing facilities and the surrounding pastures and crop lands under active dairy use
Diversified Agriculture	Commercial products grown either outdoors or in greenhouses including tomato, cucumbers, leaf crops, beans, asparagus, Okinawan sweet potato, basil, Asian spices, and smaller plantings of crops such as banana, tropical fruit, papaya, coffee too small to map out individually
Flowers/Foliage/Landscaping	Commercial hot house/shade cloth grown orchids, antheriums, tropical flowers, potted nursery plants, field stock, sod farms, and landscape trees
Macadamia Nut	Actively maintained and harvested Macadamia Nut tree orchards
Papaya	Commercial papaya plantation lands with actively growing plants (not fallow lands)
Pasture	Commercial cattle operation lands where fencing is apparent and water troughs and/or cattle trails can be identified. Small pasture plots in rural homestead areas were also included where larger parcels and contiguous pasture areas were present
Pineapple	Commercial pineapple operations
Seed Production	All arable lands in use by commercial seed companies, including in-field roads, pollen drift buffers and areas managed for future crop rotation. Acres actually planted in corn or other seed crops were substantially less than the gross acres depicted
Sugar	Commercial areas planted in sugarcane
Taro	Taro grown in wetland settings, dryland taro is included in the Diversified Crop category
Tropical fruit	A range of products planted for commercial harvest including rambutan, avocado, longan, lychee, citrus, cacao and other orchard fruit trees

included with the exception of papaya and other crops that rotate every 3–4 years. For these longer-rotation crops, only active producing areas were included, not fallowed fields. In the case of papaya, this is a departure from the previous statewide assessment which included fallowed fields. Packing or processing facilities and in-field access roads were included while other structures, reservoirs, un-farmable gulches and major roadways separating field areas were not mapped. Non-commercial ‘agri-scaping’, small backyard orchards, and home use vegetable gardens were not included in this study. While pasture lands and dedicated dairy properties were included in this study, other livestock uses including equestrian areas, piggeries, and poultry farms, were not. Additional information on the crop categories and protocols, including category modifications from the 1980 ALUM layer, can be found in the publically available metadata that accompanies the 2015 Agricultural Land Use Baseline GIS layer (<http://planning.hawaii.gov/gis/download-gis-data-expanded/#001>).

### 2.3. Prior 1980 statewide assessment dataset used in this study

Putting the 2015 agricultural footprint into proper historical context requires recognition of differences in available technology and methodologies (crop definitions, reporting of acres planted vs. harvested, imagery vs. reports, etc.) among previous statewide assessments. Here we present a brief overview of 1980 ALUM statewide agricultural assessment used in this study.

The 1980 ALUM layer was produced over a two year period (1978–79) by the Hawai‘i State Department of Agriculture (DOA), using data provided by the State Planning and Development Section and the U.S. Soil Conservation Service to generate a series of 1:24,000 hand-drafted stabiline maps. Crop boundaries on these maps were digitized by the State Office of Planning; the resulting GIS layer represents the best record of statewide agricultural land use prior to 2015 (Fig. 2A). The ALUM crop categories were used as the basis for the 2015 Assessment, with minor modifications (‘Avocado’ and ‘Guava’ were dropped from their own categories and merged into ‘Tropical Fruit’, ‘Vegetables/Melons’ were added to ‘Diversified Crop’, etc.). As mentioned earlier, the 1980 ALUM papaya layer included fallowed fields while the 2015 assessment did not. Beyond category names, no metadata about crop definitions or error estimation is provided for the

1980 ALUM layer.

## 3. Results

### 3.1. Statewide 2015 footprint and comparison with 1980 ALUM dataset

The 2015 Hawai‘i Statewide Agricultural Land Use Baseline layer, shown below with the 1980 ALUM layer for comparison (Fig. 3), represents our best effort to capture the scale and diversity of commercial agricultural activity in Hawai‘i in 2015. This dataset and metadata are publically available at <http://planning.hawaii.gov> and an accompanying report was produced for the Hawai‘i Department of Agriculture (Melrose, Perroy, & Cares, 2016).

#### 3.1.1. Crops

Altogether Hawai‘i had ~151,800 acres in active crop use in 2015, representing just 43% of the ~350,800 acres cropped in 1980. On a per-crop basis, the largest declines (in both % and total acres) occurred in pineapple and sugar (Table 2). The largest acreage increases were in commercial forestry and seed production, neither of which existed as mapped crop categories in 1980. The largest gains in pre-existing crop categories were in the coffee, diversified agriculture and macadamia nut categories. All other crop categories showed significant losses, with the exception of aquaculture and tropical fruit, which posted some gains. The relative statewide acreage changes related to losses and gains on a per-crop basis are depicted graphically in Fig. 4.

#### 3.1.2. Pasture

Between 1980 and 2015, the amount of pasture statewide declined by ~346,900 acres (31%), from 1.1 Million to ~761,400 acres. These declines are primarily due to land purchases for uses other than grazing by different agencies of the Federal government (National Park Service for Hawai‘i Volcanoes National Park, U.S. Army for training areas, and Fish and Wildlife Service for conservation). In addition, some private landowners shifted out of grazing for conservation and re-forestation purposes.

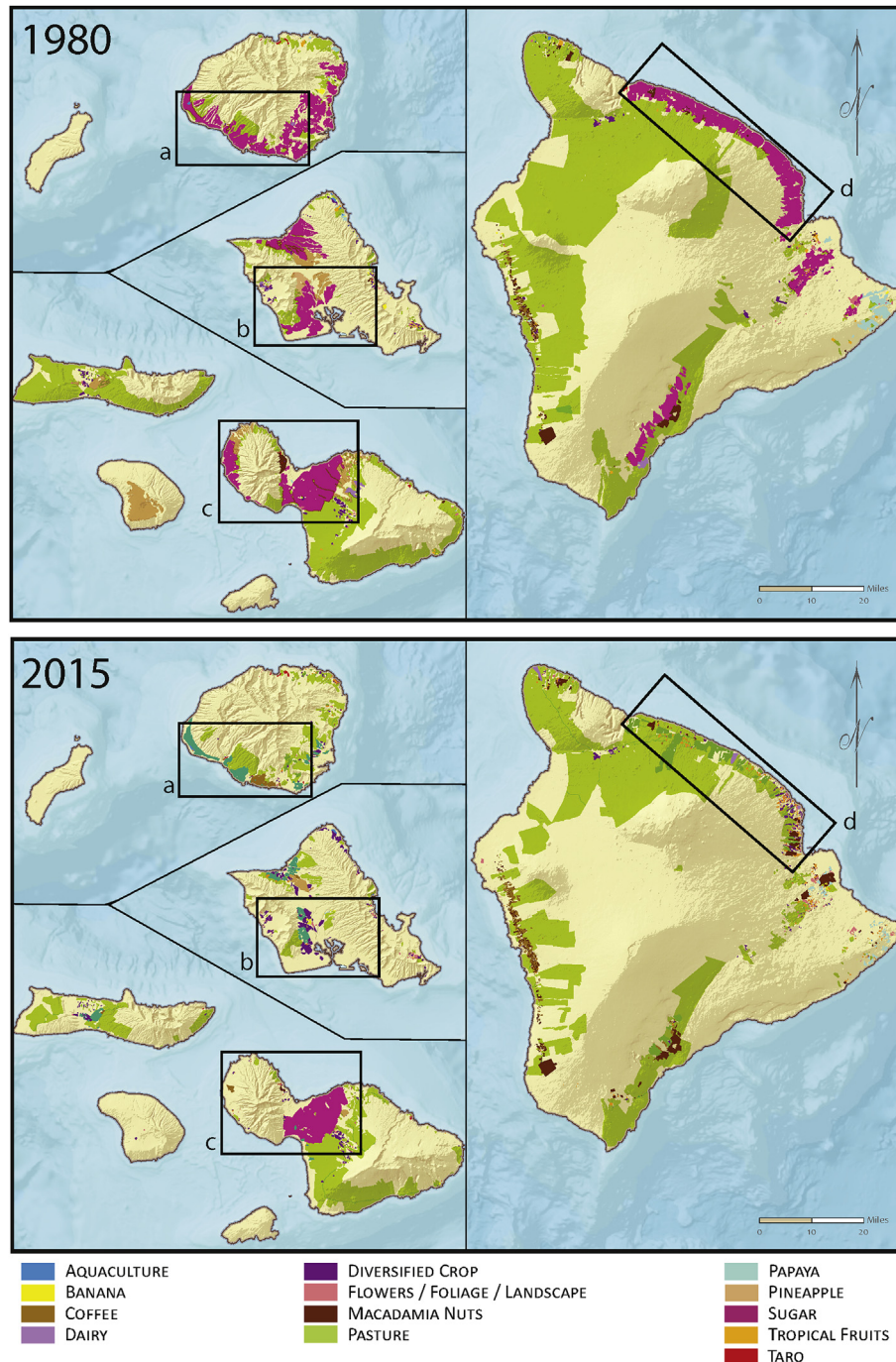


Fig. 3. The 1980 crop layer (upper panel) and the 2015 Hawai'i Statewide Agricultural Baseline layer (lower panel). Inset boxes show locations of panels in Fig. 5. Modified from Melrose et al. 2016.

4. Discussion

4.1. Statewide trends

The agriculture footprint of Hawai'i in 2015 is the result of ongoing trends that have fundamentally altered crop production and capability in the state. The first is an accelerated decline in crop and grazing activity statewide as measured in number of acres in agricultural use. Some trends were not new or surprising: grazing and pineapple acreages were already in decline by 1980 and the collapse of the sugar industry was well underway during the 1990s

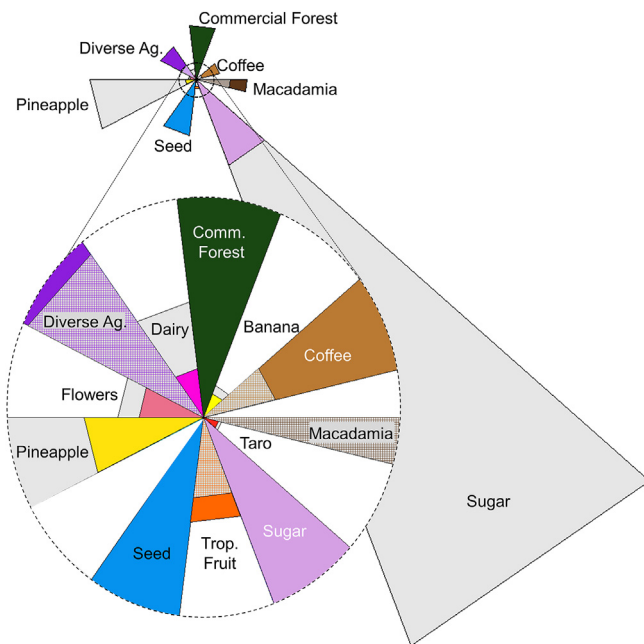
(Hawaii Agricultural Statistics Service, 1999; Suryanata, 2000, 2002). Nevertheless, the mapped declines in sugar and pineapple between 1980 and 2015 are unprecedented. Sugar alone saw a reduction in crop area of over 200,000 acres during this period, an area larger than the total acreage farmed in 2015. These declines can be attributed to increases in property values, changes in land ownership, growing competition from international producers, and high operational costs, partly the result of a highly successful labor organizing movement following World War II (Geschwender & Levine, 1983; Suryanata, 2002).

Within the context of these dramatic overall declines, the

**Table 2**  
Comparison of 1980 and 2015 crop acreage totals, acreage difference, and % change.

Crop	Acres		Change	
	1980	2015	Acres	%
Aquaculture	604	651	47	8%
Banana	1287	969	(318)	−25%
Coffee	2792	10,149	7357	264%
Commercial Forestry	—	22,864	22,864	N/A
Dairy	4397	1855	(2542)	−58%
Diversified Crop	7489	16,904	9415	126%
Flowers	3227	2432	(795)	−25%
Macadamia Nuts	14,340	21,545	7205	50%
Papaya	12,288	2824	N/A <sup>a</sup>	
Pineapple	44,858	4508	(40,350)	−90%
Seed Production	—	23,728	23,728	N/A
Sugar	255,784	38,810	(216,974)	−85%
Taro	718	612	(106)	−15%
Tropical Fruit	3049	3980	931	31%
Total Crop:	350,833	151,831	(199,002)	−57%
Pasture lands	1,108,300	761,429	(346,871)	−31%

<sup>a</sup> 2015 papaya does not include fallowed lands, 1980 papaya does.



**Fig. 4.** Comparison of statewide footprints (1980–2015) by crop type. Grey areas indicate losses in cropped area between 1980 and 2015; patterned areas indicate 1980 footprint for crops that have increased in size; solid colors (plus patterned areas where applicable) indicate 2015 footprint. Aquaculture and Papaya not shown for clarity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

second major trend revealed by the 2015 agricultural footprint is growth in a handful of crop types (Table 2, Fig. 4), often on former plantation lands. This growth is expressed in different ways across the state as local farming operations contend with particular geographic settings and constraints in the post-plantation era. In order to better understand the expression of these two trends, we have chosen four representative case studies to explore in more detail.

#### 4.2. Selected regional comparison of the 2015 footprint with the 1980 ALUM dataset

Across the eight main Hawaiian Islands there is great diversity in

physical and human geography, land use histories, and ecologic, economic, and political drivers. Together, these factors can help explain the variety of agricultural responses that have occurred (and are continuing) during the post-plantation era transition. Here we have selected four regional examples of agricultural change as a means of exploring the diversity of underlying drivers and agricultural responses taking place in the aftermath of the plantation era. These areas are the South Shore of Kaua'i, the central O'ahu Plain, western Maui, and the Hamakua Coast on the Island of Hawai'i (Fig. 5, inset boxes on Fig. 3). These regions highlight the different challenges and opportunities facing agricultural systems across the state and provide a closer look at specific interactions and decision-making at the landscape level.

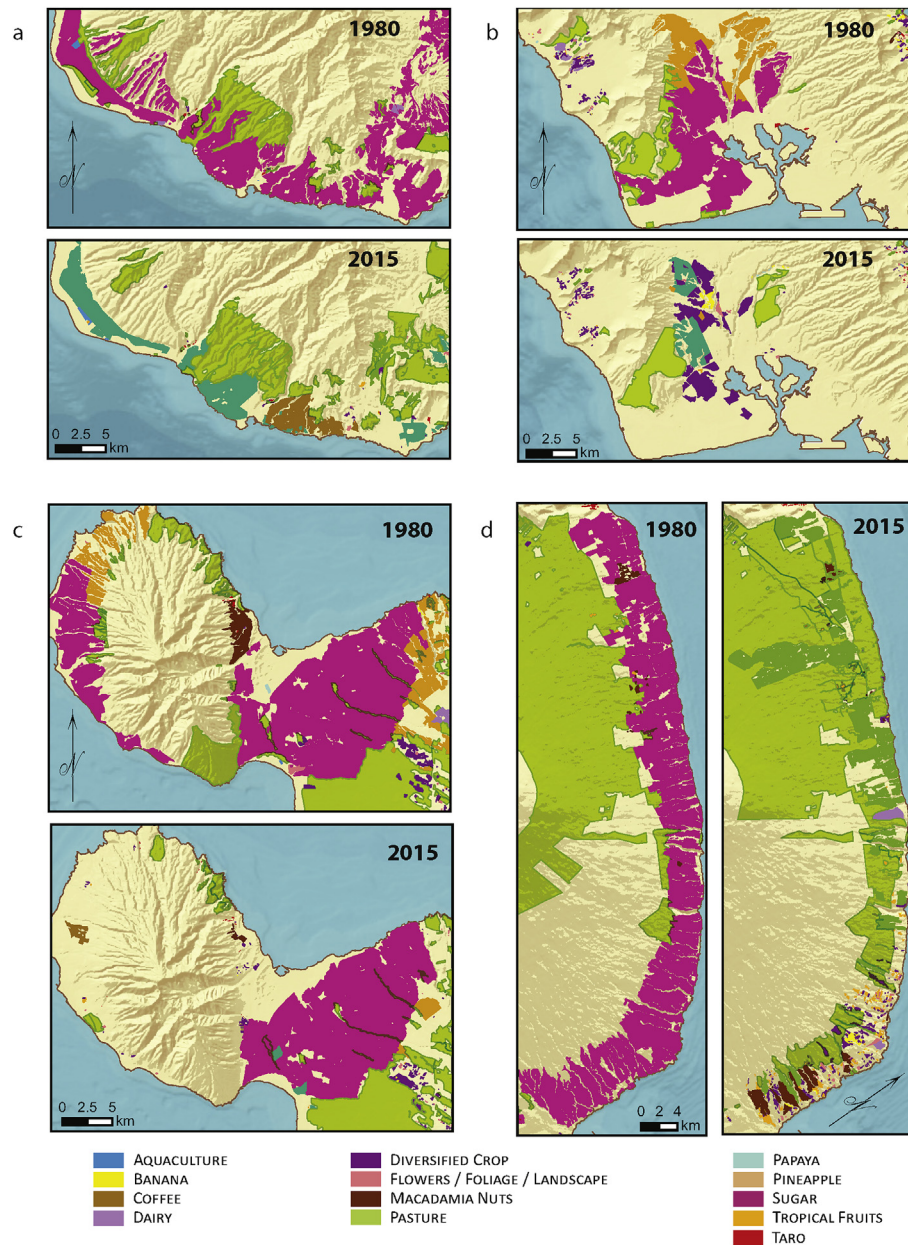
##### 4.2.1. South Shore of Kaua'i

Kaua'i's south shore (Fig. 5A) contains some of the most prime agricultural land in Hawai'i (Soil Survey, 2016), held as large consolidated tracts by a small number of landowners. Following the collapse of Kaua'i's sugar and pineapple plantations, including the shutdown of the McBryde Sugar Company in 1987, a number of new crops sprang up, including coffee and diversified agriculture. But the largest, by far, is genetically modified (GM) seed, the vast majority of which is in corn (Boyd, 2008). The entire state, particularly the South Shore of Kaua'i, has become a major hub for field trials of GM corn by companies like Syngenta, Pioneer, and Monsanto. The primary reasons, as laid out by Schragger (2014), include consistent climatic conditions that allow the production of four crops a year; available land and pre-existing infrastructure (e.g., irrigation systems, transportation networks) from the abandoned plantations; few corn-specific pests; and the efforts of the Hawai'i Crop Improvement Association (HCIA), a well-organized and effective advocate for promoting seed production in the state. These factors, despite vocal and legal opposition to GM trials in the state (Garner & Wesley-Smith, 2015; Wiley, 2015), have allowed GM seed to become the second largest crop in Hawai'i in 2015 by acreage and one of the most valuable overall, worth \$155 million in 2013–2014 (USDA, 2015a,b).

##### 4.2.2. Central O'ahu plain

O'ahu's central plain has seen dramatic losses in plantation agriculture since 1980, with the complete erasure of sugar and pineapple crops across the area (Fig. 5B). This area contains some of Hawai'i's most highly graded agricultural lands (Soil Survey, 2016) and sits very near Honolulu, the capitol and largest population center. This convenient location, and availability of high quality A and B class agricultural soils and established irrigation sources, give the O'ahu plain, more than any other region in the state, the potential to achieve a higher degree of food security, particularly in terms of local produce. As Hawai'i has an extremely low degree of food self-sufficiency overall (Loke & Leung, 2013), the diversified crop operations established in the central plain since 1980 are vitally important to this effort. In fact, there is now more diversified agriculture taking place in the O'ahu plain (7300 acres) than in the rest of the state combined, mostly conducted by relatively large vegetable and melon growers like Sugarland Farms. In addition to the rise of diversified crops in the central plain, GM seed companies are active with research and farming operations, occupying an acreage roughly equivalent to that of diversified agriculture in the area.

While providing a large and easily accessible market for its agricultural produce, the proximity of the central O'ahu plain to Honolulu also subjects these lands to persistent pressure for urban development. In the greater Honolulu area, the amount of land in active agricultural cultivation declined by 77% between 1980 and 2008 (Plasch Econ Pacific, 2011), and the threat is ongoing. Hawai'i has led the nation in highest median home values since 1960 (US



**Fig. 5.** Side-by-side comparison of the 1980 and 2015 agricultural datasets for (A) the southern coast of Kaua'i; (B) The central plain of O'ahu; (C) Western Maui; and (D) the Hilo-Hamakua coastline of Hawai'i Island. Locations are shown with inset boxes in Fig. 3.

Census, 2012) and there is a chronic housing shortage on O'ahu. As a means of securing agricultural use in the central plain, the Hawai'i state government and the Office of Hawaiian Affairs have embarked on a land purchasing program to put former plantations into new agriculture use. These purchases include 1700 acres from the Galbraith Estate and several former Dole properties, to encourage new agricultural activity and to develop a food processing hub for local producers. Tension between demands for increased food security through local food production, and development pressure in the face of ever-rising land values, is evident in the central plain. Separating the agricultural value of these lands from their real estate value will remain a key challenge in the years ahead.

#### 4.2.3. Western Maui and the central isthmus

Western Maui provides another microcosm for the varied fate of plantation agriculture across the state between 1980 and 2015.

With the cessation of farming activities in far western Maui by the Pioneer Mill and Maui Land and Pineapple companies (in 1999 and 2009 respectively), fourteen thousand acres of sugar and pineapple crops were taken out of production (Fig. 5C). The majority of these former plantation lands are currently idle, supporting nonnative dryland vegetation communities highly prone to wildfires (Trauernicht et al., 2015). Others have been subdivided into smaller parcels and sold off for private homes and resorts, commanding real estate prices that make a return to significant agricultural use in this area unlikely. In addition, many plantation-era reservoirs have been decommissioned (Hawai'i Dam and Reservoir Safety Program, 2014) and irrigation systems re-purposed to supply water to residential and resort areas. Although large-scale agricultural activity in western coastal Maui is almost completely gone, an exception is the Ka'anapali Coffee Company, a novel 'blended' agricultural and real estate venture of 4–7 acre parcels pre-planted

in coffee with available mechanized harvesters and graded residence sites. For Hawai'i, with its high land values and labor costs, this type of blended approach is one way to maintain at least some semblance of agriculture on the landscape.

While western coastal Maui has seen significant changes to its agricultural footprint, comparable to those observed throughout the rest of the state, Maui's central isthmus was another story. This area remained essentially stable between 1980 and 2015, retaining the last remaining large plantation in the state of Hawai'i, the 36,000 acre Hawaiian Commercial & Sugar Company (HC&S). HC&S was able to continue operations while other plantations closed due to its overall size, high quality soils and plentiful water sources, vertically integrated business structure, and early conversion to drip irrigation (Osgood and Jones, 2016). Although able to hold out longer than other plantations in Hawai'i, HC&S recently announced its plan to shutter sugar operations in 2017. The HC&S closure will be the largest single land use change in the state's history, affecting roughly 800 employees and concluding the sugar era in Hawai'i.

#### 4.2.4. Hamakua Coast on the Island of Hawai'i

Like other areas highlighted here, the Hamakua Coast north of Hilo on the windward side of Hawai'i Island (Fig. 5D) was once a major sugar producing region. Unlike those other areas, however, the vast majority of sugar operations in this part of the state were not irrigated, reliant instead on abundant and reliable rainfall and strong independent plantation communities to sustain operations. Mean annual rainfall in some former-plantation areas along the Hamakua coast easily surpass 4 m per year (Giambelluca et al., 2013). In the post-plantation era, the trajectories of agricultural land use along the Hamakua coast have generally taken one of two distinct directions, largely controlled by differences in patterns of land ownership.

In 2015, the northern half of the Hamakua coastline contained 14,500 acres of commercial forestry, mostly planted in large eucalyptus groves to produce wood fiber and biomass for energy production (Kinoshita & Zhou, 2000). These forestry lands were part of a single 30,000 acre purchase made by Kamehameha Schools from the Hamakua Sugar Company after it went into foreclosure in 1992. Kamehameha Schools, Hawai'i's largest landowner and one committed to long term ownership, leased part of these lands to a forestry investment firm as part of a forestry strategy for the region. The trees are currently harvested and shipped to China for use in furniture framing, plywood, and pallet building. Local use of the wood is minimal, though a planned 20 Megawatt bio-energy power plant built from a converted sugar mill power plant would provide a future steady demand. In addition to the forestry initiative, roughly 4000 acres of the Kamehameha Schools property were leased to ranchers to help stimulate the local cattle industry.

The former plantation lands in the southern portion of the Hamakua coast have followed a different path in the post-plantation era. Located north of Hilo, the largest settlement on Hawai'i Island, these lands were sold off piecemeal in a variety of large and small parcels. The result has produced a mix of small agricultural estates, including macadamia, coffee, and tropical fruit orchards, along with a variety of diversified agriculture operations interspersed with residential lots. Though less expensive than other areas in the state, rising real estate prices on the southern Hamakua coast and a patchwork of small parcels make it difficult for farmers to secure long term leases and build sustainable operations.

## 5. Conclusions

Hawai'i's 2015 agricultural footprint reveals dramatic reductions in large scale sugar and pineapple plantation operations compared to the 1980 statewide assessment, dwarfing gains in other crop

types on an acreage basis and producing an overall decrease in agricultural output for the state (Table 2, Fig. 4). With the impending closure of another 36,000 acres of sugar production, these decreases will continue in the short-term.

But these same closures and reductions also provide an opportunity. Hawai'i has a surplus of agricultural land, and valuable infrastructure already in place from past plantation-era investments. Taking advantage of these conditions, the seed industry has established a thriving industry in Hawai'i, one that will become the number one crop in both acreage and value once HC&S ceases operations in 2017. Beyond GM seed, boutique export crops like coffee and macadamia nuts are also on the rise, filling in similar voids in former plantation lands.

On their own, these types of increases in agricultural productivity, should they continue, do little to impact Hawai'i's tenuous level of food self-reliance or address a growing movement and demand for locally produced foods in Hawai'i (Costa & Besio, 2011; Department of Business Economic Development and Tourism, 2012). Although there have been clear gains in the amount of diversified agriculture in the state and increasing attention paid to 'canoe plants' like Breadfruit, which formed the basis of sustainable food systems for the pre-contact native Hawaiian society (Ladefoged, Kirch, GonChadwick, Hartshorn, & Vitousek, 2011, 2009; Liu, Ragone, & Murch, 2015), without fundamental changes in consumption patterns, availability and cost of imported food, and government policies, these gains will continue to be incremental and barely dent the food security issues facing the state.

There are many obstacles to maintaining existing levels of food production in Hawai'i, let alone increasing production capabilities. Many experienced farmers are nearing retirement age or leaving agriculture altogether; ever-rising land values and costs associated with meeting food safety requirements, existing and new tropical plant diseases, and drought and higher temperatures associated with climate change all present real challenges for future agriculture in the state (Chapman, Messing, & Harwood, 2015; Hooks, Wright, Kabasawa, Manandhar, & Almeida, 2008; Wheeler & von Braun, 2013). If Hawai'i is going to meet these challenges and ensure the continuation and growth of its diverse agricultural economy, informed discussion and strategic decision-making are needed. Hawai'i's agricultural landscape and overall production capability will continue to contract without substantial changes in policy and practice. It is our hope that the spatial analyses and regional trends described in this paper can help contribute meaningfully to these efforts.

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