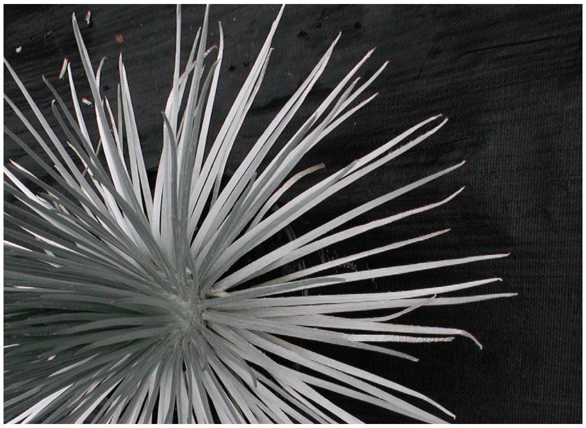

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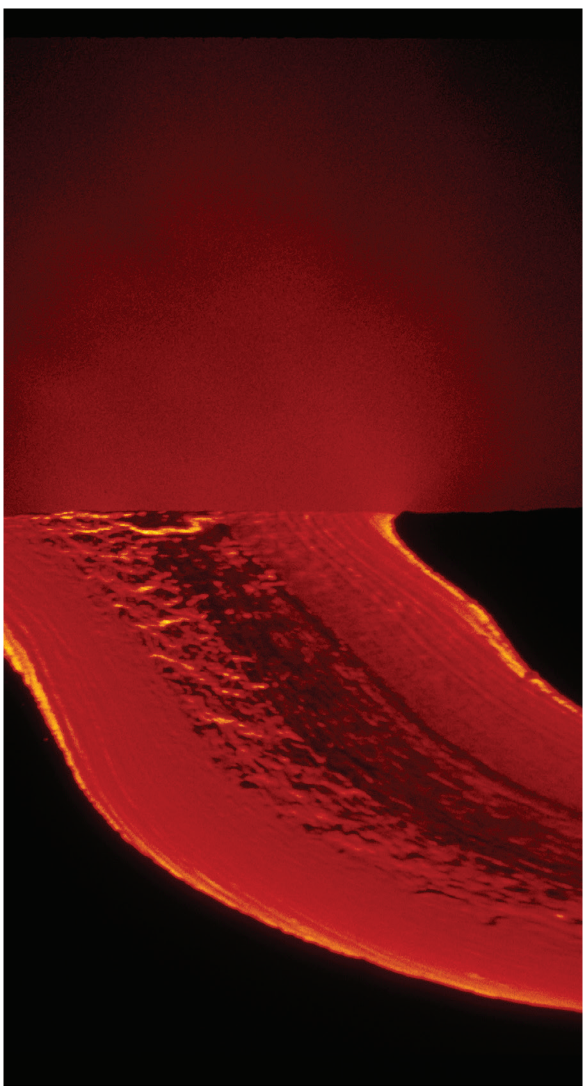
THE ECONOMIC RESEARCH ORGANIZATION AT THE UNIVERSITY OF HAWAIʻI

PROJECT ENVIRONMENT

Benefit-Cost Analysis of Watershed Conservation

DECEMBER 18, 2014



THE ECONOMIC RESEARCH ORGANIZATION
AT THE UNIVERSITY OF HAWAIʻI

BENEFIT-COST ANALYSIS OF WATERSHED CONSERVATION

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EXECUTIVE SUMMARY

The objectives of this report are (1) to review studies that estimate the relationship between watershed conservation activities and groundwater recharge in Hawai'i and (2) to estimate the volume of freshwater yield saved per dollar invested in conservation at several sites on Hawai'i Island. We conclude from the literature review that more work should be done to integrate information from smaller-scale studies of invasive-native water use differences into regional water balance models. This would help to inform decisions related to watershed conservation activities statewide. Using budget information obtained from the Nature Conservancy and the Division of Forestry and Wildlife as well as publicly available landcover and evapotranspiration (ET) data, we estimate the gallons of freshwater yield saved per dollar invested in watershed conservation. Under baseline conditions—a 3 percent discount rate and a 10 percent rate of spread for existing invasive plant species—roughly 400 gallons are saved on average across management sites per dollar invested. In other words, about $2.50 in present value terms is required to protect every one thousand gallons of freshwater over a 50 year time horizon. Annual benefits increase continuously as the avoided loss of freshwater yield rises over time, while conservation costs tend to be front-loaded, as a result of high fence installation and ungulate removal costs. Thus, it is important to consider the long run when comparing the benefits and costs of conservation activities.

OBJECTIVES

This study has two primary objectives. First, we review studies that estimate the relationship between various conservation activities and groundwater recharge in Hawai'i. In doing so, we highlight areas where future research in watershed sciences would be most useful for informing decision making about watershed conservation. Second, using publicly available spatial landcover and water balance data in combination with watershed conservation project budgets, we estimate the volume of freshwater yield saved per dollar invested across Hawai'i Island with implications for freshwater benefits throughout the state.

INVASIVE PLANT SPECIES AND GROUNDWATER RECHARGE

Understanding the relationship between landcover and groundwater recharge is key to estimating the benefits of watershed conservation activities in Hawai'i. Using information from over 40 published studies from around the world, Cavaleri and Sack (2010) found several-fold differences in water use among pairwise combinations of native and invasive plant species. Yet, very few studies have taken the extra steps required for estimating a relationship between plant species and recharge; none that we are aware of have done so in Hawai'i.

Several studies in Hawai'i have, however, examined differences between native and alien plant species and between different types of invasive plant species in terms of other water balance components that are ultimately linked to recharge or more generally, freshwater yield. From these eight studies (Table 1), we can generally conclude that when compared to native plant species, invasive plant species in Hawai'i tend to have higher evapotranspiration (ET) rates, generate larger throughfall rain drops, have higher sap flux density, reduce the velocity of water to depths of 1-meter, have lower canopy water storage capacity and cloud water interception capability, and generate lower net rainfall. In aggregate, these results suggest that native plants tend to use less water, thus leaving more to recharge underlying aquifers, but quantifying the exact effect on recharge remains a challenge.

In 2011, the USGS published a groundwater recharge assessment for the island of Hawai'i (Engott, 2011). A water budget model was developed, and groundwater recharge was estimated under two scenarios: (1) current landcover and (2) invasive-dominated landcover replaced by native forest. Results from the model showed an increase in recharge of approximately 10 percent for several of the hydrological units when going from scenario 1 to 2. The increase was smaller for the remainder of the units. Nevertheless, aggregated over decades, the freshwater benefits of watershed conservation are likely to be substantial. As detailed in the methodology section, however, we were unable to build directly off of this study for the current project due to data sharing restrictions.

TABLE 1. LIST OF STUDIES REVIEWED

Author(s)	Year	Location	Species	What was measured	Results
Cavaleri et al.	2014	Hilo	'ohia (M. polymorpha), trumpet tree (C.obtusifolia), bingabing (M. mappa) and Indian rhododendron (M. septemnervium)	Sap-flow rate, transpiration	'ohia had the lowest sap-flow rate per unit sapwood but the highest rate per tree; a 54% decrease in plot-level transpiration (400 mm/yr) was observed in plots where non-native trees were removed.
Giambelluca et al.	2008	Hawai'i Island	Strawberry guava (P. cattelianum), 'ohia (M. polymorpha)	Evapotranspiration	A site heavily invaded by s. guava had 27% higher ET than a site within a M. polymorpha forest, with the difference rising to 53% during dry-canopy periods.
Giambelluca et al.	2009	Hilo	Miconia (M. calvescens), 'ohia (M. polymorpha)	Throughfall rain drops	Throughfall raindrops under miconia had a median diameter of 3.8 mm and a max of 7 mm vs. 1-3.5 mm out in the open. Drop diameter in a spray experiment was 5.33 mm for miconia versus 3.66 mm for 'ohia

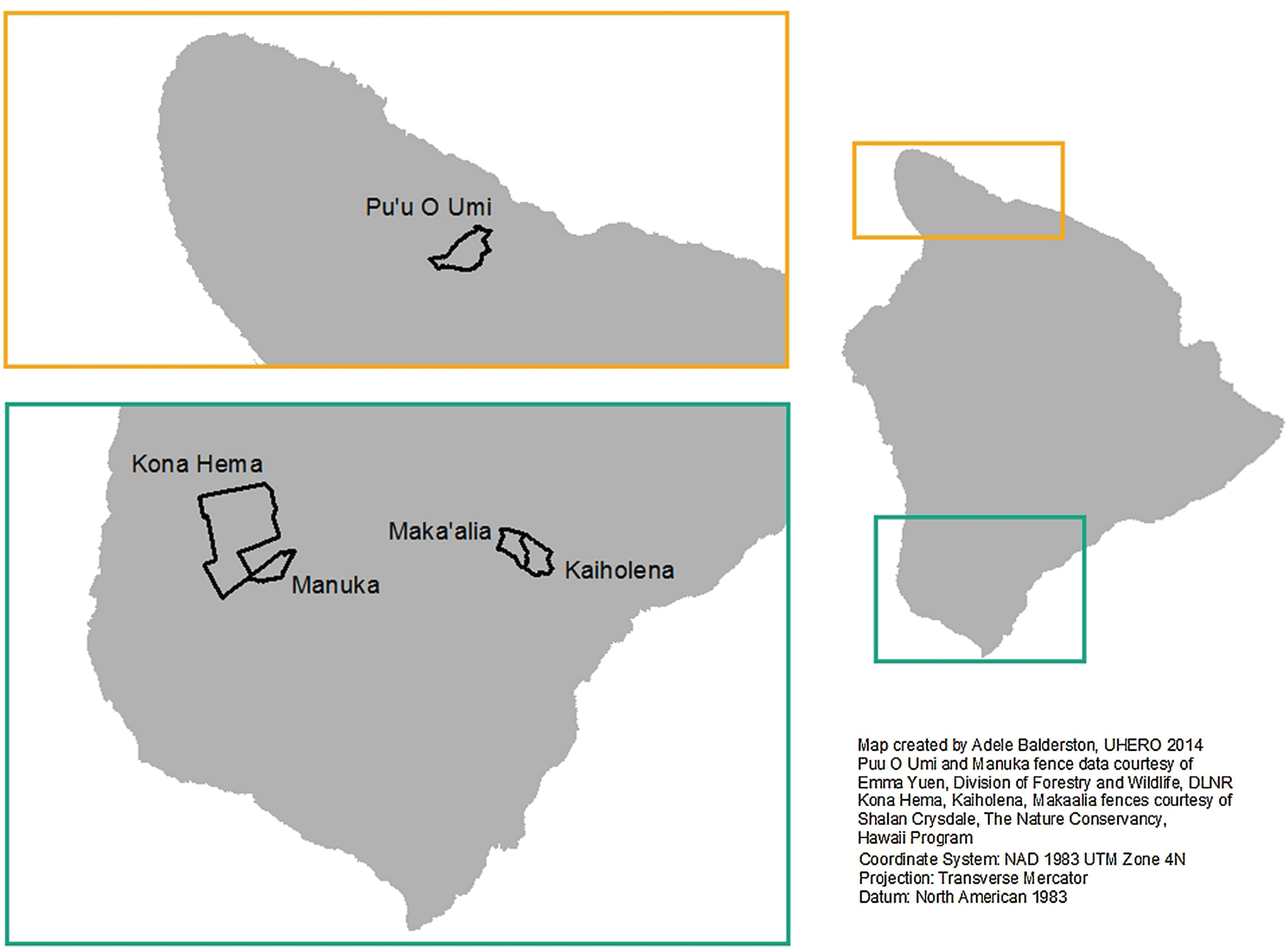
Kagawa et al.	2009	Honaunau Forest Reserve	‘ohia (M. polymorpha), eucalyptus (E. saligna), ash (F. uhdei)	Sap flux density, water use	‘ohia had the lowest value for sap flux density (8 kg/d) compared to eucalyptus (33 kg/d) and ash (34 kg/d); ash used 1.8 mm/d, more than twice the water used by eucalyptus or ‘ohia
Mair and Fares	2010	Makaha Valley	Christmas berry (S. terebinthifolius), coffee (C. arabica), strawberry guava (P. cattleianum)	Throughfall	S. guava had the lowest mean throughfall (44%) compared to 59% and 60% for coffee and Christmas berry respectively.
Perkins et al.	2014	Auwahi	Olopua (N. sandwicensis), ‘a‘ali‘i (D. viscosa), kikuyu grass (C. clandestinus)	Water velocity	Compared to invaded grassland areas, water in reforested sites moved to depth faster: median first arrival velocity at depths below 75 cm was greater by a factor of 13 at the 99% confidence level
Safeeq and Fares	2014	Makaha Valley	Christmas berry (S. terebinthifolius), strawberry guava (P. cattleianum), java plum (S. cumini), coffee (C. arabica),	Throughfall, stemflow, canopy interception	Throughfall was lowest under a monotypic stand of SG (43.3%) and highest under a mixture of CB, SG, and JP (56.5%); Stemflow was highest under SG (33.9%) and lowest under a mixture of CB, SG, and JP (3.6%); canopy interception was lowest for SG (23%) and highest for coffee (45%).
Takahashi et al.	2011	Hawai‘i Volcanoes National Park	Strawberry guava (P. cattelianum), ‘ohia (M. polymorpha)	Canopy water storage capacity, cloud water interception, net rainfall (throughfall + stemflow)	Canopy water storage capacity was 1.86 mm at the native site and 0.85 mm at the invaded site; Annual CWI was 1,188 mm at the native site compared to 734 mm at the invaded site; net rainfall was 123% of rainfall at the native site versus 110% at the invaded site.

From the surveyed studies, we conclude that past and ongoing work in this area tends to focus on at most a few water balance components at a time on a relatively small spatial scale. This type of research is valuable and should be continued because it highlights important differences between native and invasive species that may not be easily distinguishable at courser resolutions. However, given the spatial diversity of landscapes across Hawai‘i, extending the results of small-scale studies is essential for estimating the benefits of watershed conservation activities. The approach taken in the 2011 USGS study may be an appropriate starting point; it takes a big-picture approach, while still allowing for some flexibility in water balance components for specific types of landcover. Thus, recharge benefits under different landcover scenarios could be updated without developing an entirely new model, e.g., when new information becomes available on the differences in ET between ʻohia and strawberry guava. To summarize, we believe that integrating information obtained in small-scale studies into regional water balance models is the logical next step for accurately estimating the recharge benefits of conservation over space and time.

CONSERVATION SITES

This study includes five conservation sites across Hawaiʻi Island, illustrated in Figure 1. In order to estimate the freshwater yield saved per dollar invested in watershed conservation, we attempted to collect data on conservation activities and budget information from the following groups: The Nature Conservancy, the Division of Forestry and Wildlife, the Three Mountain Alliance, the Kohala Watershed Partnership, the Mauna Kea Watershed Alliance, and the U.S. National Park Service. At the time of this writing, we were only able to obtain detailed spatial information about conservation activities and expenditures from The Nature Conservancy and the Division of Forestry and Wildlife.

FIGURE 1. LOCATIONS OF CONSERVATION SITES



Conservation sites were selected according to the following criteria: large scale (close to 1,000 acres or more), mostly native forest, and important for groundwater recharge. As illustrated in Table 2, the selected sites ranged in size from 800 to over 8,000 acres. For comparison, statewide, the average unit fenced for watershed protection as of 2011 was 1,291 acres (DLNR, 2011).

TABLE 2. LIST OF CONSERVATION SITES

Name of Preserve	Fenced Subunit	Size (acres)	Manager
Ka‘ū	Kaiholena	1200	TNC
Ka‘ū	Maka‘ālia	968	TNC
Kona Hema	Kona Hema	8089	TNC
Manuka	Kipuka	810	DOFAW
Pu‘u O‘Umi	Lahomene	1930	DOFAW

In most cases, conservation agencies remove ungulates and weeds with the intent to prevent existing native forest from converting to non-native forest. This conversion typically starts with ungulate-related disturbances in the understory, which are conducive to the establishment of non-native plants in favor of native ones. As invasive plants become dominant, hydrological processes (e.g. fog-drip capture, runoff, and evapotranspiration) that ultimately affect groundwater recharge become altered. Although the conversion process starts in the understory, changes to water recharge are likely to be more strongly dependent on ET from both native and invasive canopy-reaching trees. Given the dearth of conclusive scientific research in this area, however, it is difficult to attribute changes in recharge specifically to canopy trees or understory plants with confidence. In our analysis, we compare native landcover with non-native dominated canopy for the purpose of estimating changes in freshwater yield.

CONSERVATION SITES MANAGED BY THE NATURE CONSERVANCY

Ka‘ū Forest Preserve

Site Description

The 3,548-acre Ka‘ū Preserve is located on the southwest flank of Mauna Loa volcano on the southern end of the island of Hawai‘i, located between 2,160 and 5,770 feet in elevation. Ka‘ū Preserve is part of the largest and most intact expanse of native forest in the state. Made up of four separate parcels of forested land, the preserve features mountainous ridgelines with narrow plateaus broken by alternating steep valleys. Closed-canopy koa and ‘ōhi‘a forest shelters an understory of native uluhe and hāpu‘u tree ferns. All four parcels consist of nearly pristine native forest and form a boundary between the largely intact native alpine and subalpine forest above, and the agricultural land below. In 2002, the Conservancy purchased four parcels of private forestlands adjoining the Ka‘ū Forest Reserve from a subsidiary of C. Brewer & Co., Ltd. Acquisition of these parcels enables management access to state forest reserve lands.

TNC provided us with a map denoting preserve boundaries, fences, and weed removal activities in the Ka‘ū Preserve, all of which were combined with spatial landcover and evapotranspiration data to estimate freshwater yield per conservation dollar.

Conservation Activities

TNC installed five miles of fencing in 2007 in the Kaiholena management unit and has kept roughly 1,200 acres free of pigs since 2009. Weed control is focused at the edge of an infestation in Lower Hīlea, and has ranged from 35-50 acres/year cleared, along with kahili ginger control at Kāhilipali, Kī‘olokū and Keaīwa (outside the fence) that amounts to 10 acres/year combined. Since completion of the ungulate removal project, native ferns have begun to replace pig wallows and bare soil.

Volunteers visit once every other month to pull weeds, help replace rusted fence, and clear drains along roadways. Monitoring of weeds and ungulates is conducted through reading of 6 transects once per year. Because the area is relatively pristine, much of the labor effort is expended on searching for new and isolated weed populations. TNC also conducts fence checks regularly. Full replacement of fences (not including the posts) is required about once every five years.

Preparations have begun to fence and remove ungulates in the 900-acre Maka‘ālia unit, which is located above the existing Kaiholena fence, over the next two years.

Kona Hema Preserve

Site Description

The 8,089-acre Kona Hema Preserve consists of three adjoining forest parcels in South Kona on the slopes of Mauna Loa purchased between 1999 and 2003 at Honomalino, Kapu‘a and Pāpā. The Kona Hema Preserve protects part of an ancient koa-‘ōhi‘a forest that spans more than 100,000 acres along the leeward coast of the Island of Hawai‘i. Pigs, goats and mouflon sheep are the preserve’s primary threats. TNC provided us with a map denoting preserve boundaries, fences, and weed removal activities in Kona Hema, all of which were combined with spatial landcover and evapotranspiration data to estimate freshwater yield per conservation dollar.

Conservation Activities

TNC installed 24 miles of fencing to exclude feral ungulates. Through trapping and dog hunting within three fenced units, over 600 pigs and 100 sheep have been removed since 2000. It is estimated that only 2 pigs remain in the Kapu‘a unit and less than three mouflon in the Honomalino unit. Much of the native understory is now returning (passive regeneration).

Weed control is restricted to relatively small priority areas. In the lower northwest corner of the preserve, 250 acres of strawberry guava (understory control, not canopy) have been removed so far at a rate of 50 acres per year. It is estimated that roughly

450-500 acres of strawberry guava remain in the understory. Removal methods include pulling, basal application of herbicide, and frilling. All methods have low material costs but are labor intensive.

In addition to protecting the native forests, TNC is developing a model of sustainable koa forestry that will help other landowners maintain the biological and economic value of their lands. Nearly 400 acres of former pasture in the upper preserve have been put into koa regrowth through low-cost bulldozer scarification.

Four transects are monitored for ungulates and weeds once per year.

CONSERVATION SITES MANAGED BY THE DIVISION OF FORESTRY AND WILDLIFE

The Natural Area Reserves System (NARS) currently consists of 20 reserves on five islands, encompassing 123,431 acres of the state's most unique ecosystems. Eight of those 20 reserves are located on Hawai'i Island: Pu'u O'Umi, Laupahoehoe, Mauna Kea Ice Age, Waiakea 1942 Lava Flow, Pu'u Maka'ala, Kahauale'a, Kipahoehoe, and Manuka. Given our focus on large scale projects that protect native forests and are important for groundwater recharge, however, we have obtained data specifically for the Manuka and Pu'u O'Umi management units.

The highest water yield is generally in the 2,500-3,500 foot elevation. However, most large landscape actions of conservation fencing and ungulate removal take place above 4,000 feet, due to higher quality forest, less invasive weed presence, abundance of remaining native bird habitat, and a preference to avoid fencing areas that are popular for public hunting. In the managed units, weeds generally account for less than 5% total coverage and usually less than 1%.

Manuka

Site Description

Manuka is the largest NAR in the system, extending from sea level to an elevation of 5,000 feet. It includes a wide range of habitats including subalpine shrublands and forests, mesic montane kipuka forests, wet montane forests, lowland mesic and dry forests, and lava anchialine ponds.

Conservation Activities

Given limited resources and because most NARS management units are relatively pristine, effort is spent primarily on building and maintaining fences and ungulate removal rather than on weed control. Once ungulates are removed, fenced areas are allowed to passively regenerate.

Pu'u O'Umi

Site Description

Pu'u O'Umi ranges from the west upper slopes and summits of the Kohala Mountains down to the dry coastal sea cliffs and contains montane bogs, montane wet grasslands, shrublands, and forests.

Conservation Activities

As with Manuka, effort is spent primarily on building and maintaining fences and ungulate removal rather than on weed control. Once ungulates are removed, fenced areas are allowed to passively regenerate.

COSTS OF CONSERVATION

Ka'ū Preserve

The Ka'ū Preserve is part of the state Natural Area Partnership Program, which means that some of the budget is allocated to outreach and education. For this particular preserve, it is estimated that 30% of the budget is allocated to ungulate control, 30% is allocated to weed control, and the remaining 40% is split between outreach, education, and other activities. Because not much weed control occurs inside the fenced areas that we are focusing on, expenditures for this site include only those for fence construction and maintenance and ungulate control.

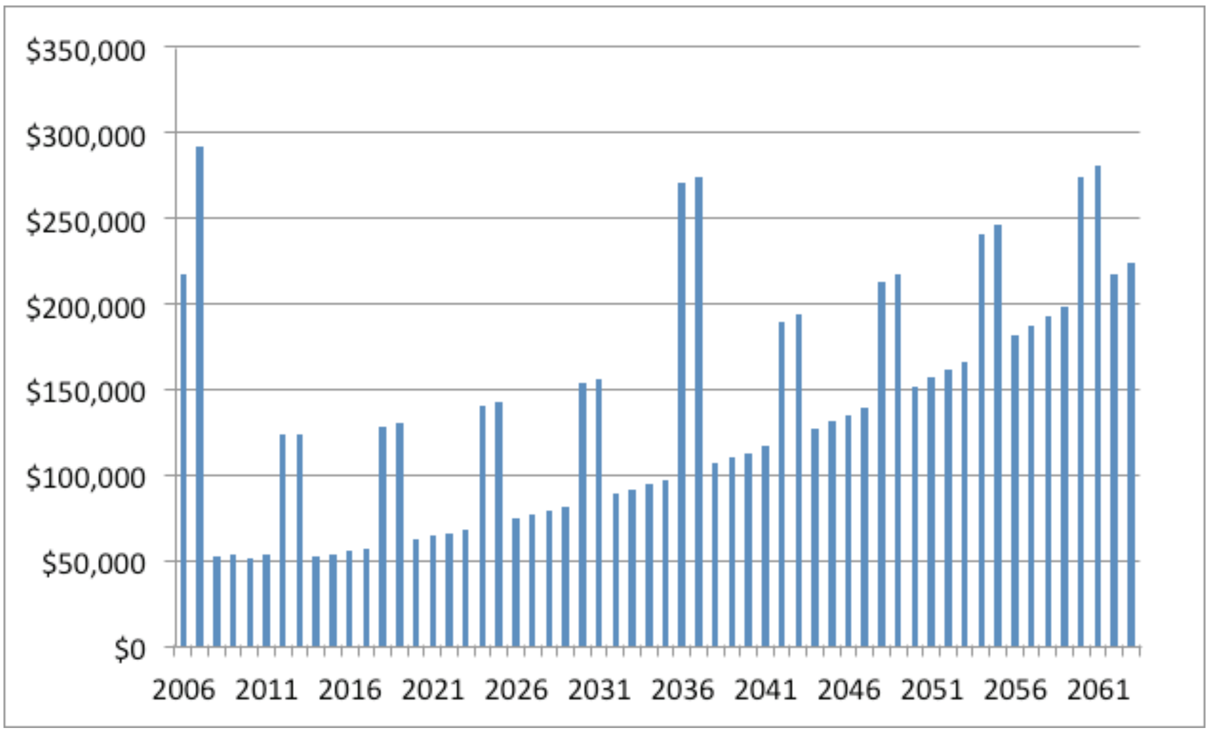
Kaiholena

The Kaiholena fenced unit is the largest enclosed area in the preserve, spanning roughly 1,200 acres. The fence was paid for in two installments, $217,934 in 2006 and $292,500 in 2007. In the three years that followed, pigs were removed via six volunteer hunts (Nov 2007-Feb 2008), a $50,000 ungulate removal contract (Jul-Aug 2008), and TNC staff trapping and hunting efforts (Oct 2008-Jan 2009). Although specific measures of effort (e.g. person-hours) were not available, we estimate expenditures on ungulate control based on the 30% share of total expenditures, which amounted to approximately $52,000 annually from 2008-2011. Given the upward trend in expected personnel and fringe expenditures, we assume a 3 percent annual growth rate in ungulate related maintenance expenditures going forward.

In 2012 and 2013, 4 staff members at 0.15 FTE and 740 volunteer hours were expended to replace the wire for the Kaiholena fence. Assuming a wage plus fringe rate of $29.17 per hour (established Department of Labor wage for ungulate fencing), the total labor cost of wire replacement was $94,394. The cost of materials alone was roughly $45,000, resulting in a total wire replacement cost of $139,394. The wire will likely need to be replaced every 5-10 years because Kaiholena is directly in the vog path.

The cost of replacing the entire fence (posts included) is expected to range from 1/2 to 2/3 of the original installation cost. Assuming the cost is on the higher end of the spectrum, two installments of approximately $170,000 will be required. Although the posts have not been replaced since the fence was built, we anticipate the need for full replacement once every 30 years. Historical and projected expenditures over the next 50 years (2006-2063) are presented in Figure 2. The initial installation cost is high, but maintenance costs are relatively low with the exception of wire replacement every five years. The present value (PV) cost of conservation in Kaiholena projected out to 2063 at a discount rate of 3% is $3.1 million or $2,619 per acre.

FIGURE 2. ANNUAL WATERSHED INVESTMENT COSTS FOR KAIHOLENA (KAʻŪ)



Makaʻālia

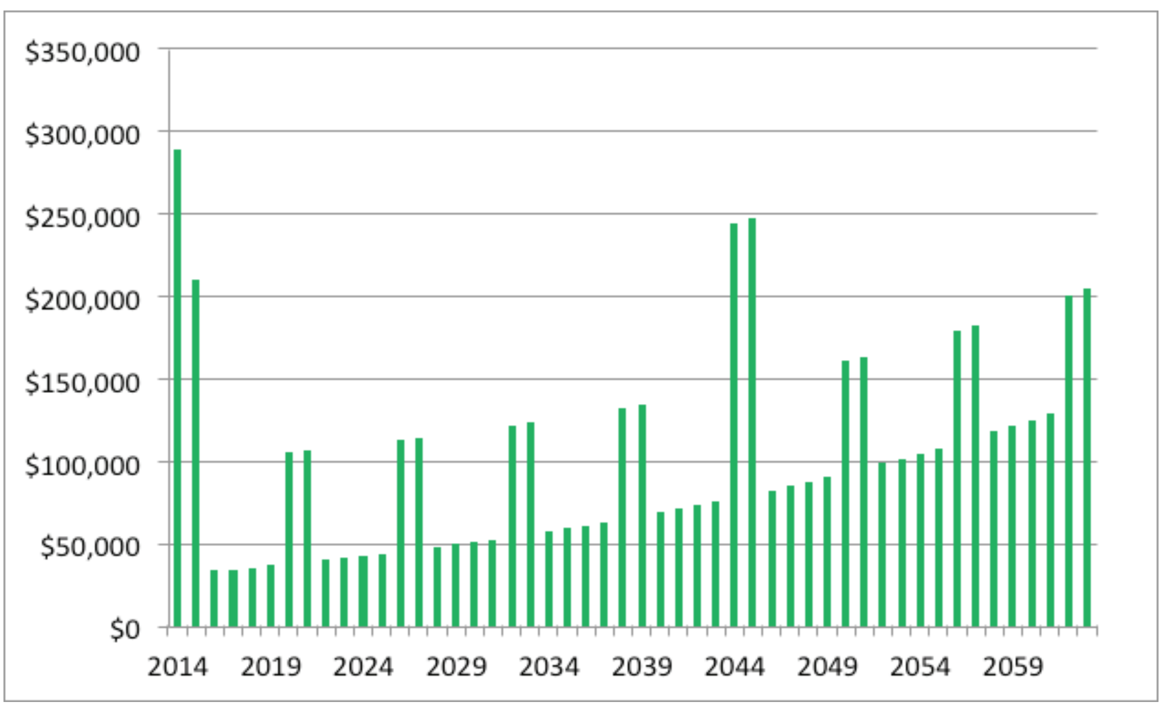
Projected expenditures over the next few years in Kaʻū (Table 3) are larger than in previous years, due primarily to the planned Makaʻālia fence, which will be constructed adjacent to the existing Kaiholena fence.

TABLE 3. PROJECTED EXPENDITURES IN KAʻŪ

Cost Category	FY2015	FY2016	FY2017
Personnel and Fringe	$271,915	$280,072	$288,475
Contractual	$289,433	$210,741	$37,980
Other Expenses (Supplies, Travel, Occupancy, etc.)	$79,816	$82,210	$84,676
Total	$641,164	$573,023	$411,131

The Makaʻālia fenced unit will span approximately 900 acres. The fence will be paid for in two installments, $289,433 in 2014 and $210,741 in 2015. The cost of maintenance is assumed proportional (acre-wise) to that of Kaiholena, totaling $34,000 per year initially, and grows at an annual rate of three percent. We further assume that the fence wire must be replaced every five years at a cost equal to 27% of the initial installation cost, the same percentage as for Kaiholena. Similarly, total fence replacement cost is 2/3 of the original installation cost or $333,449 and is incurred once (spread over two periods) every 30 years. Projected expenditures over a 50-year period (2014-2063) are presented in Figure 3. Like for Kaiholena, the initial installation cost is high, but maintenance costs are relatively low with the exception of wire replacement every five years. The present value cost of conservation in Makaʻālia over 50 years is $2.6 million or $3,303 per acre.

FIGURE 3. ANNUAL WATERSHED INVESTMENT COSTS FOR MAKAʻĀLIA (KAʻŪ)



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Kona Hema Preserve

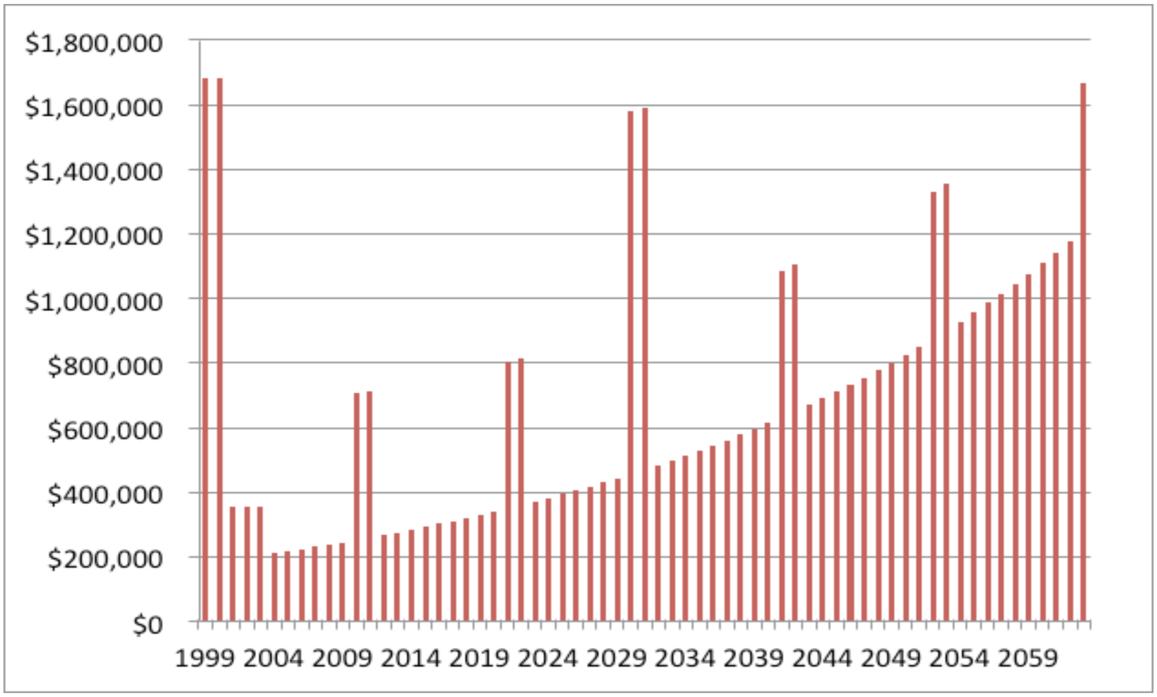
Using the average fence construction cost in Kaʻū of $146,304 per mile, we estimate that the Kona Hema fence was constructed at a cost of roughly $3.4 million, paid in two installments. We similarly calculate ungulate removal costs in Kona Hema under the assumption that costs are proportional acre-wise to Kaʻū and that major removal efforts were undertaken during the first three years after fence completion. Thereafter annual maintenance expenditures are calculated based on projected costs (Table 4). Given the trend in expected expenditures and the fact that annual expenditures in Kona Hema have remained fairly steady at approximately $250,000-300,000 over the past few years, we assume a 3 percent annual growth rate in routine maintenance expenses which include fence checks and some strawberry guava removal. We further assume that fence wire needs replacement every ten years at 27% of the initial fence construction cost, in this case equal to two installments of $454,275. The frequency of fence replacement is lower than for Kaʻū because the conditions are milder.

TABLE 4. PROJECTED EXPENDITURES IN KONA HEMA

Cost Category	FY2015	FY2016	FY2017
Personnel and Fringe	$160,315	$165,125	$170,078
Contractual	$34,900	$35,947	$37,025
Other Expenses (Supplies, Travel, Occupancy, etc.)	$107,178	$110,394	$113,705
Total	**$302,394**	**$311,465**	**$320,809**

Full replacement of the fence (including posts) will be required every 30 years at only a fraction of the original installation cost because clearing and post alignment will not have to be redone. The cost of replacement could range from 1/2 to 2/3 of the original installation cost. Assuming the cost is on the higher end of the spectrum, two installments of approximately $1.2 million will be required. Historical and projected expenditures over the next 50 years (1999-2063) are presented in Figure 4. The initial installation cost is high, but maintenance costs are relatively low with the exception of wire replacement every ten years. The present value cost of conservation in Kona Hema through 2063 is $17.8 million or $2,198 per acre.

FIGURE 4. ANNUAL WATERSHED INVESTMENT COSTS FOR KONA HEMA



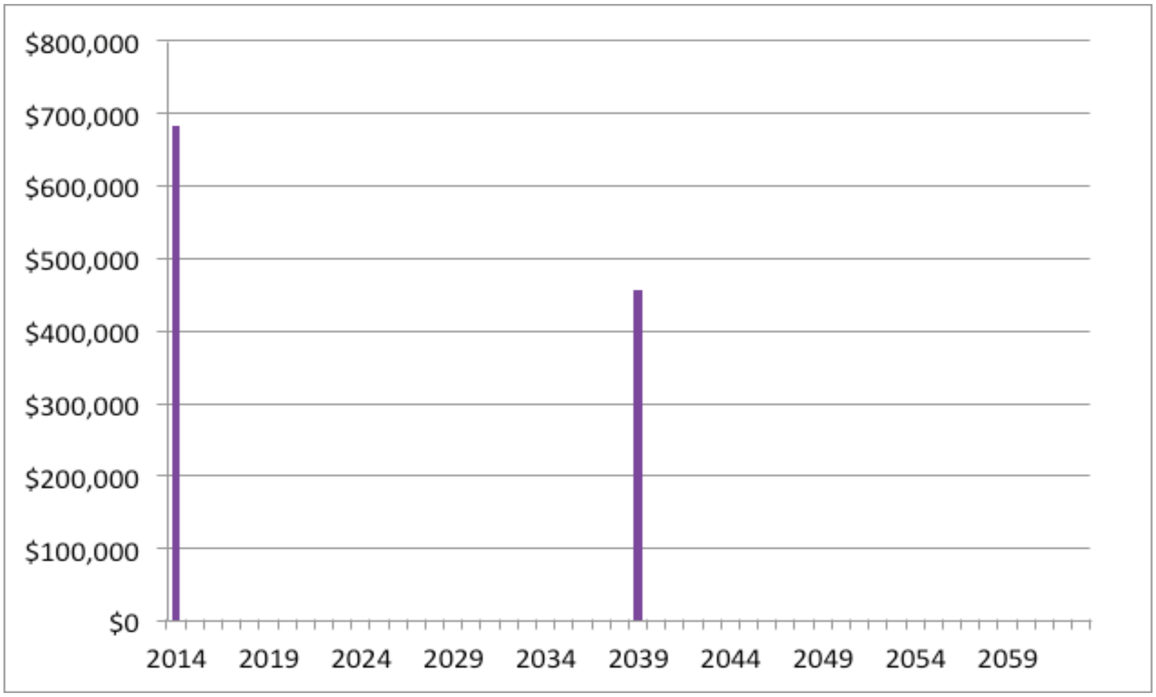
Manuka Natural Area Reserve

The Kipuka unit within the Manuka NAR spans 986.9 acres. DOFAW estimates that the average per-mile cost of 48" ungulate-proof fence is roughly $118,860—$29,715 for materials and $89,145 for labor[1]. We estimate that the total installation cost of the 5.75-mile fence in Kipuka was $683,393. Given that approximately 8,000 meters of fence can be checked per person-day, and fences are checked at least once quarterly, annual maintenance for this unit requires 4.63 person-days. At the established Department of Labor wage plus fringe rate for ungulate fencing of $29.17 per hour and assuming an 8 hour workday, the annual maintenance cost is $1,080 plus any additional costs for materials required to repair fence damage. Due to limited resources, weed control is not feasible within the fenced area. It is expected that total replacement of the fence will be required every 25 years at a cost of $455,595, or 2/3 of the initial installation cost. Projected expenditures over the next 50 years are presented in Figure 5[2]. The initial installation cost is high, but maintenance costs are very low with the exception of total fence replacement every 25 years. The present value cost of conservation in Kipuka is $928,014 or $940 per acre.

1 The cost may be higher or lower depending on the type of terrain and fence. Using 75" mouflon/ungulate proof fencing would raise the per-mile cost of materials and labor by approximately $10,000 and $25,000 respectively. For comparison, planned fences for other NAR units on Hawai'i Island have projected installation costs ranging from $114,800 to $145,571 per mile.

2 Because we do not have the exact dates of fence construction within the NAR management units, we are treating the costs as if installation occurred in the current period.

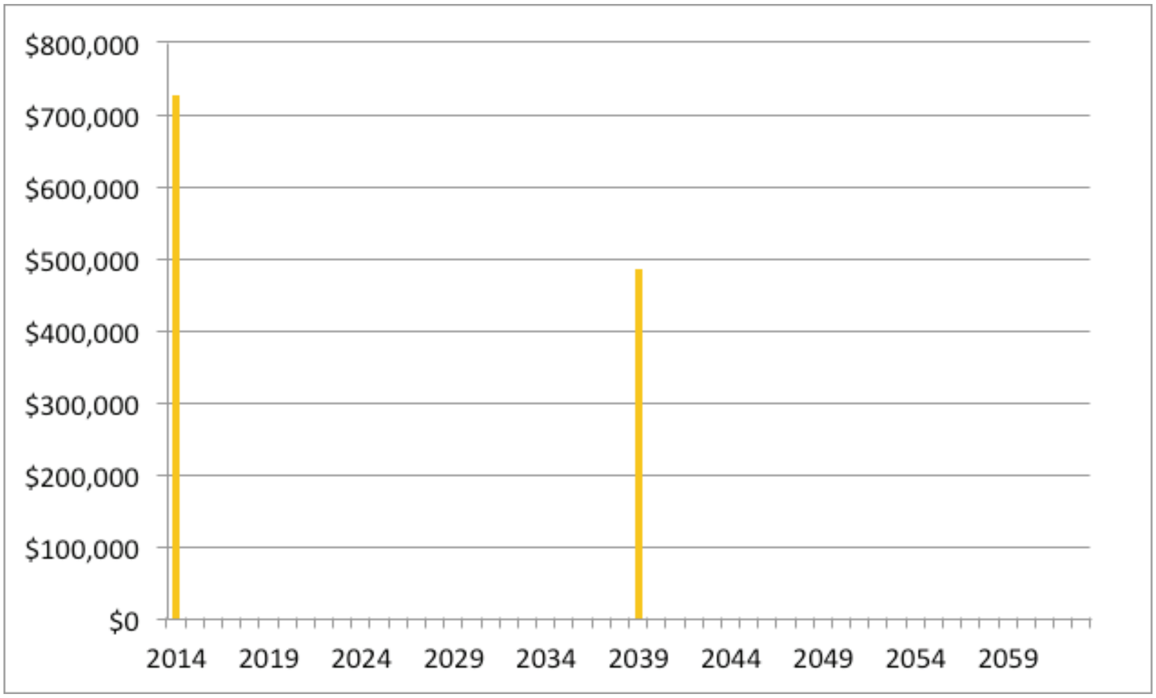
FIGURE 5. ANNUAL WATERSHED INVESTMENT COSTS FOR KIPUKA (MANUKA)



Pu'u O'Umi Natural Area Reserve

The Lahomene unit within the Pu'u O'Umi NAR spans 1,930 acres. Given the DOFAW estimated per-mile cost of $118,860, the total installation cost of the 6.12 mile fence in Lahomene was roughly $727,781. Annual maintenance for the unit requires 4.93 person-days. At the established Department of Labor wage plus fringe rate for ungulate fencing of $29.17 per hour and assuming an 8 hour workday, the annual maintenance cost is $1,150 plus any additional costs for materials required to repair fence damage. As is the case for Kipuka, limited resources prevent regular weed control within the fenced area. It is expected that total replacement of the fence will be required every 25 years at a cost of $485,187, or 2/3 of the initial installation cost. Projected expenditures over the next 50 years are presented in Figure 6. The initial installation cost is high, but maintenance costs are very low with the exception of total fence replacement every 25 years. The present value cost of conservation in Kipuka is $988,287 or $510 per acre.

FIGURE 6. ANNUAL WATERSHED INVESTMENT COSTS FOR LAHOMENE (PU'U O'UMI)



Summary of Present Value Costs

The present value cost of watershed conservation per acre varied from as low as $512 at Lahomene to over $3,100 at Kaiholena. Costs tend to be lower for the DOFAW units because ungulate removal costs were not available and fence maintenance costs only included labor for quarterly fence checks. Per-acre costs also tended to vary across units due to differences in fence perimeter shapes and because some projects expanded off of existing fences or natural barriers.

TABLE 5. PV MANAGEMENT COST FOR EACH FENCED SUBUNIT

Name of Preserve	Fenced Subunit	Size (acres)	PV Cost (million)	PV Cost (per acre)
Ka'ū	Kaiholena	1128	3.5	3106
Ka'ū	Maka'ālia	968	2.6	2731
Kona Hema	Kona Hema	7515	17.8	2366
Manuka	Kipuka	810	0.9	1146
Pu'u O'Umi	Lahomene	1930	1	512

BENEFITS OF CONSERVATION

Freshwater benefits per dollar spent on conservation are calculated for each watershed management unit. We start by identifying invasive-dominated landcover within each management area, through a combination of discussions with land managers and examination of the U.S. Geological Survey Landfire Dataset for Hawai'i (http://landfire.cr.usgs.gov/viewer). We then consider how long it would take invasive-dominated cover to completely replace existing native cover if current conservation activities ceased. These landcover changes are combined with spatial information about evapotranspiration (ET) to determine freshwater yield losses avoided by current watershed management practices.

Existing Studies

The most closely related study estimates the difference in groundwater recharge under two landcover scenarios on Hawai'i Island: (1) current landcover and (2) invasive-dominated landcover replaced by native forest (Engott, 2011). This represents a situation where conservation efforts are focused on removing existing invasive plant infestations. For the purposes of our project, we would prefer a scenario where native forest is replaced with alien forest, the idea being that landcover conversion would occur over time if current watershed conservation practices did not continue. Nevertheless, a baseline could be established if it were possible to combine recharge maps from the 2011 USGS study with an existing landcover map, e.g., from the USGS Landfire Dataset. However, the GIS-files produced for the 2011 USGS study are not in the public domain, so we instead focus on changes in ET as measure of watershed conservation benefits.

ET and Freshwater Yield

One of the main goals of watershed conservation is to increase (or avoid the loss of) groundwater storage to ensure freshwater availability for future generations. For a given landcover, groundwater storage increases with precipitation and inflow from adjacent freshwater bodies, and decreases with fog interception, overland flow, evapotranspiration, and discharge to the ocean. Recharge or infiltration could therefore be directly calculated if maps were available for precipitation, ET, streamflow, and fog interception. Although information is available for precipitation and ET, data collection at USGS stream gauges has been greatly reduced in recent years, and there are currently no fog interception maps for Hawai'i. Given the data currently available, we believe that changes in ET are the best measure of watershed conservation benefits. Holding fog interception[3] and precipitation constant, an increase in ET is equal to the aggregate decrease in recharge and overland flow. Avoiding losses to ET by maintaining the watershed, therefore, avoids reductions in recharge and overland flow (hereafter freshwater yield). Though we cannot confidently measure changes in overland flow independently and they technically do not increase groundwater storage, they do generate positive instream benefits,[4] which should be attributed to watershed conservation.

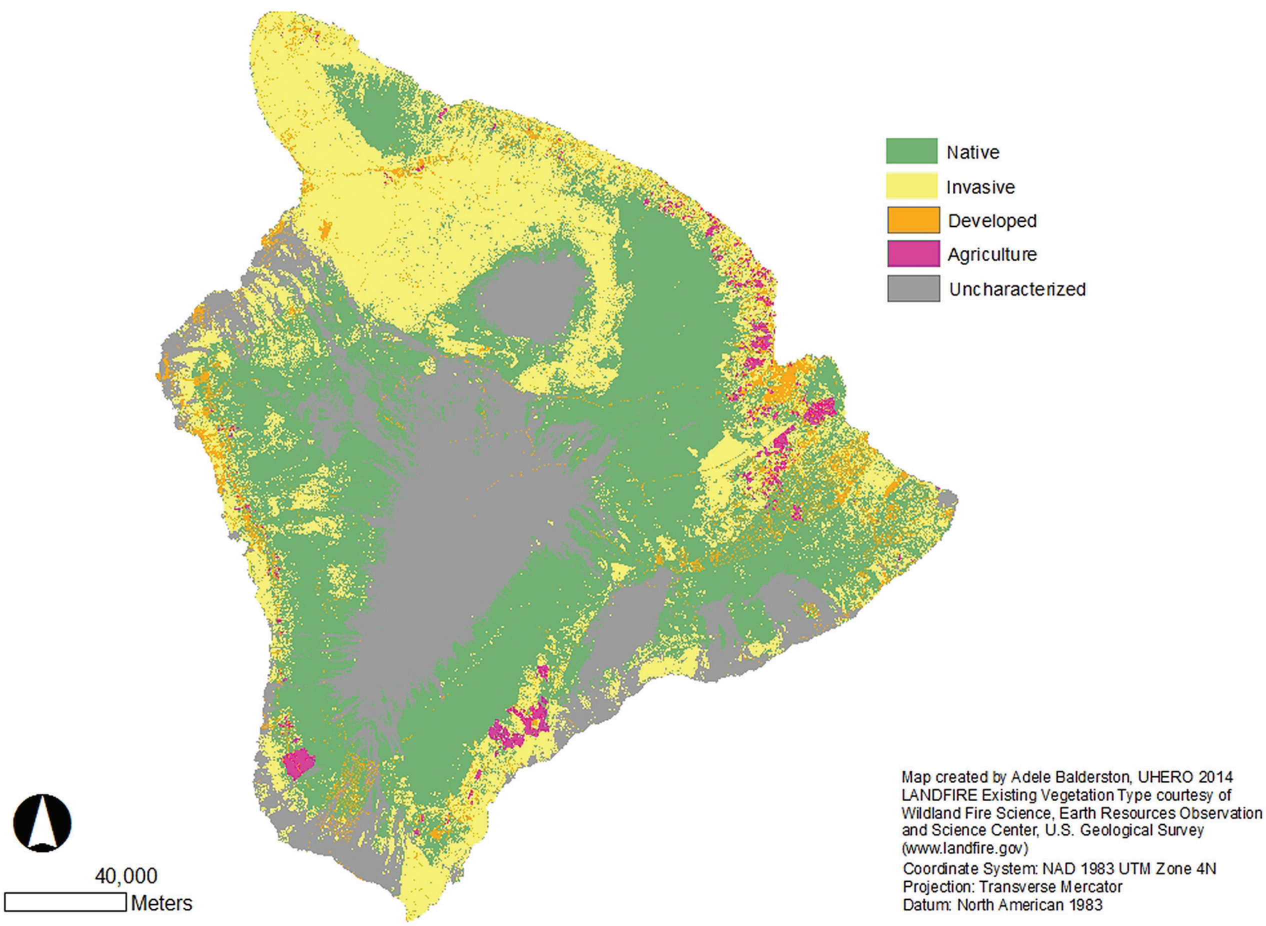
3 Fog interception has been shown to vary by species (Takahashi et al., 2011), but more studies are needed to accurately quantify those differences.

4 In some situations, increased overland flow can also generate negative effects such as sedimentation. Here, we are focusing on well-maintained management units, wherein such effects are likely to be outweighed by the positive additions to freshwater storage.

Landcover Scenarios

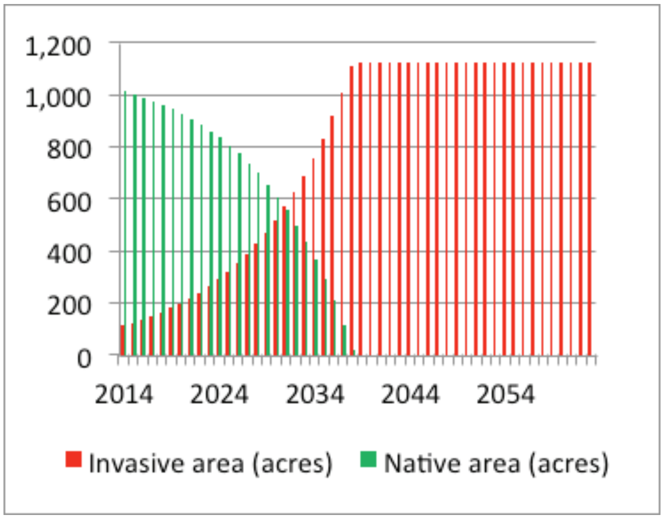
Current landcover is identified using maps generated by the USGS Landfire Dataset (Figure 7). Although the raw data includes a number of classifications, we focus on the difference between native and alien dominated 30m×30m parcels. In our simulations, we assume that only native parcels are converted to alien if conservation activities are ceased; other parcels remain unchanged.

FIGURE 7. HAWAIʻI ISLAND CURRENT LANDCOVER

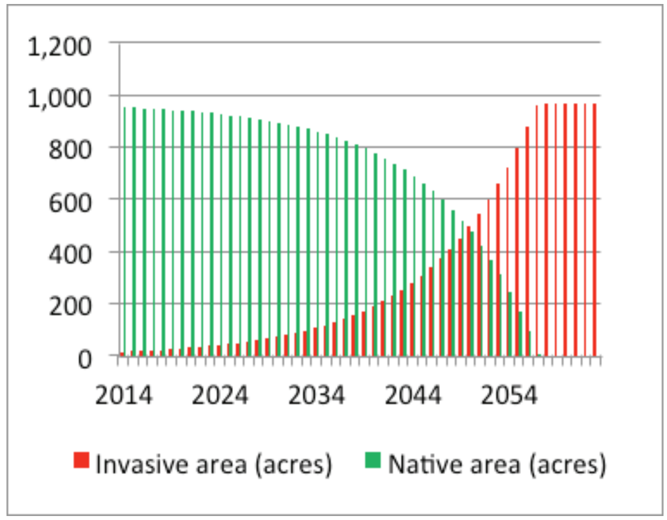


In order to estimate the benefits of current watershed conservation activities (e.g. fencing, weeding), we need assumptions about how landcover would convert from native to alien over time if those activities were ceased. Although growth/spread rates vary according to the type of invasive species and a variety of site characteristics, we do not have enough information to project landcover conversion at that level of detail. Instead we assume that strawberry guava growth, which has been estimated in the range of 9-12% per year on Hawai'i Island (NPS 2008; Geometrician Associates LLC 2010), is representative of other invasive plants. Starting with the initial coverage of alien species, we simulate alien spread as follows: a number of native parcels equal to 10% of the current total number of alien parcels are converted each year. So for example if there are 100 alien parcels in a particular management unit in a given year, 10 native units will be converted, and the total number of alien parcels in the following year will be 110. As the proportion of invasive-dominated landcover increases every year, the freshwater yield declines, i.e. the annual benefit of conservation increases over time. We abstract from the possibility that entry from outside the management unit boundary could result in new isolated populations. Landcover change out to year 2063 is depicted for each fenced unit in Figure 8.

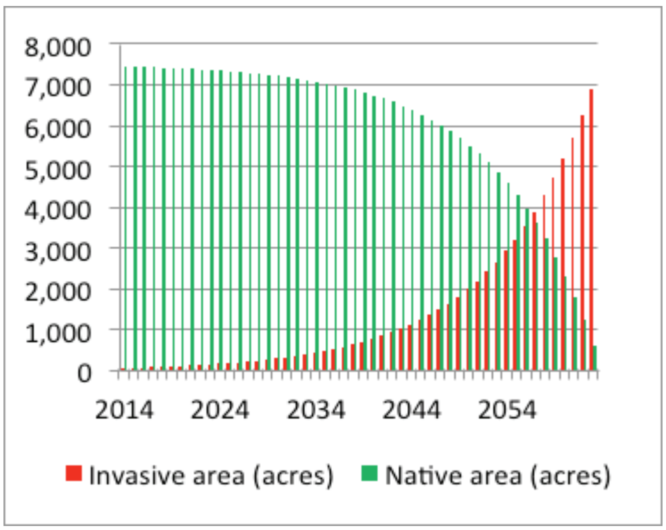
FIGURE 8. NATIVE VS INVASIVE LANDCOVER OVER TIME



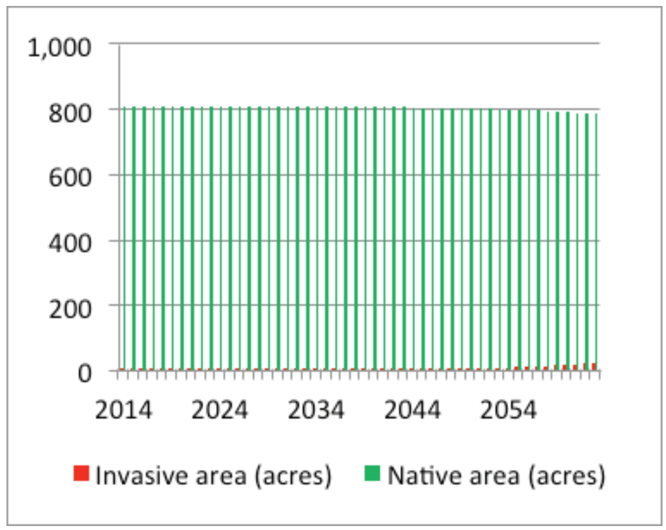
Kaiholena (Ka‘ū)



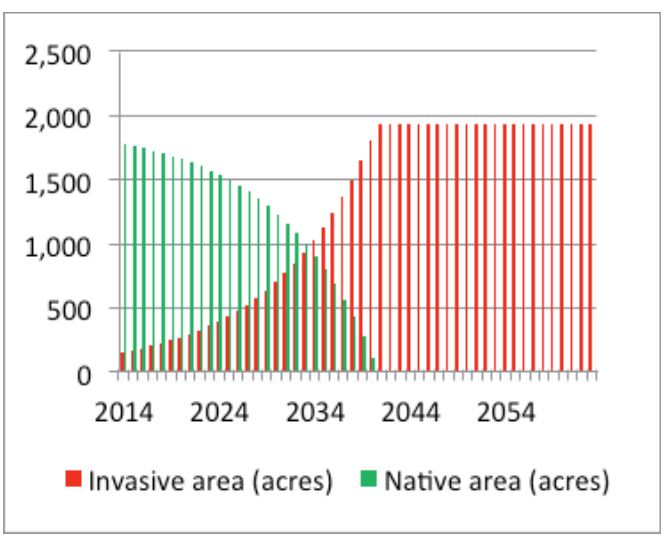
Maka‘ālia (Ka‘ū)



Kona Hema



Kipuka (Manuka)



Lahomene (Pu‘u O‘Umi)

In all fenced areas except for Kipuka and Kona Hema, native landcover is entirely hypothetically converted before year 2063, although the timing varies according to the size of the initial invaded area. Kipuka's conversion is particularly slow because it currently has no invasive landcover; to ensure some conversion in every period, we assume a single unit of invaded area at the outset. Kipuka and Kona Hema would eventually be entirely converted like the other fenced areas if the time horizon were extended beyond 2063. Figures 9-14 illustrate the spatial spread of invasive landcover for each of the fenced areas.

FIGURE 9. MAKAʻĀLIA AND KAIHOLENA CURRENT LANDCOVER

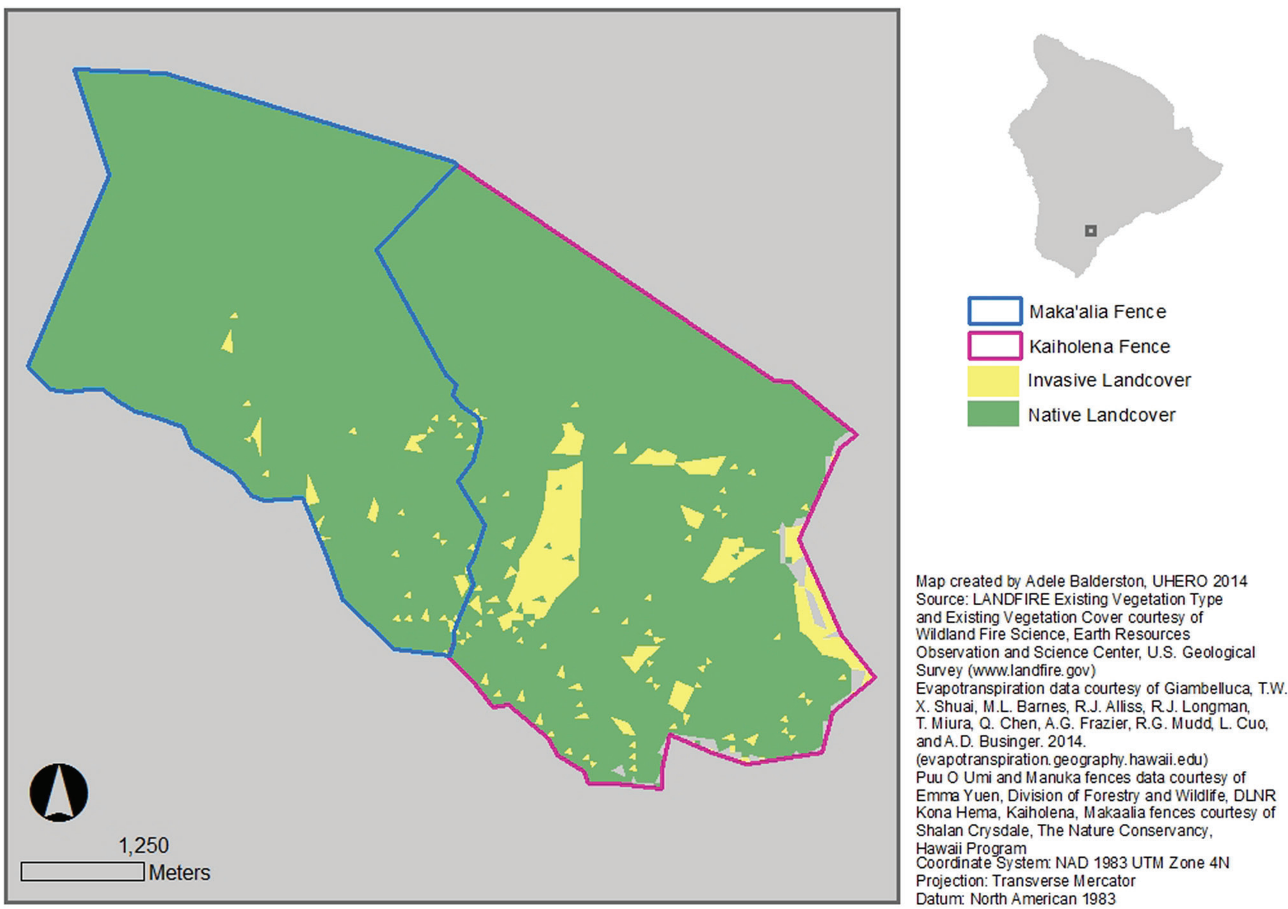


FIGURE 10. MAKAʻĀLIA AND KAIHOLENA LANDCOVER IN 20 YEARS

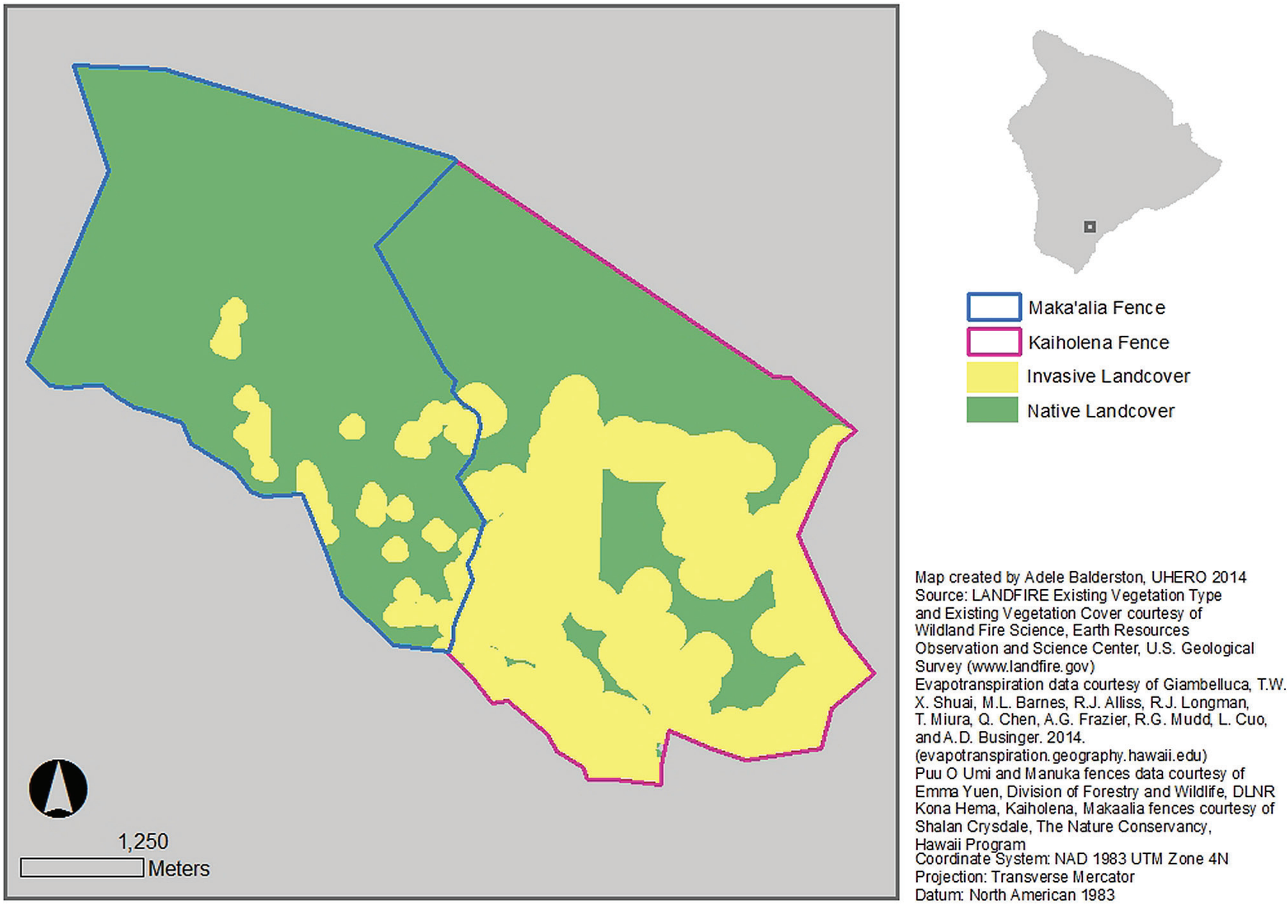


FIGURE 11. KONA HEMA AND MANUKA CURRENT LANDCOVER

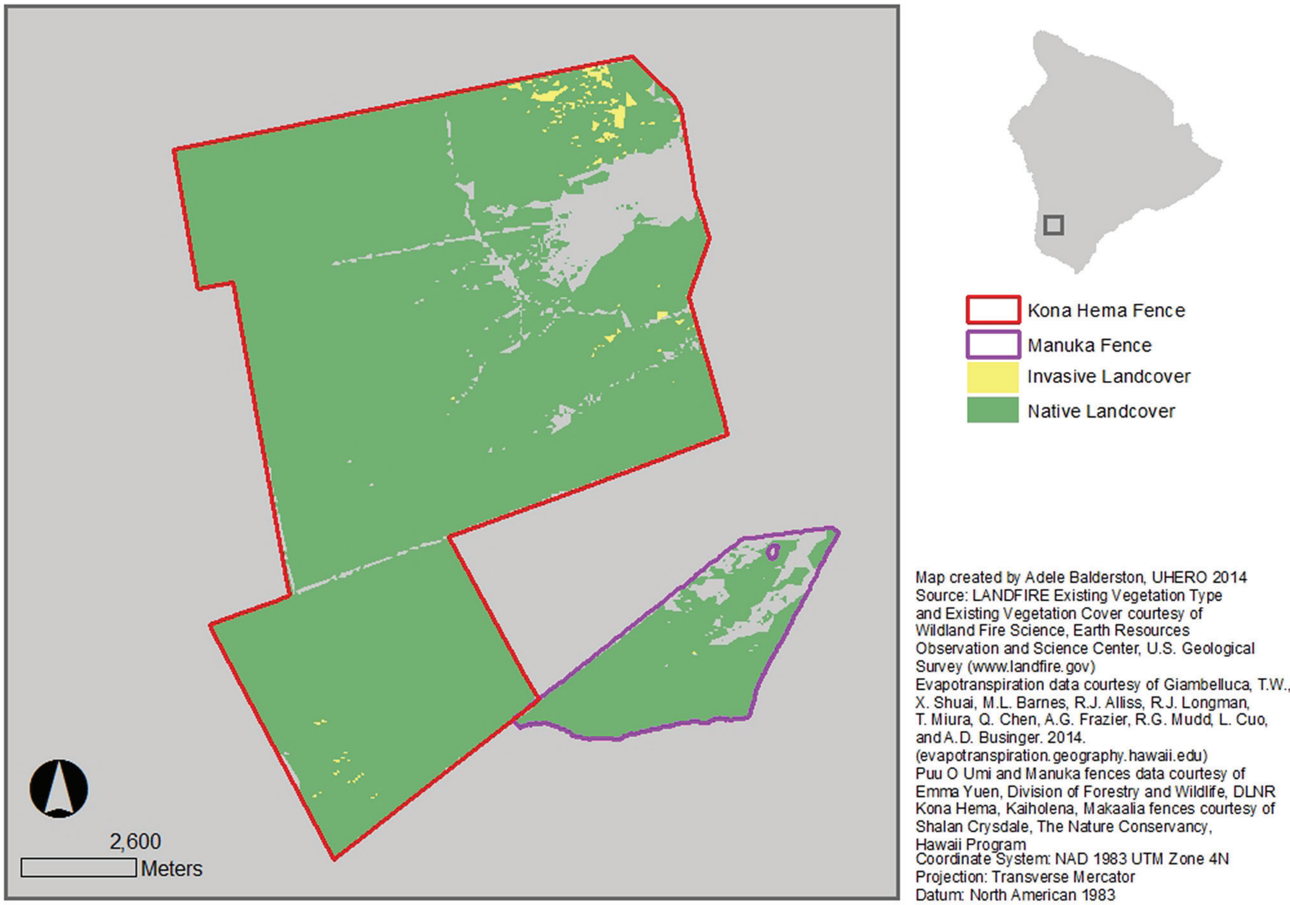


FIGURE 12. KONA HEMA AND MANUKA LANDCOVER IN 20 YEARS

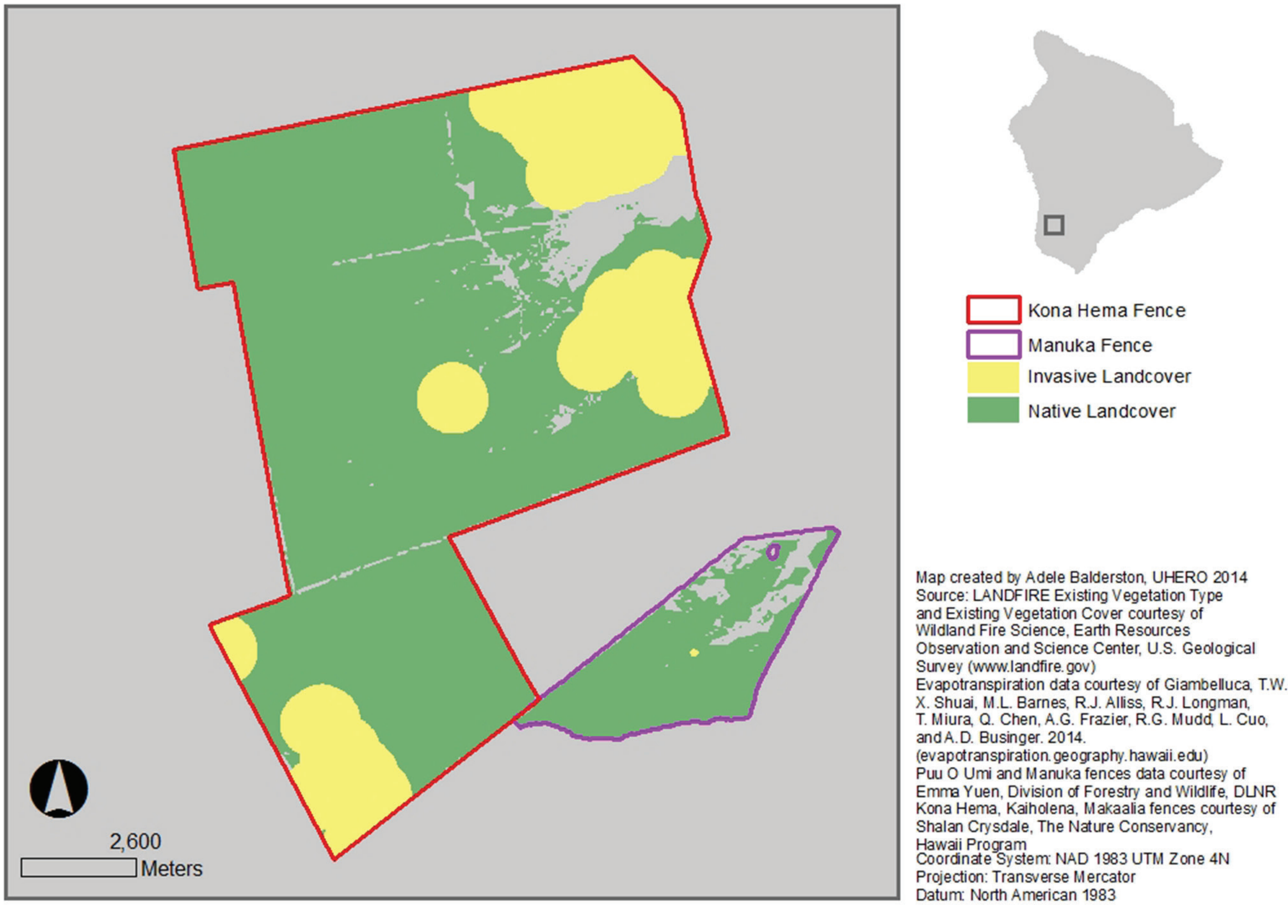


FIGURE 13. PU‘U O‘UMI CURRENT LANDCOVER

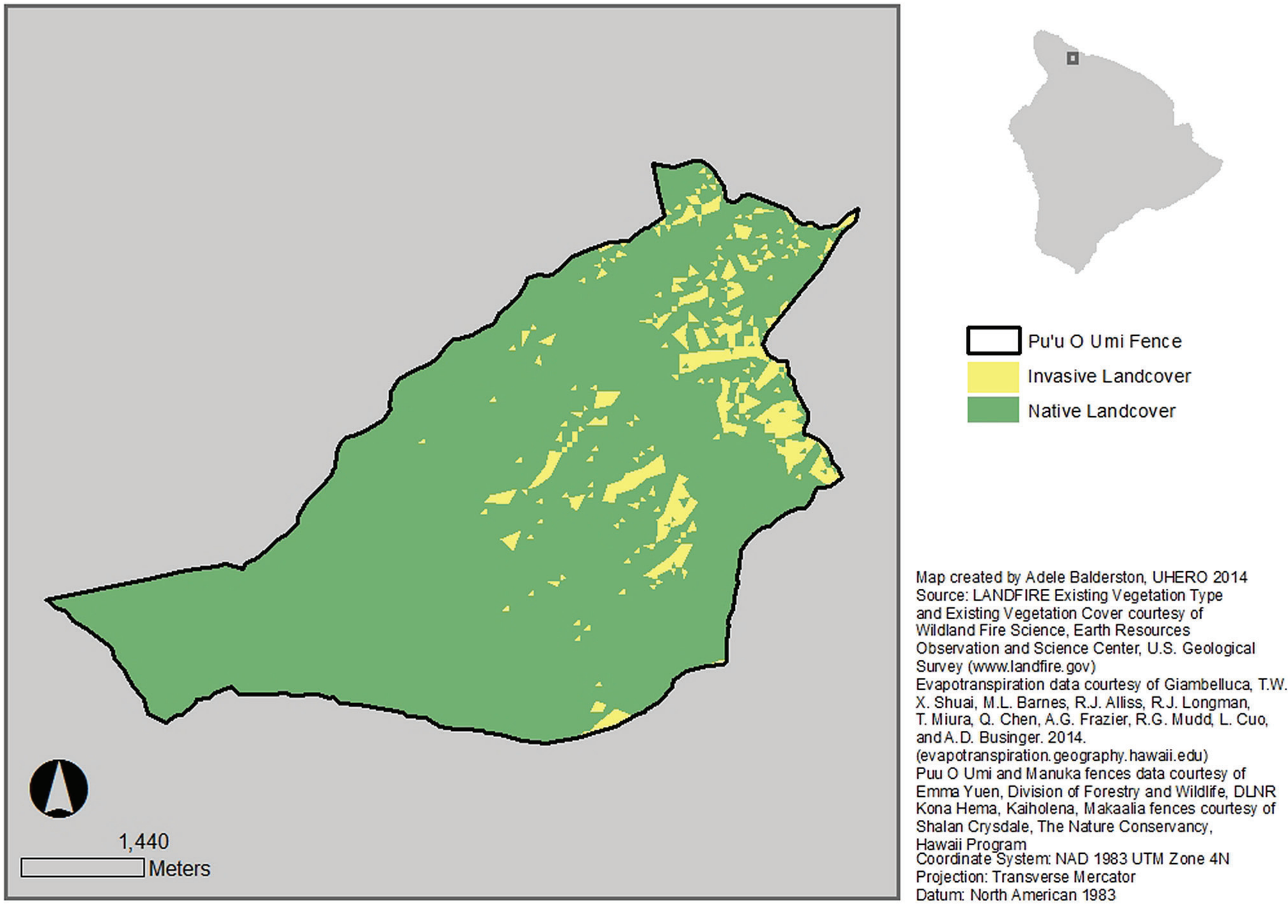
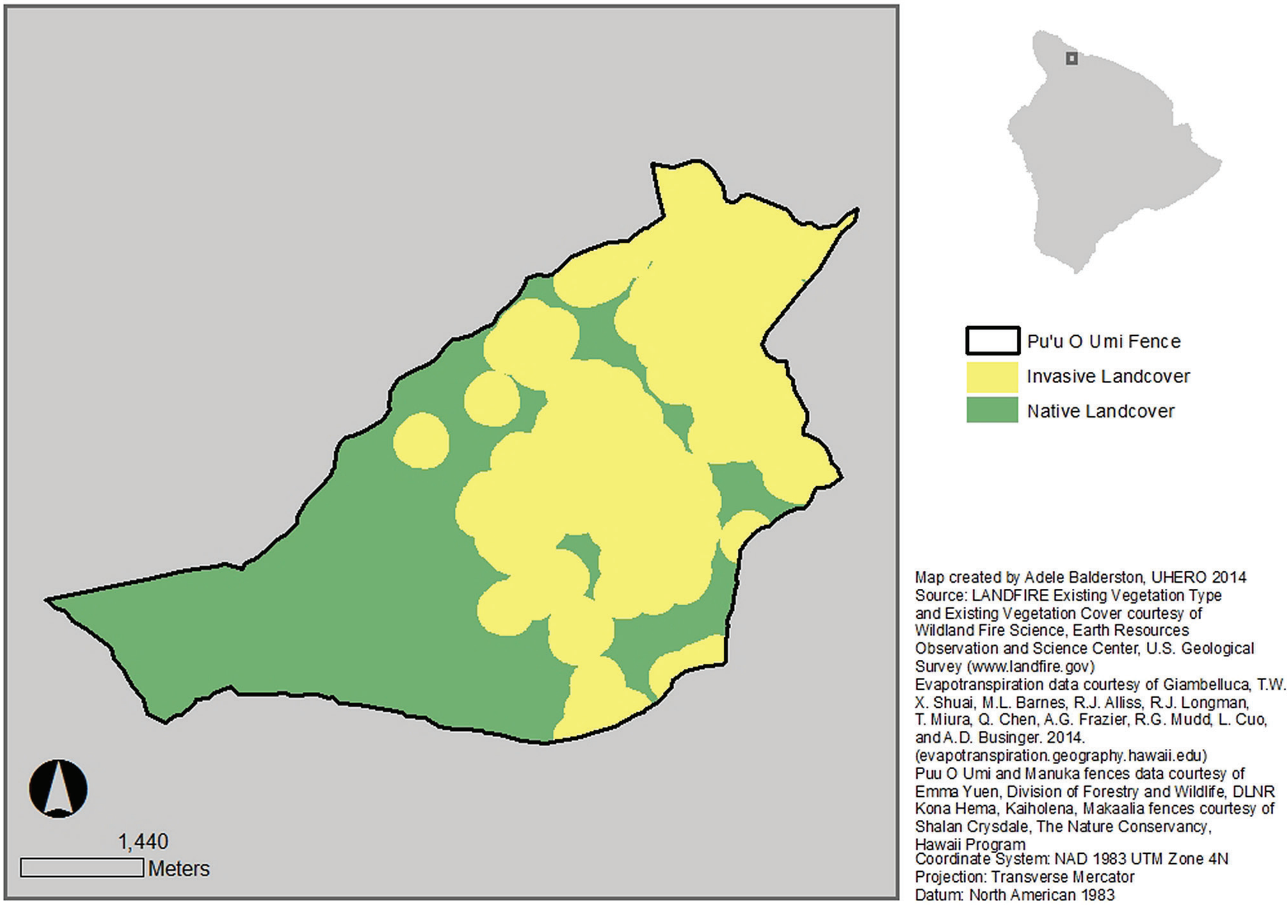


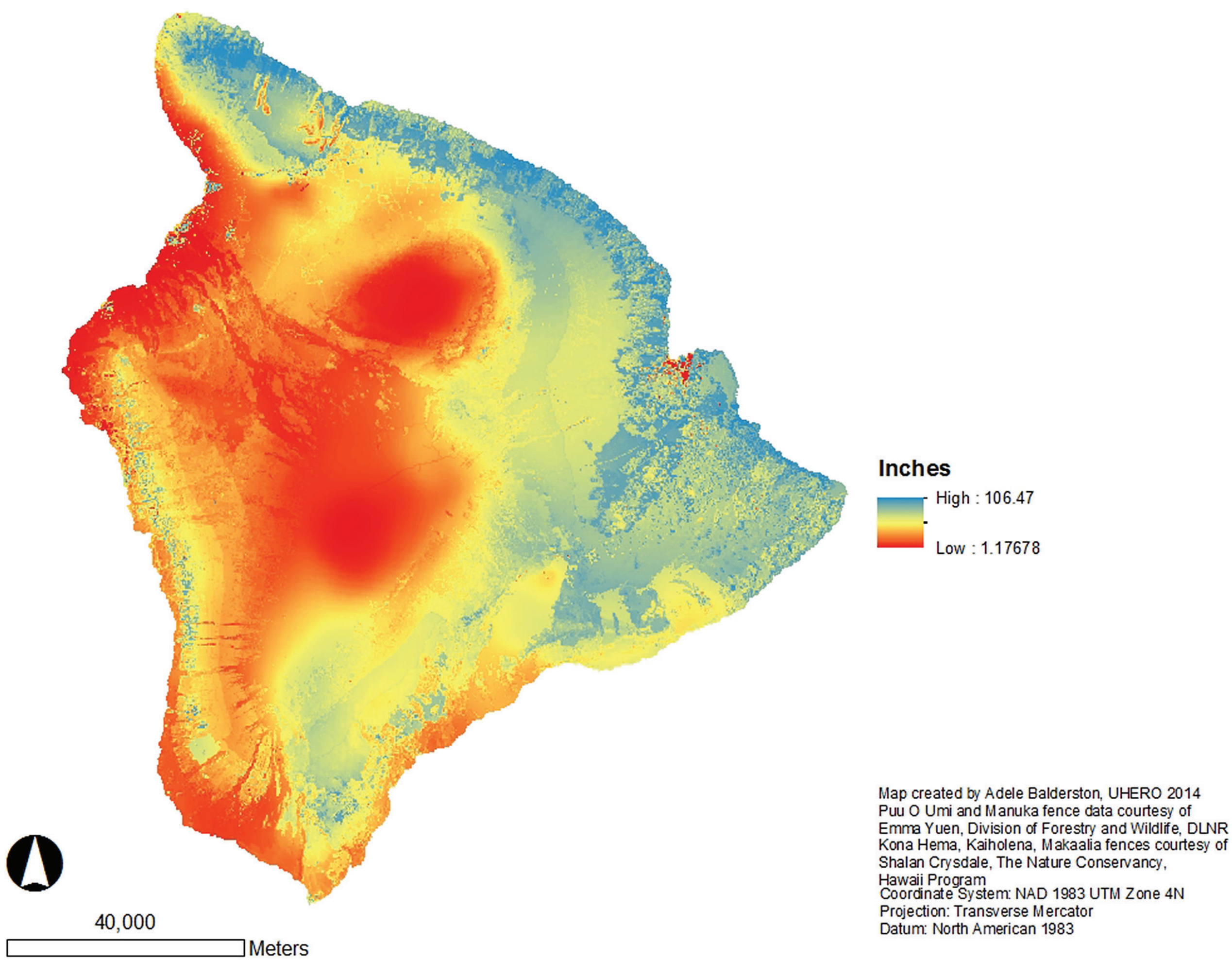
FIGURE 14. PU‘U O‘UMI LANDCOVER IN 20 YEARS



Evapotranspiration Scenarios

Existing ET maps (Giambelluca et al., 2014) were matched up with current landcover maps to determine the baseline for our analysis. Figure 15 below depicts inches of average annual ET on Hawai‘i Island.

FIGURE 15. HAWAI‘I ISLAND AVERAGE ANNUAL ET



Evapotranspiration varies over space, largely due to differences in climate variables such as precipitation but also partly due to differences in landcover. Although there is no way to directly measure ET for our counterfactual scenario, wherein alien forest continuously replaces native forest over time, we can extrapolate changes based on observed differences in the baseline map. We start by separately calculating mean ET across all native units and mean ET across all invasive units classified as "tree cover". Other types of invasive landcover (e.g. herb cover, shrub cover, etc.) are not included in the baseline ET calculation because we assume that all units will eventually be converted to invasive canopy if watershed conservation is discontinued. For each year, we simulate landcover conversion as described in the previous section; the area of invasive landcover is increased by 10%, and the native landcover is reduced by enough to exactly offset that change. Baseline ET is then subtracted from post-conversion ET in each year to determine the benefits (avoided freshwater yield loss) of maintaining watershed conservation activities at their current levels. Total evapotranspiration increases out to year 2063 in each fenced unit, which means that avoided ET losses correspondingly increase, as illustrated in Figures 16-20.

FIGURE 16. AVOIDED ET LOSS (TG) IN KAIHOLENA (KAʻŪ)

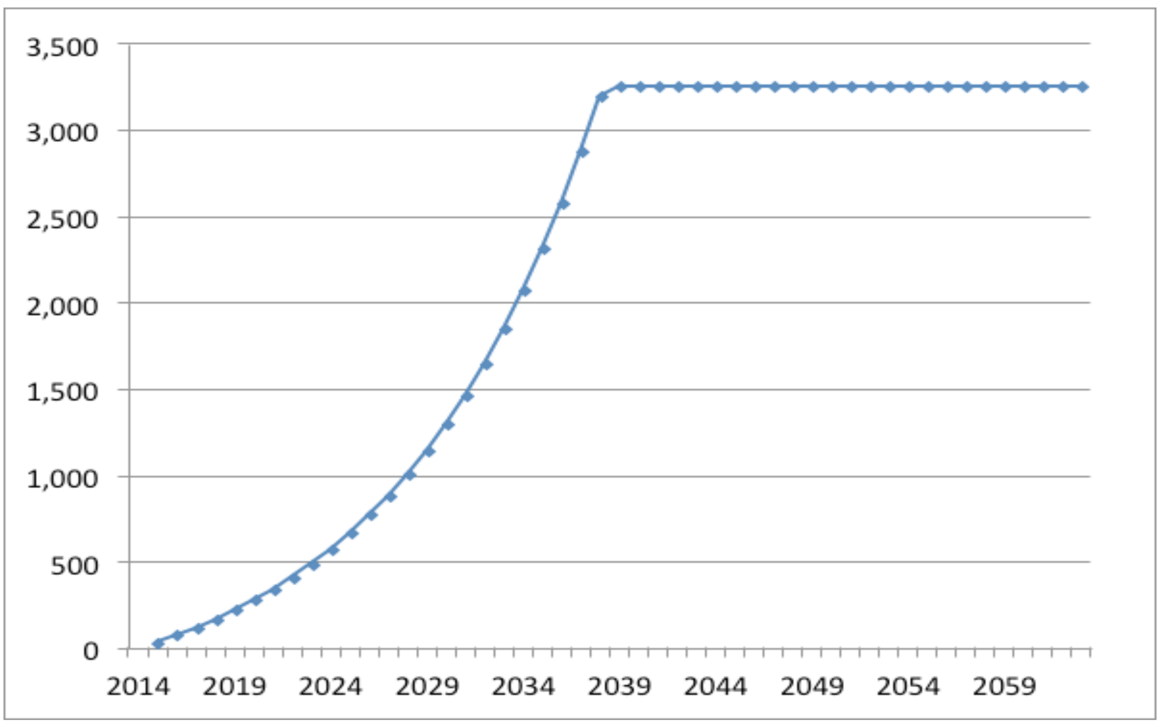


FIGURE 17. AVOIDED ET LOSS (TG) IN MAKAʻĀLIA (KAʻŪ)

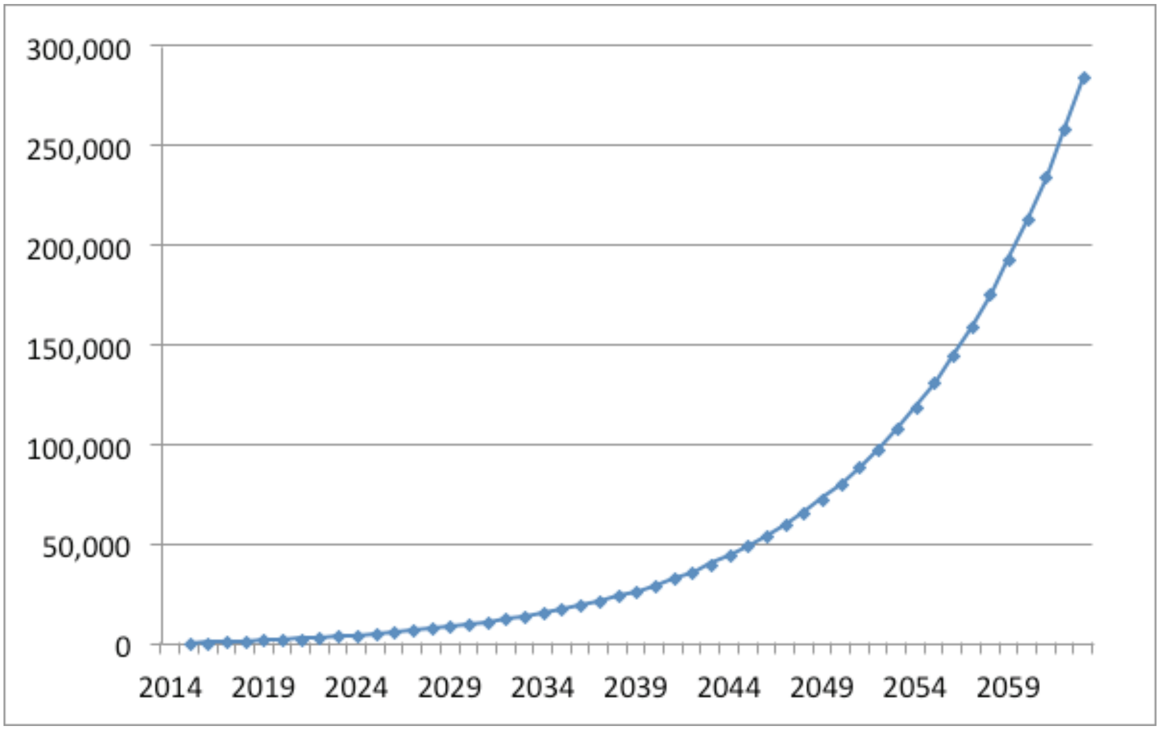


FIGURE 18. AVOIDED ET LOSS (TG) IN KONA HEMA

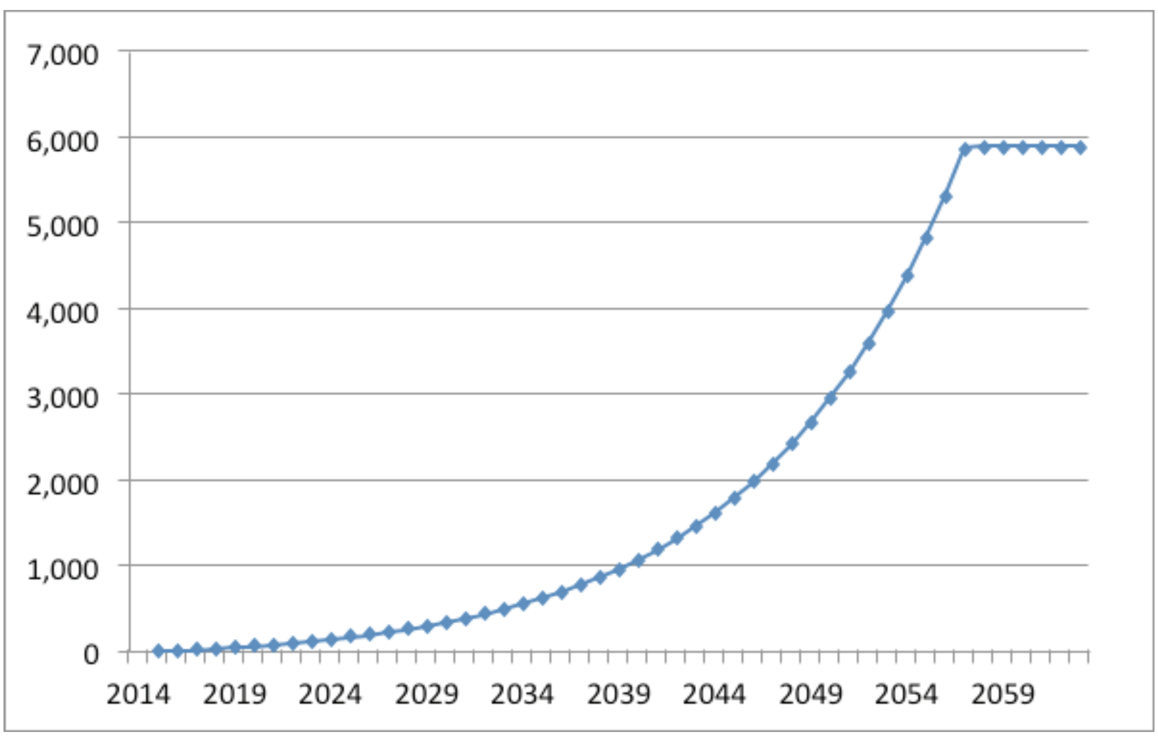


FIGURE 19. AVOIDED ET LOSS (TG) IN KIPUKA (MANUKA)

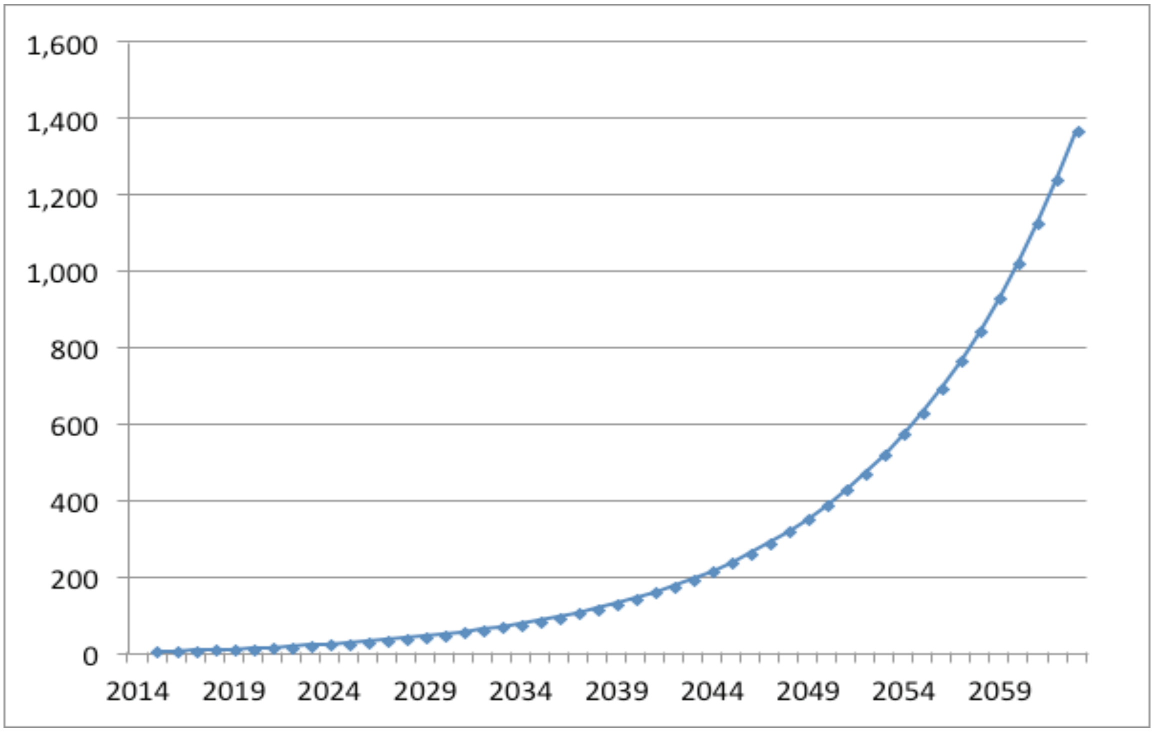
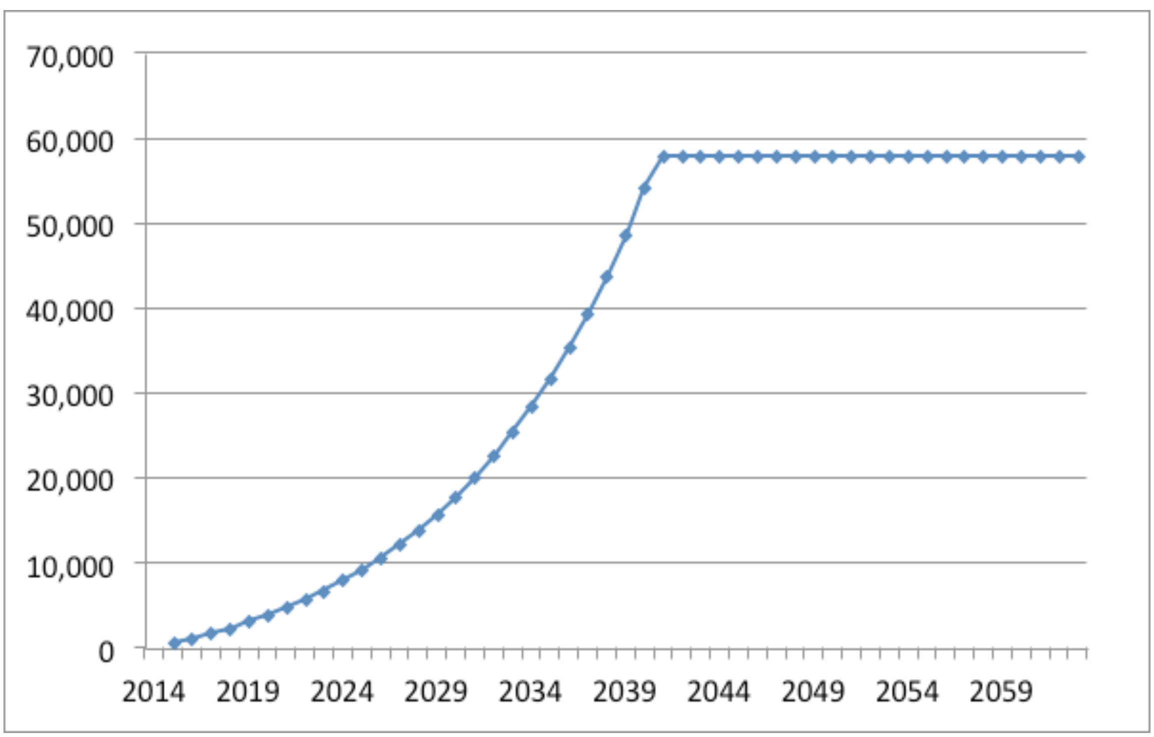


FIGURE 20. AVOIDED ET LOSS (TG) IN LAHOMENE (PU‘U O‘UMI)



RESULTS

Freshwater Yield Savings per Conservation Dollar

For each management unit, we calculate freshwater yield saved per conservation dollar by dividing total avoided ET loss over the planning horizon by the present value (PV) costs of conservation (Table 5).

TABLE 5. PV COSTS AND FRESHWATER YIELD PER DOLLAR

	r=3%			r=5%			r=7%		
Fenced Unit	PV Cost	PV cost per acre	Gallons per dollar	PV Cost	PV cost per acre	Gallons per dollar	PV Cost	PV cost per acre	Gallons per dollar
Kona Hema	$17.8 M	$2,366	168	$11.7 M	$1,555	256	$8.7 M	$1,161	343
Kaiholena	$3.5 M	$3,106	31	$2.3 M	$2,061	46	$1.7 M	$1,519	63
Makaʻālia	$2.6 M	$2,731	36	$1.9 M	$1,930	51	$1.4 M	$1,481	67
Puʻu OʻUmi	$1.0 M	$512	1,818	$0.9 M	$462	2,015	$8.3 M	$432	2,157
Manuka	$0.9 M	$1,146	15	$0.8 M	$1,034	17	$7.8 M	$965	18
Average	$5.2 M	$1,972	414	$3.5 M	$1,408	477	$2.7 M	$1,112	530
Standard Dev	$7.1 M	$1,099	787	$4.6 M	$662	865	$3.4 M	$444	919
Weighted Avg	$11.6 M	$2,092	393	$7.7 M	$1,425	480	$5.8 M	$1,092	558

For a discount rate of 3%, the volume of freshwater saved per dollar invested in watershed conservation ranges from 15 gallons in Manuka to over 1,800 gallons in Puʻu OʻUmi, with a weighted average of 393 gallons across all sites. In other words, almost 400 gallons is saved per dollar invested in watershed conservation, or equivalently, every $2.54 spent on conservation activities protects on average 1,000 gallons of freshwater yield. As the discount rate is increased, the savings per dollar also increases because only the costs are discounted in this exercise (the benefits are measured in volume, not dollars). If the discount rate is increased to 7%, the average savings per dollar increases to 580 gallons, i.e. only $1.72 is required for the protection of every 1,000 gallons of freshwater. For comparison, the current Honolulu Board of Water Supply residential Block-1 price (up to 13,000 gallons) is $4.03 per thousand gallons, and the per unit cost of desalination may be several times that amount. In Carlsbad (San Diego County, CA), for example, a 50-MGD $1-billion seawater desalination plant is expected to be completed in 2016. The unit cost will be roughly $7 per thousand gallons, i.e. every $1 would produce 143 gallons of freshwater.

Projected net benefits vary greatly across sites, due to the differences in available cost data and the initial coverage of invasive species. For example, while the historical and projected budgets for the TNC sites (Kona Hema, Kaiholena, Makaʻālia) include fence construction, maintenance, and ungulate removal costs, expenditures for the NAR sites (Puʻu OʻUmi, Manuka) were estimated using average fence expenditures across all DOFAW natural area reserves and ungulate removal and maintenance costs were not available. Hence, return on investment per dollar in gallons is highest for Puʻu OʻUmi. At the same time, ROI for Manuka is particularly small (even though costs are underestimated) because the initial invasive population is non-existent. Over a longer horizon, avoided freshwater losses would increase dramatically as the invasive landcover would be allowed to spread further.

Annual benefits increase continuously because avoided ET loss rises as one considers the hypothetical spread of invasive plants over time. Costs, on the other hand, are lumpy and front-loaded. The initial cost of installing a fence, for example, is very high but maintenance costs are relatively low thereafter except during years in which the wire and/or posts need to be replaced. It is important, therefore, to consider the big picture when comparing the costs and benefits of conservation. Costs incurred today to build a fence cannot be justified by the expected benefits next year or in even the next five years. But over the next 50 years, the benefits may largely outweigh the costs.

RESEARCH NEEDS AND DIRECTIONS FOR FURTHER RESEARCH

Further scientific investigation is needed to clarify the extent to which alien species differ from native species in terms of their effects on various water balance components including evapotranspiration, fog interception, overland flow, and recharge. More data collection on precipitation, streamflow and fog interception would also help to advance the creation of statewide maps that match landcover with various water balance components, including recharge.

Data limitations notwithstanding, the research detailed in this report could also be extended in a variety of ways. The ET estimation method could make fuller use of the spatial landcover and ET data by calculating percentage differences in native and invasive ET in sample subunits of space. ET for a native unit up for conversion in a given year would then be adjusted by the percentage difference in the nearest sample subunit. In other words, ET adjustments would vary spatially for converted units, depending on how ET tends to vary between native and invasive units in the immediate vicinity. Another extension would be to overlay a map of saved freshwater yield with physical/geographical characteristics of each cite in order to identify factors that may be important when extrapolating results to similar sites throughout the state.

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