Tyler Gerken
HERS
07/26/19

Native Hawaiian Teas in Peril: Habitat Loss and preservation and *Māmaki* and *Koʻokoʻolau* in lowland rainforests in Puna, Hawaiʻi Island, Hawaiʻi

Introduction:

Hawaiian ecosystems contain high rates of endemic species found nowhere else in the world. The suitable habitat quality of Hawaiian ecosystems is continuously degraded due to anthropogenic—urbanization and invasive species introductions—and natural disturbances—such as from Rapid *ʻŌhiʻa* Death (ROD) from two *Ceratocystis* spp. causing vascular wilt and high rates of mortality in this pioneer tree species threatening the abundance and rich flora of Hawaiʻi. The Hawaiian Islands are home to around 1200 native species of vascular plants, many of which are threatened, endangered, or extinct (Price et al. 2012). Furthermore, half of Hawaiian flora are naturally restricted to a single island (Price 2004) threatening the resiliency of these isolated plant species to survive against a decrease in suitable habitat to persist. Hawaiian ecosystems are sensitive to human disturbances which has manifested in 109 historical plant extinctions, in addition to ~400 (~43%) of all federally listed threatened and endangered native plant species are from the Hawaiian Islands (Fortini et al. 2013; Vorsino et al. 2018). Preservation and restoration of remaining Hawaiian ecosystems require an assessment of the individual and cumulative impacts of habitat loss in Hawaiian ecosystems, particularly within lowland wet and mesic rainforests. Lowland wet and mesic rainforests contain culturally and ethnobotanically important plants and herbs that are a key component of Hawaiians cultural identity to the *ʻāina* (land), their culture, and to the *lāhui* (community).

Two important endemic Hawaiian plants—*Māmaki* (*Pipturus albidus*) and *Koʻokoʻolau* (*Bidens hawaiensis)*—are major components of traditional and contemporary Hawaiian medicine; however, the distribution of these highly foraged upon herbal plants are decreasing in both abundance and current/potential range. While *Māmaki* and *Koʻokoʻolau* are important plants used as medicine, they are just two of more than 180 different species of medicinal plants (Handy et al. 1934; Nagata 1971) that were used by k*āhuna lāʻau lapaʻau* (Hawaiian traditional herbal medical practitioners) (Tabrah and Eveleth 1966; Gutman 1976). Traditionally the leaves of *Māmaki* and *Koʻokoʻolau* were prepared as an herbal green tea and most commonly consumed as a tonic in combination with a plethora of other herbs to heal a wide range of medical ailments ranging from *ʻea* (thrush), diabetes, hypotension, asthma, and tuberculosis (Chun 1994; Krauss

2001). Native Hawaiians believed that socery was the causative agent responsible for illness and pain yet their experimentation of "folklore" herbal therapeutics may provide modern insight into disease prevention using traditional knowledge; research by Locher et al. (1995) found the leaves and stems of *Māmaki* contain anti-bacterial, anti-viral, and anti-fungal properties. Naturally foraged upon in Hawaiian lowland rainforests, *Māmaki* and *Koʻokoʻolau* were extensively utilized in Hawaiian medicine. Preserving these medicinal plants to sustain a diverse and healthy rainforest is integral to the Hawaiian cultural medicine supporting spiritual and physical resilience in the health of the *lāhui*.

Research Question:

Throughout the Hawaiian Islands, lowland rainforests have largely dissapeared. The impacts of urbanization, invasive species introductions, and ROD are responsible for the decline of suitable habitat and habitat quality. My research question seeks to analyze the impacts of habitat loss upon the habitat range of *Māmaki* (*Pipturus albidus*) and *Koʻokoʻolau* (*Bidens hawaiensis*) in lowland wet and mesic rainforests in the district of Puna on Hawaiʻi Island. As one of the last remaining lowland rainforest in Hawaiʻi, the district of Puna was a revered and highly sought out resource—plants and herbs were frequently sought after and collected for use in *hula* and *lāʻau lapaʻau*—for local and surrounding Hawaiians in neighboring *ahupuaʻa* (land divisions) due to its abundant natural resources. As currently available data include only simplified range maps, species distribution models of *Māmaki* and *Koʻokoʻolau* will inform natural resource managers of the limited range and threats to these medicinal plants of ethnobotanical and biocultural value in Puna. By analyzing the individual and cumulative anthropogenic and naturally occurring stressors impacting the natural resources and habitat quality in Puna, land management actions and policies impacting natural resources in Puna are imperative for the preservation and restoration of Native Hawaiian plants in Puna emphasizing *Māmaki* and *Koʻokoʻolau*.

Literature Review:

Native Hawaiian culture is intrinsically linked to the natural elements observed throughout the surrounding environment where cultural engagement requires a healthy, pristine environment fostering an interconnected relationship with nature. When I look at all the contributions scholars and natural resource land managers are making, the overwhelming need to incorporate traditional ecological knowledge with scientific monitoring and restoration events in Hawaiian ecosystems are critical for the success of restoration projects governing Hawaiian ecosystems. Sharing similar ideologies with indigenous peoples' globally, Hawaiian culture is deeply rooted within a sustainable, self-governing *ahupuaʻa* (traditional land-management system) which allowed for healthy, sustainable communities thereby fostering an abundance of resources for cultural subsistence and rituals to be performed. Native Hawaiians fostered a strong relationship to their environment, where *akua* (spiritual entities) and *ʻaumakua* (gods and ancestral spirits) were personified and legends and myths were constructed to describe their dynamic and embedded relationships to the natural elements around themselves (McGregor 2007). Native Hawaiians traditionally viewed illness as inducible via magic or socery, which resonates with Hawaiians viewpoint on the sacredness of *mana* (spiritual energy) and *kapu* (ancient Hawaiian code of laws and regulations); to rectify this imbalance, a combination of chants, prayers, and herbal medicine were prepared to aid in healing a person's physical, mental, and spiritual health to refill the depleted mana reservoir (Chun 1986). When collecting medicinal plants in the forest, certain *akua*, such as *Kū* and his wife *Hina*—associated with the male and female properties of healing plants and in ritual—were often beseeched ((Camp et al. 2018). Native Hawaiians holistic approach to health of the *ahupuaʻa*—from mountain to sea—established a system which allowed natural resources to be consumed, replenished, and respected for future generations of the *lāhui* to benefit from. An imbalance of *mana*, manifesting in illness exemplified the necessity of maintaining a holistic physical, mental, and spiritual connection to the *ʻāina*. To aid in restoration of our lowland rainforests containing abundant resources for *lāʻau lapaʻau*, my contribution seeks to demonstrate the necessity to preserve native Hawaiian herbs used in traditional Hawaiian medicine for biocultural and ethnobotanical preservation.

Foraging for medicinal plants was a key component in the practice of *lāʻau lapaʻau*, where healthy thriving forests were necessary to procure all of the necessary herbs for making the herbal medicine. When I look at fascinating conclusions researchers are drawing, I notice the pattern that many native Hawaiian plants exhibit antimicrobial properties substantiating the validity of traditional folklore. Historically, *kahuna lāʻau Lapaʻau* utilized over 180 different plant species to heal the community (Handy et al., 1934; Nagata, Kenneth 1971) and thus required high-quality forests to obtain these herbal plants for cultural subsidence. *Māmaki* and *Koʻokoʻolau* are two widely utilized tea plants, traditionally and comtemporarily, were prepared as an herbal green tea and used as a tonic; *Māmaki* was used to treat thrush, purify the blood and regulate blood sugar, blood pressure, and cholesterol (Chun, Malcolm 1986; Krauss, Beatrice 2001) whereas *Koʻokoʻolau* was used used to treat thrush, constipation, asthma, and tuberculosis but was often used in combination with many other plant species (e.g., *ʻōhiʻa lehua – Metrosideros polymorpha, ʻōhiʻa ʻai – Eugenia malaccensis, kukui – Aleurites moluccana, and kō – Saccharum officinarum*) (Krauss, Beatrice 2001). While little evidence exists for the medicinal properties of *Koʻokoʻolau*, scientific evidence demonstrated that the stems and leaves of *Māmaki* contain anti-bacterial, anti-viral, and a lesser degree anti-fungal properties (Locher et al. 1995). The practice of gathering forest plants traditionally and contemporarily occupies a critical role in procuring medicine for the Hawaiian people. Therefore, I am seeking to understand the drivers of habitat loss for biocultural preservation of native Hawaiian plants, particularly *Māmaki* and *Koʻokoʻolau* in the district of Puna on Hawaiʻi Island. However, due to multiple anthropogenic and natural disturbances infringing upon the habitat quality and habitat range of Hawaiian plants, Hawaiians cultural identity with the forests will continue to erode away unless human intervention preserving remaining natural resources and restoration is encouraged.

To mitigate habitat loss of Hawaiian ecosystems, researchers are determing the best management strategies to combat the conversion of native forests into urban and agriculture development, management of ecosystem-modifying invasive species, and ROD. Actions to preserve and restore Hawaiian ecosystems are paramount to preserve as much remaining high-quality remaining rainforests. Intact native dominated lowland rainforests have largely dissapeared throughout the Hawaiian Islands due to conversion of landscapes to support an ever-growing human population. However, few high quality fragmented rainforests remain throughout Hawaiʻi and Kauaʻi, where a prime example is located in the Kalapana rainforest, which is "recognized to be one of the tallest statured lowland rainforest strands documented in Hawaiʻi" (Grossman 1992). Hawaiian culture is intrinsically rooted in nature where preservation of these remaining forests are important because the health of Native Hawaiians was traditionally synonymous with the healthy and functioning on a healthy forests; this relationship to the *ʻāina* is highlighted by Davianna McGregor stating that, "these Hawaiian rural communities are the cultural *kīpuka* (oases) from which the Hawaiian culture regenerates, as the native trees of the *kīpuka* propagate and, in time, re-establish the forest on the lava flow" (Nālehualawakuʻulei 2017). In order to preserve these ethnobotanical and biocultural resources while anticipating the impacts of climate change and land use degradation, my research seeks to determine suitable habitat ranges of *Māmaki* (*Pipturus albidus*) and *Koʻokoʻolau* (*Bidens hawaiiensis*). Constructing species range maps to estimated the current and projected range of these medicinal plants will support forest management restoration tactics to improve the abundance of these medicinal plants in our remaining intact lowland forests.

Scholars are focusing on the surveillance, preservation, and restoration of Hawaiʻi's unique and diverse biocultural natural resources throughout the archipelago. Hawaiian ecosystems are threatened due to conversion of native forests into agriculture and urban land, invasive species' introductions, and ROD. Research by Schulten et al. (2014) sought to determine which native Hawaiian trees with divergent life histories can survive and tolerate invasive species due to light and water constraints in a lowland wet rainforest. A similar research study explored the resilience of lowland rainforest to recover following a major clearcutting event by analyzing the revegetation of native and exotic species (Grossman 1992). In addition, research that may better assist land managers restoration plans are exhibited by Fortini et al. (2013) who quantified the vulnerability of native Hawaiian plants to persist under projected climate change by creating maps illustrating the change in species range. Therefore, my research question seeks to analyze how habitat loss is impacting the distribution of medicinal Hawaiian plants – *Māmaki (Pipturus albidus)* and *Koʻokoʻolau (Bidens hawaiiensis)*. Preserving as much remaining lowland wet and mesic rainforests with ethnobotanically important flora is necessary for *Kanaka Maoli* (Native Hawaiians) to remain interconnected and holistically rooted to the *ʻāina*, culture, self, and to the *lāhui*. Assessing ecological drivers of habitat loss in combination with the construction of *Māmaki* and *Koʻokoʻolau* species distribution maps will provide natural resource managers a risk-assessment toolset to guide preservation and restoration efforts to combat habitat loss and improve habitat quality of medicinally important plants.

Data/methods:

For this study, quantitative and qualitative data was collected and analyzed to assess the individual and cumulative impacts of habitat loss of medicinal plants via urbanization, ecosystem-modifying invasive species, and ROD. Quantiative data was primarily obtained via multiple datasets available on the State of Hawai‘i, Office of Planning, Hawai‘i Statewide GIS Program. Construction of species distribution models (SDM) for *Māmaki* and *Ko‘oko‘olau* was developed using the program Maxent to project the current (2019) estimated habitat ranges in the district of Puna on Big Island, Hawai‘i. The program MAXENT is a popular SDM tool which uses the maximum entropy approach to model species distributions by comparing georeferenced species occurrence datasets to selected environmental (climatic) grids (Phillips et al. 2006). Models are fit in environmental space and subsequently projected into geographic space to provide an image of predicted environmental suitability. Datasets containing the georeferenced data came from a plethora of sources via the Global Biodiversity Information Facility (GBIF). In Maxent, minimum and maximum temperature data was clipped to fit the precipitation layer, two environmental variables used to overlay onto the species occurance dataset. For *Māmaki*, 72 occurance data points was used and randomly separated into two datasets (n = 36 each): one for calibration and testing of the model and a second dataset for projection of the model. During testing, a 25% (n = 9) random test percentage, 0.65 regularization multiplier, 1000 max number of background points, 15 replicates, with bookstrop was used; extrapolation and clamping was turned off and all other settings were left as default. Due to limited georeferenced data on *Ko‘oko‘olau* (n = 5) a SDM model was not constructed. Constructed species distribution models of *Māmaki* in combination with quantitative analyses from peer-reviewed sources was synthesized to characterize habitat loss of lowland rainforests and the dwindling suitable habitat of *Māmaki* and *Ko‘oko‘olau*. By assessing the individual and cumulative drivers of habitat loss for these medicinal plants, natural resource managers may implement suitable tactics to preserve these remaining rainforests of biocultural and ethnobotanical value.

Analysis:

The district of Puna on Hawai‘i Island (Fig. 1) is experiencing one of the highest rates of population growth in the Hawaiian Islands threatening the habitat quality and continued fragmentation of remaining lowland rainforests. In unaltred states these native forests once supported a rich diversity of flora and fauna and with increasing population growth, particularly within urban subdivisions is fueling a regime change from a native dominated to an invasive dominated landscape. Between the year 2000 and 2007, the census population was 31,335 which increased ~37% to 43,071 (“Puna Community Development Plan” 2008). This positive trend in population growth continued where by the year 2010, the population in Puna increased to 45,326, increasing ~45% from the year 2000 (The State of Hawaii Data Book 2017). Furthermore, the district of Puna contains nearly 45% of all subdivided parcels on Hawai‘i Island, yet only ~25% of these lots have been developed upon (“Puna Community Development Plan” 2008). Additionally, a majorty of the landscape is native-dominated (45%), and to a lesser degree contains 22% native/alien mix, and 17% is heavily disturbed (non-native dominent) (Fig. 2) (Jacobi et al. 2017). Unprecedented population growth in Puna will occur and will continue to place strains upon the surrounding natural resources where native dominated landscapes will likely decrease with population growth thus increasing the percentage of land in Puna that is non-native dominant. With an increase in population growth, the likelihood of additional ecological drivers of habitat loss, including invasive species introductions in addition to the increased pressure from the spread of Rapid *‘Ōhi‘a* Death are likely to continue.

Ecosystem modifying invasive plants (EMIP) have potential to single handedly or collectively displace and fragment native-dominated ecosystems, where a dominant EMIP presence places an increasing burden on the resiliency of native-dominated plant communities. Whereas naturalized non-native plants may adapt to various climate zones within Hawai‘i these species do not compete with native flora as EMIPs do. Two of the top 17 EMIPs in Hawai‘i are Strawberry Guava (*Psidium cattleianum*) and Miconia (*Miconia Calvescens*) (Figs. 3, 4) (Vorsino et al., 2017) whose suitable habitat will increase by the year 2100. One of the most noxious and invasive plants is Strawberry guava, which creates impenetrable dense thickets and is capable of invading over half (~120,000 ha) of all conservation lands on Hawai‘i Island (“Strawberry Guava: Not All Green Is Good”) as well as Miconia which occupies ~100 ha on

Hawaiʻi Island and quickly shades out native trees (Tavares, Kim 2002). Alien plant surveys conducted between 2000 and 2010 in Hawaiʻi Volcanoes National park quantified the distribution of 134 non-native plant species, which found 101 species had localized distributions and 33 species occupied widespread distributions within the park; there were sixteen species which were never previously record to occur within the park and an additional 15 species were found by Pratt et al. (2012) to be newly detected non-native species found within the park. In order to preserve native plants with limited geographical ranges, it is imperative that to manage the spread of EMIPs to allow for restoration of targeted plant species, such as *Māmaki* and *Koʻokoʻolau*. The control of EMIPs particularly within our natural area reserves and state forests are imperative to preserve what is one of the last remaining protected habitats containing intact ecosystems for cultural subsistence, gathering, and cultural integrity for future generations.

The threat of Rapid *ʻOhi'a* Death (ROD) will erode high-quality suitable habitats for the entire Island of Hawaiʻi—with possibility of mobilizing throughout the Hawaiian archipelago—unless paramount action to *mālama* (take care of) our forests are prioritized. When an *ʻŌhiʻa lehua* tree dies, the forest canopy allows nearby plant species to capitalize on the abundance of high-light which facilitates the dominance of non-native invasive species such as Strawberry guava and Miconia. ROD is associated with 2 invasive pathogens, a vascular wilt fungus (*Ceratocystis lukuohia*) and a canker pathogen (*Ceratocystis huliohia*) which is killing the *ʻŌhiʻa*, the most dominant/codominant tree in Hawaiʻi (Barnes 2018) (Fig. 5). ROD was first detected in 2010 in the Puna District and as of September 2017, over 40,000 ha have been affected on Hawaiʻi Island, with the greatest mortality densities and canopy loss occurring in Puna (Camp 2019). Furthermore, *ʻŌhiʻa* accounts for more than 50% of the total basal area of woody plants throughout the Hawaiian archipelago (Mortenson 2016). A majority of the current research revolving around ʻ*Ōhiʻa* is centered around rapid detection and control of *ʻŌhiʻa* trees and aerial footage to monitor the spread of the fungi. However, it is unclear how restoration goals are being implemented to deal with the decreasing *ʻŌhiʻa* abundance on Hawaiʻi Island. Future studies are suggested to explore native and non-native regeneration under dead *ʻŌhiʻa* stands as well as determining suitable restoration practices to manage the spread of invasive species. Managing these disturbances to the ecosystem are paramount while finding solutions to preserve and restore the habitat of *Māmaki* and *Ko'oko'olau* as well as other native flora in Hawai'i.

Suitable habitat of *Māmaki* and *Ko'oko'olau* in the district of Puna will continue to decline unless human intervention reconvenes for the preservation of these endemic green teas in Hawaiian lowland rainforests. While *Māmaki* (*Pipturus albidus*) occupies a wide bioclimatic envelope to survive in throughout the Hawaiian Islands, *Ko'oko'olau* (*Bidens hawaiensis*) is geographically restricted to the districts of Puna and Kohala on Hawai'i Island. Using data obtained from the Biodiversity Global Information Facility (GBIF), a species distribution model was created for *Māmaki* (*Pipturus albidus*) (Fig 6) using the program Maxent which closely matches the species distribution model created by Fortini et al. (2013) (Fig 7). However, due to the limited species occurance data for *Ko'oko'olau* (*Bidens hawaiensis*), a SDM was not possible to be constructed which suggests the limited abundance of this species. This corroborates with the SDM map (Fig. 8) where *Ko'oko'olau* occupies a small suitable habitat range in lower Puna. Furthermore, the SDM of *Māmaki* and *Ko'oko'olau* (Figs 8, 9) illustrate by the year 2100, the bioclimatic envelope where these plants currently occur at will shift higher due to changes in temperature and precipitation in Hawai'i driving the suitable habitat from lower elevations, where they will cease to exist at transitioning to higher elevations where a smaller percentage of suitable habitat is gained. By utilizing the SDMs of *Māmaki* and *Ko'oko'olau*, natural resource managers, particularly those in charge of the natural forest reserve systems and state forests and other community stakeholders may pinpoint suitable habitat for these endemic green teas for preservation and possible restoration. Using these SDMs provide the opportunity to assess suitable habitat worth investing to preserve and restore native plants within, particularly regarding *Ko'oko'olau* with its narrow biogeographic range.

Discussion:

This study analyzes the individual and cumulative stressors impacting the declining habitat and abundance for native flora—emphasizing *Māmaki (Pipturus albidus)* and *Ko'oko'olau (Bidens hawaiensis*)—in the district of Puna on Hawai'i Island. Furthermore, this study highlights how the current state of habitat quality of Hawaiian flora in the district of Puna emphasizing the urgency for mitigate adverse impacts to the environment from unprecedented population growth (Fig. 1), an expanding population of invasive species outcompeting native flora (Fig. 2-4), and the extent of *ʻŌhiʻa* mortality on habitat suitability. Furthermore, species distribution maps of *Māmaki* and *Koʻokoʻolau* illustrate the narrow bioclimatic envelope where these species currently and will in the future exist at (Figs 6-8); given no intervention, these species will continue to decline in population and abundance. Research has shown that *Māmaki* has demonstrated strong pioneering abilities reestablishing a clearcut forest (high cover and abundance) in lower Puna (Grossman 1992) and is capable to surviving and growing in low-light environments (Schulten 2014) which makes it potential candidate for ongoing, managed restoration projects. However, *Koʻokoʻolau* (*Bidens Hawaiensis*), a listed species of concern, occupies a much narrower and geographically isolated narrow band of suitable habitat in lower Puna (and Kohala) (Fig. 9); due to insufficient georeferenced data on *Koʻokoʻolau* (n = 5), a SDM was unable to be created which suggests the low abundance and limited habitat range of this species. Therefore, to mitigate the increasing loss of habitat quality and abundance for Native Hawaiian flora in Puna, it is paramount the County and State of Hawaii addresses population growth, maangement of EMIPs and restoration of ROD-impacted landscapes. Furthermore, SDMs of *Māmaki* and *Koʻokoʻolau* may be utilized to selectively target and guide restoration of these plants within their suitable habitat ranges.

The construction and enforcement of strict environmental policies that fulfill the vision of the Puna Community Development Plan are imperative to preserve some of the last remaining intact lowland wet and mesic rainforests and natural beauty of Puna. The district of Puna, County of Hawaiʻi, and State of Hawaiʻi should: 1) rezone a percentage of urban and agriculture lands to conservation lands in lowland rainforests, 2) hold major private landowners within the State of Hawaiʻi responsible for mutually beneficial ecosystem restoration projects, and 3) create a natural resource management task force to serve as a liaison between private and public stakeholders to fulfill the vision of protecting natural resources within the district of Puna. In 2008, The Puna Community Development Plan Steering Committee adopted a vision statement for Puna revolving around three themes: *Mālama I Ka ʻĀina* (take care of the land), growth management, and transportation, which states, "residents of Puna live in harmony with the *ʻāina* while promoting a sustainable vibrant local economy, healthy communities, and a viable transportation system that is accessible, friendly and safe for now and future generations" ("Puna

Community Development Plan" 2008). If this vision plan is to be fulfilled, mitigating the impacts of population growth on natural resources needs to be addressed, where nearly half (~45%) of all development on Hawaiʻi Island is occuring in Puna while also experiencing the highest growth rate of any district in the County of Hawaiʻi ("Puna Community Development Plan" 2008). Furthermore, increases in population growth will continue to increase the percentage of heavily disturbed land in Puna (17%) thereby reducing the relative percentage of native dominated (45%) ecosystems (Fig. 2). The construction of environmental policies aimed to preserve and restore the natural resources and beauty of the environment of Puna will work by mitigating the impacts of habitat loss. Without these policies, Hawaiian flora, including *Māmaki* and *Koʻokoʻolau* will face decreased resiliency to survive and adapt to a rapidly changing environment, thereby harming and fragmenting the Native Hawaiian community most through a direct assult on the *ʻāina* with decreasing habitat quality.

Conclusion

The individual and cumulative ecological drivers negatively impacting habitat loss and quality of lowland rainforests in the district of Puna are due to population growth, ecosystem-modifying invasive plants, and mortality of the *ʻŌhiʻa lehua*. Two plants are biocultural and ethnobotanical concern are *Māmaki* (*Pipturus albidus*) and *Koʻokoʻolau* (*Bidens hawaiensis*)—two endemic plants prepared as a herbal green teas and used in the traditional practice of *laʻau lapaʻau*—whose habitat range is decreasing thereby reducing its abundance for cultural subsistence. For Native Hawaiians who rely on maintaining their cultural practice of *lāʻau lapaʻau* and procuring plants used as medicine, a healthy forest is required to sustain the *lāhui* (community). Population growth in Puna is a major driver altering the natural ecosystem through conversion of lowland rainforests to urban residences. Additionally, another major threat to native flora is competition to survive against invasive species, such as Strawberry Guava (*Psidium cattleianum*) and Miconia (*Miconia malvescens*), two species which occupy significant areas of conservation forest on Hawaiʻi Island. Lastly, the recent emergence of two *Ceratocycstis* spp., capable of causing widespread mortality of *ʻŌhiʻa lehua*, is driving unprecedented regime changes of high-quality *ʻŌhiʻa* forests to potentially invasive-dominant landscapes. To preserve *Māmaki* and *Koʻokoʻolau*, targeted restoration efforts are necessary to restore these plants back into the landscape where they naturally occur at, particularly within conservation forests. Environmental policies aimed at a combination of rezoning agriculture and urban landscapes and creation of a Puna natural resource task force to foster the vision of *Mālama I Ka Puna* is necessary to follow through with the vision of the Puna Community Development Plan. These management actions are imperative to mitigate habitat loss of the Hawaiian lowland rainforests, particularly the native flora used in hula and lāʻau lapaʻau for current and future generations.

References:

U.S. Fish and Wildlife Service, 2012, Species reports—Listings and occurrences for Hawaii: U.S. Fish and Wildlife Service Environmental Conservation Online System, accessed at http://ecos.fws.gov/ tess_public/pub/stateListingAndOccurrenceIndividual.jsp?state=HI.

Price, Jonathan P., Samuel M. Gon, James D. Jacobi, and Dwight Matsuwaki. 2007. Mapping Plant Species Ranges in the Hawaiian Islands: Developing a Methodology and Associated GIS Layers." *Technical Report 8. Hawaiʻi Cooperative Studies Unit*.

Price, Jonathan P., and Warren L. Wagner. 2004. "Speciation in Hawaiian Angiosperm Lineages: Cause, Consequence, and Mode." *Evolution* 58 (10): 2185–2200. https://doi.org/10.1111/j.0014-3820.2004.tb01597.x.

Fortini, Lucas, Jonathan Price, James Jacobi, Adam Vorsino, Jeff Burgett, Kevin Brinck, Fred Amidon, et al. 2013. "A Landscape-based assessment of climate change vulnerability for all native Hawaiian plants." HCSU-044. Hawaiʻi Cooperative Studies Unit: University of Hawaiʻi at Hilo.

Price, Jonathan P., Samuel M. Gon, James D. Jacobi, and Dwight Matsuwaki. 2007. "Mapping Plant Species Ranges in the Hawaiian Islands: Developing a Methodology and Associated GIS Layers." *Technical Report 8. Hawaiʻi Cooperative Studies Unit*.

Carr, Gerald C. 2006. "Native Hawaiian Plant Genera." University of Hawaiʻi Botany Department. 2006. http://www.botany.hawaii.edu/faculty/carr/natives.htm.

Handy, Edward Smith Craighill, Mary Kawena Pukui, and Katherine Livermore. 1934. *Outline of Hawaiian Physical Therapeutics*. Bernice P. Bishop Museum Bulletin, 126. Honolulu, Hawaii.

Nagata, Kenneth M. 1971. "Hawaiian Medicinal Plants." *Economic Botany* 25 (3): 245–54.

Chun, Malcolm Naea. 1986. *Hawaiian Medicine Book: He Buke Laau Lapaau*. Honolulu, Hawaii: Bess Press, Inc.

Krauss, Beatrice H. 2001. *Plants in Hawaiian Medicine*. The Bess Press, Inc.

Kaaiakamanu, D.M, and J.K. Akina. 1922. Hawaiian Herbs of Medicinal Value, Found among the Mountains and Else Where in the Hawaiian Islands and Known to the Hawaiians to Possess Curative and Palliative Properties Most Effective in Removing Physical Ailments. Honolulu: Territory of Hawaii Board of Health.

Abbott, Isabella Aiona, and Charles H. Lamoureux. 1991. "A Survey of Hawaiian Medicinal Plants in the East Rift Zone of Kilauea Volcano." Report. http://evols.library.manoa.hawaii.edu/handle/10524/23386.

Kartika, H., Q. X. Li, M.. Wall, S. T. Nakamoto, and W. T. Iwaoka. 2007. "Major Phenolic Acids and Total Antioxidant Activity in Mamaki Leaves, *Pipturus Albidus*." *Journal of Food Science* 72 (9): S696–701. https://doi.org/10.1111/j.1750-3841.2007.00530.x.

Locher, C. P., M. T. Burch, H. F. Mower, J. Berestecky, H. Davis, B. Van Poel, A. Lasure, D. A. Vanden Berghe, and A. J. Vlietinck. 1995. “Anti-Microbial Activity and Anti-Complement Activity of Extracts Obtained from Selected Hawaiian Medicinal Plants.” *Journal of Ethnopharmacology* 49 (1): 23–32. https://doi.org/10.1016/0378-8741(95)01299-0.

“Puna Community Development Plan.” 2008. File. Hawaiʻi County Planning Department Community Development Plans. 2008. https://www.hawaiicountycdp.info/puna-cdp/draft-plan-recommendations/1%20%20Puna%20CDP%20amended%20Nov-2011.pdf.

The State of Hawaii Data Book. 2017.

Jacobi, James D, Jonathan P Price, Lucas B Fortini, Gon III M Samuel, and Paul Berkowitz. 2017. “Hawaii Land Cover and Habitat Status.” U.S. Geological Survey. https://doi.org/10.5066/f7db80b9.

Ziegler, Alan C. 2002. *Hawaiian Natural History, Ecology, and Evolution*. Honolulu, Hawaii: University of Hawaii Press.

“Strawberry Guava: Not All Green Is Good.” 2016. Pacific Southwest Research Station. 2016. https://www.fs.fed.us/psw/topics/biocontrol/strawberryguava/strawberry_guava.shtml.

Tavares, Kim. 2002. “Emergency Environmental Workforce Hilo April 15, 2002 - Final Report.” Big Island Invasive Species Committee. http://www.hear.org/operationmiconia/eewfnewsehawaii.html.

Vorsino, Adam E., Lucas B. Fortini, Fred A. Amidon, Stephen E. Miller, James D. Jacobi, Jonathan P. Price, Sam ’Ohukani’ohi’a Gon, and Gregory A. Koob. 2014. “Modeling Hawaiian Ecosystem Degradation Due to Invasive Plants under Current and Future Climates.” *PLoS ONE* 9 (5). https://doi.org/10.1371/journal.pone.0095427.

Nālehualawakuʻulei. “Wao Kele o Puna Comprehensive Management Plan.” 2017.

Phillips, Steven, Miroslav Dudík, and Robert E. Schapire. n.d. “Maxent.” Accessed June 19, 2019. https://www.gbif.org/en/tool/81279/maxent.

GBIF.org. Accessed June 29, 2019. GBIF Occurrence Download https://doi.org/10.15468/dl.itumi0.

Barnes, I., A. Fourie, M.J. Wingfield, T.C. Harrington, D.L. McNew, L.S. Sugiyama, B.C. Luiz, W.P. Heller, and L.M. Keith. 2018. “New Ceratocystis Species Associated with Rapid Death of Metrosideros Polymorpha in Hawai’i.” *Persoonia : Molecular Phylogeny and Evolution of Fungi* 40 (June): 154–81. https://doi.org/10.3767/persoonia.2018.40.07.

Camp, Richard J., Dennis A. LaPointe, Patrick J. Hart, Daniel E. Sedgwick, and Lisa K. Canale. 2019. “Large-Scale Tree Mortality from Rapid Ohia Death Negatively Influences Avifauna in Lower Puna, Hawaii Island, USA.” *The Condor: Ornithological Applications* 121 (2). https://doi.org/10.1093/condor/duz007.

Schulten, Jodie R., T. Colleen Cole, Susan Cordell, Keiko M. Publico, Rebecca Ostertag, Jaime E. Enoka, and Jené D. Michaud. 2014. “Persistence of Native Trees in an Invaded Hawaiian

Lowland Wet Forest: Experimental Evaluation of Light and Water Constraints." *Pacific Science* 68 (2): 267–85. https://doi.org/10.2984/68.2.7.

Grossman, Dennis Howard. 1992. "Early Recovery of a Hawaiian Lowland Rainforest Following Clearcutting at Kalapana on the Island of Hawaii." Ph.D., United States -- Hawaii: University of Hawai'i at Manoa. http://search.proquest.com/docview/304001718/abstract/D9D07593A9494567PQ/1.

"Rapid '*Ōhi'a* Death." n.d. Accessed July 1, 2019. https://www.arcgis.com/apps/MapJournal/index.html?appid=744195474c3747d2a954f3a1855a41cd.

Pukui, Mary, E.W. Haertig, and Catherine Lee. 1972. *Nānā I Ke Kumu (Look to the Source)*. Vol. 1. Honolulu, Hawaii'i: Hui Hānai.

RStudio Team (2015). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA. http://www.rstudio.com/.

Tabrah, Frank, and B.M. Evelith. 1966. *Evaluation of the Effectiveness of Ancient Hawaiian Medicine*.

Figures:

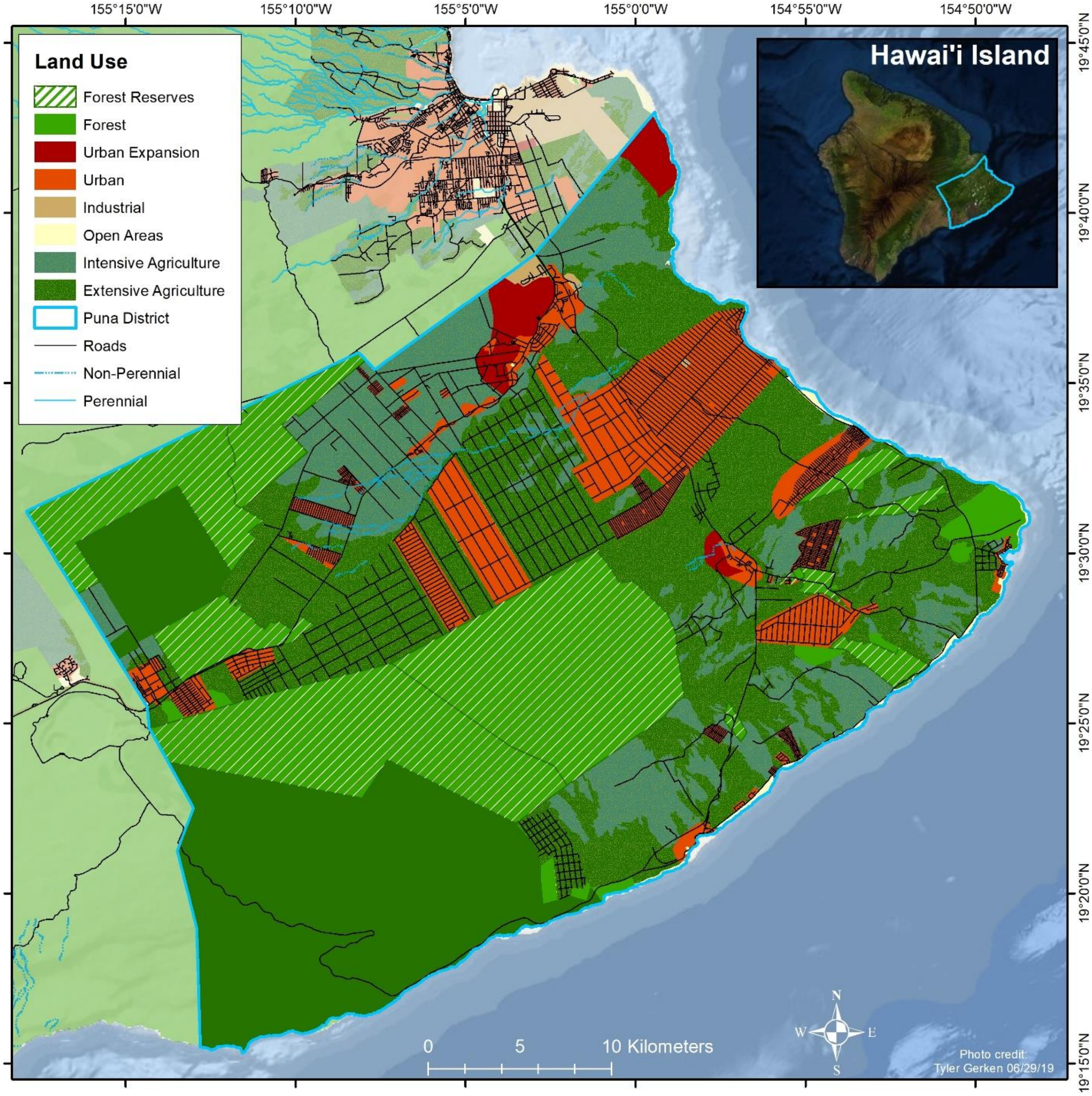

Figure 1*:* Land use map of the district of Puna, *Hawai'i* Island, *Hawai'i*. Total land is estimated at 1300 km^2 comprised of: conservation forest: 558 Km^2 (43%), urban: 179 Km^2 (14%), open areas: 9 Km^2 (1%), and agriculture: 556 Km^2 (43%).

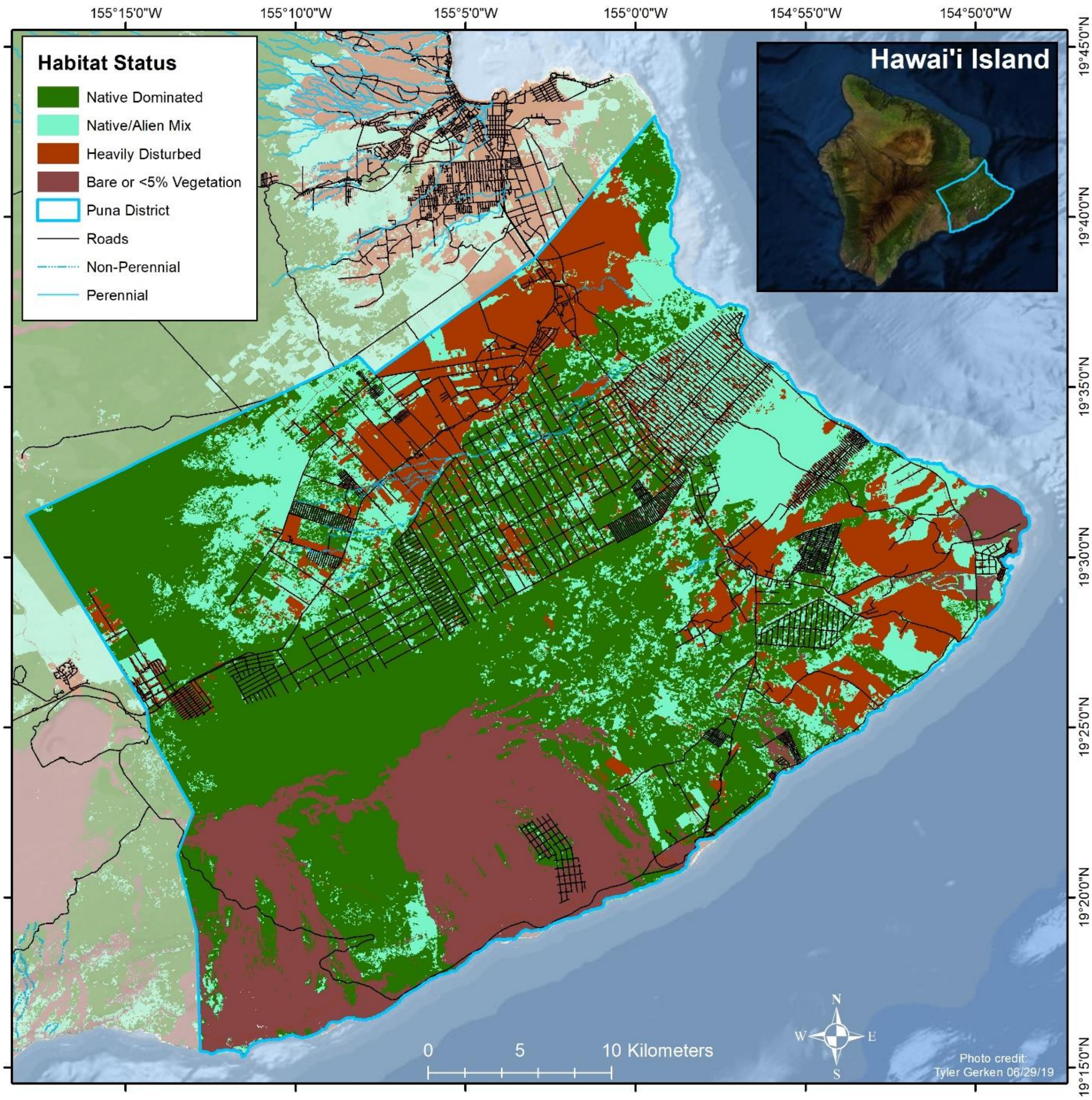

***Figure 2**:* Habitat status map of the district of Puna, *Hawai'i* Island, *Hawai'i*. Habitat status is estimated to be: native dominated: 579 Km^2 (45%), native/alien mix: 284 Km^2 (22%), heavily disturbed: 225 Km^2 (17%), and bare or <5% vegetation: 213 Km^2 (16%). Habitat status data obtained via Jacobi et al. (2017) and analyzed in ArcGIS for the district of Puna.

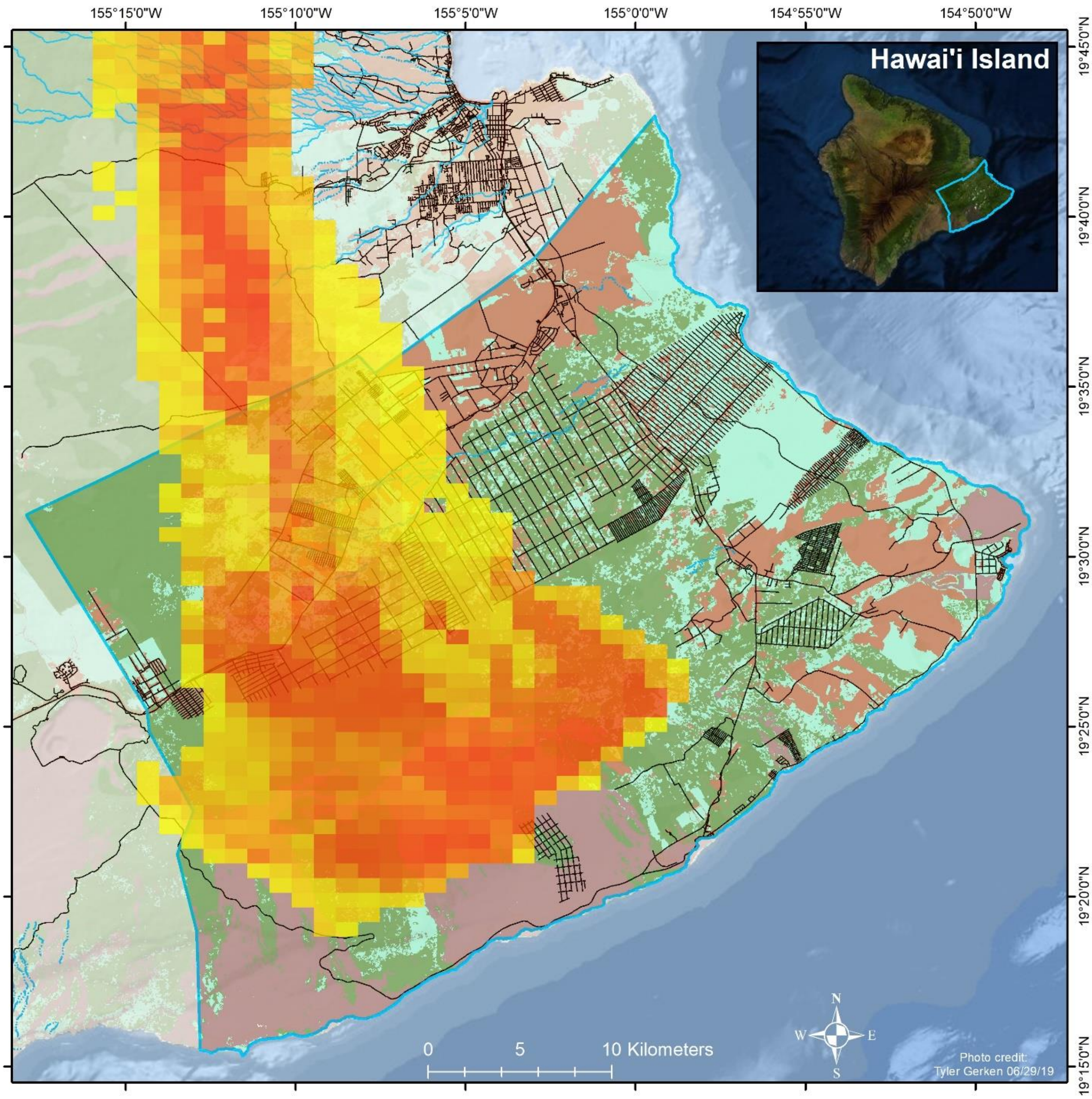

Figure 3: Current (2013) species distribution model/invasibility suitability index of Strawberry Guava (*Psidium cattleianum*) in the district of Puna, *Hawai'i* Island, *Hawai'i*. Invasibility suitibility index of Strawberry guava data was obtained via Vorsino et al. (2014).

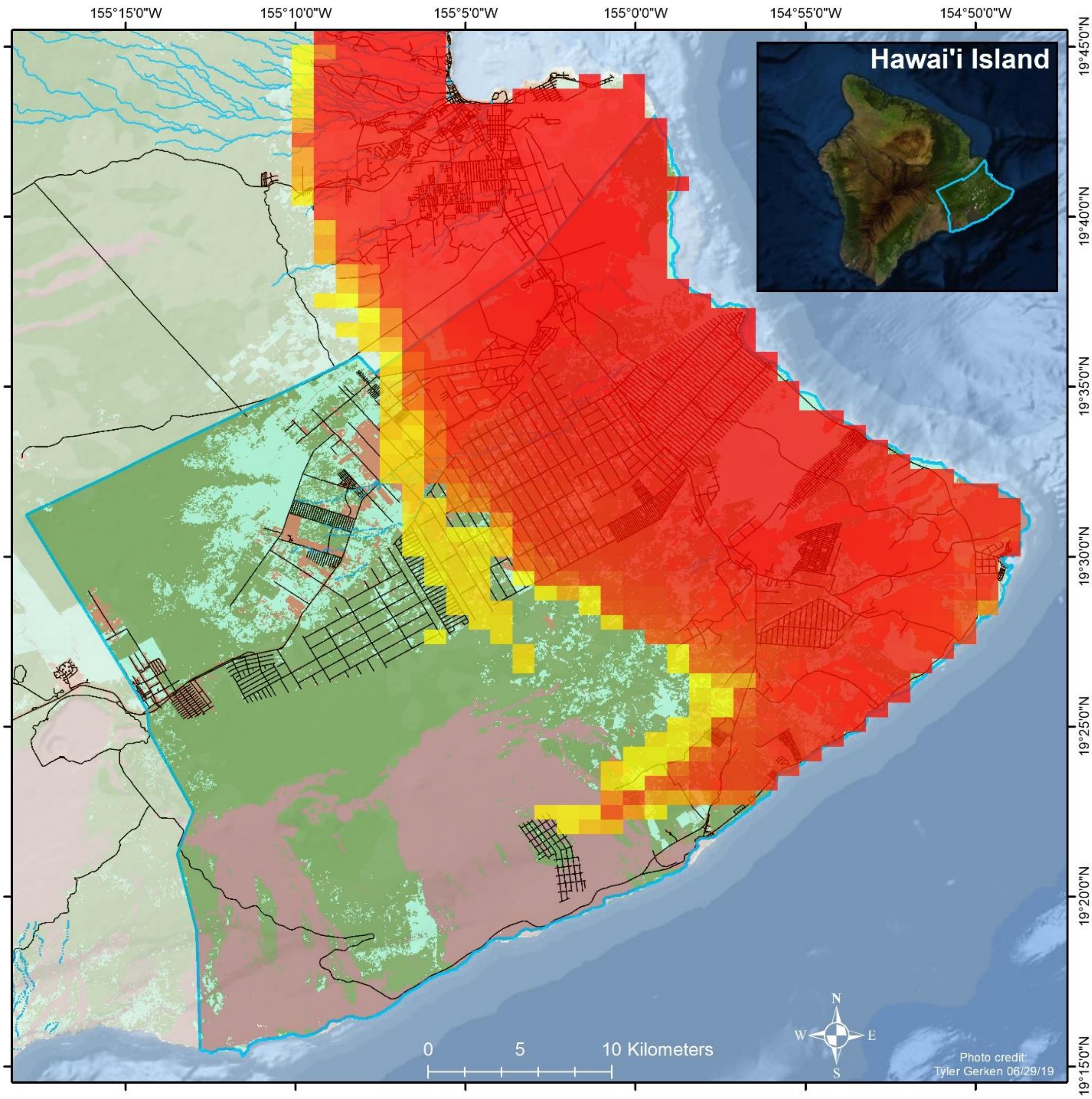

Figure 4: Current (2013) species distribution model/invasibility suitability index of Miconia (*Miconia Calvenscens*) in the district of Puna, *Hawai'i* Island, *Hawai'i*. Invasibility suitibility index of Miconia data was obtained via Vorsino et al. (2014).

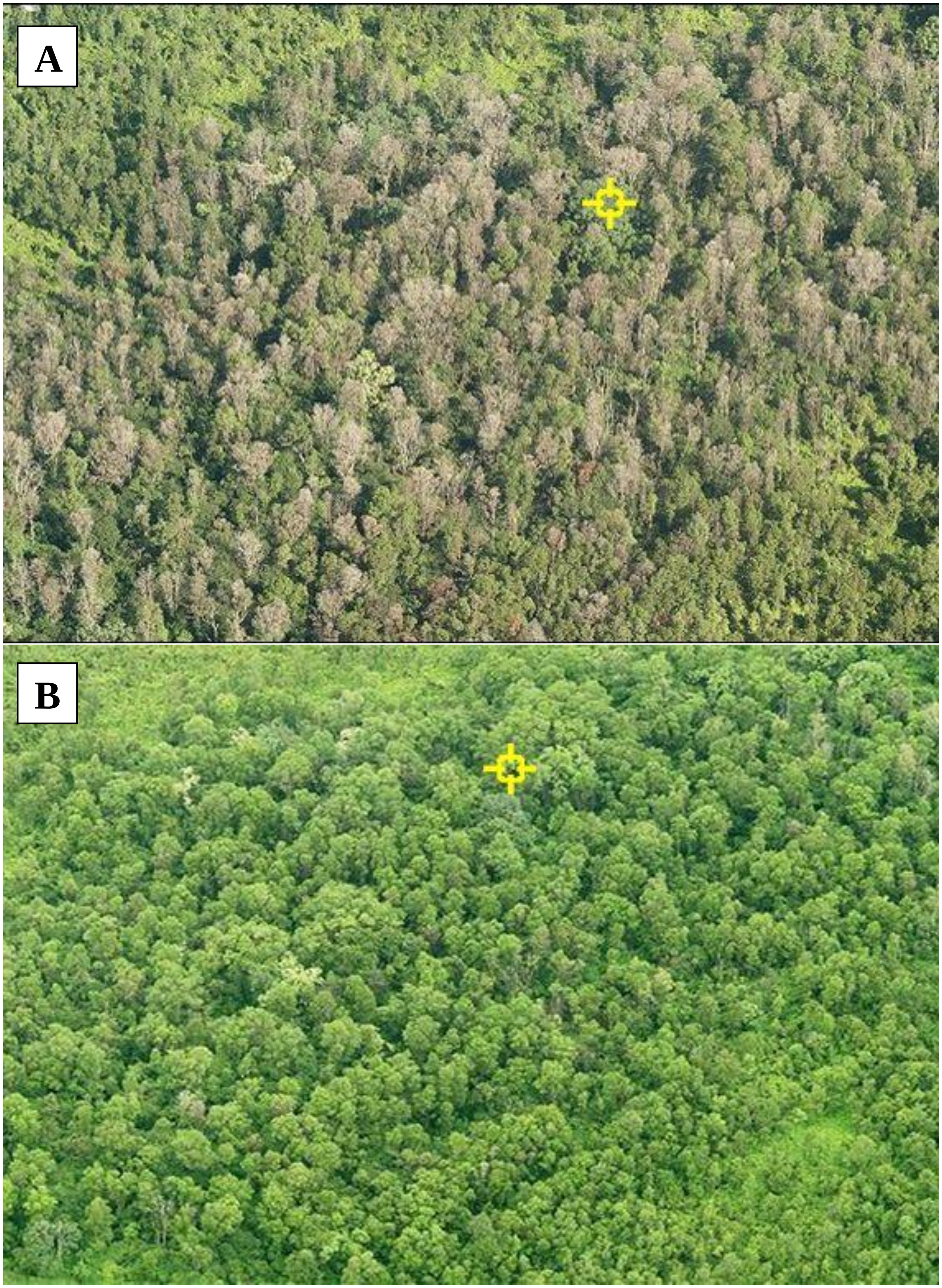

Figure 5: **A**: Forest canopy before Rapid *'Ōhi'a* Death (ROD) (2008); **B**: Forest canopy after (ROD). Photos obtained via "Rapid *'Ōhi'a* Death".

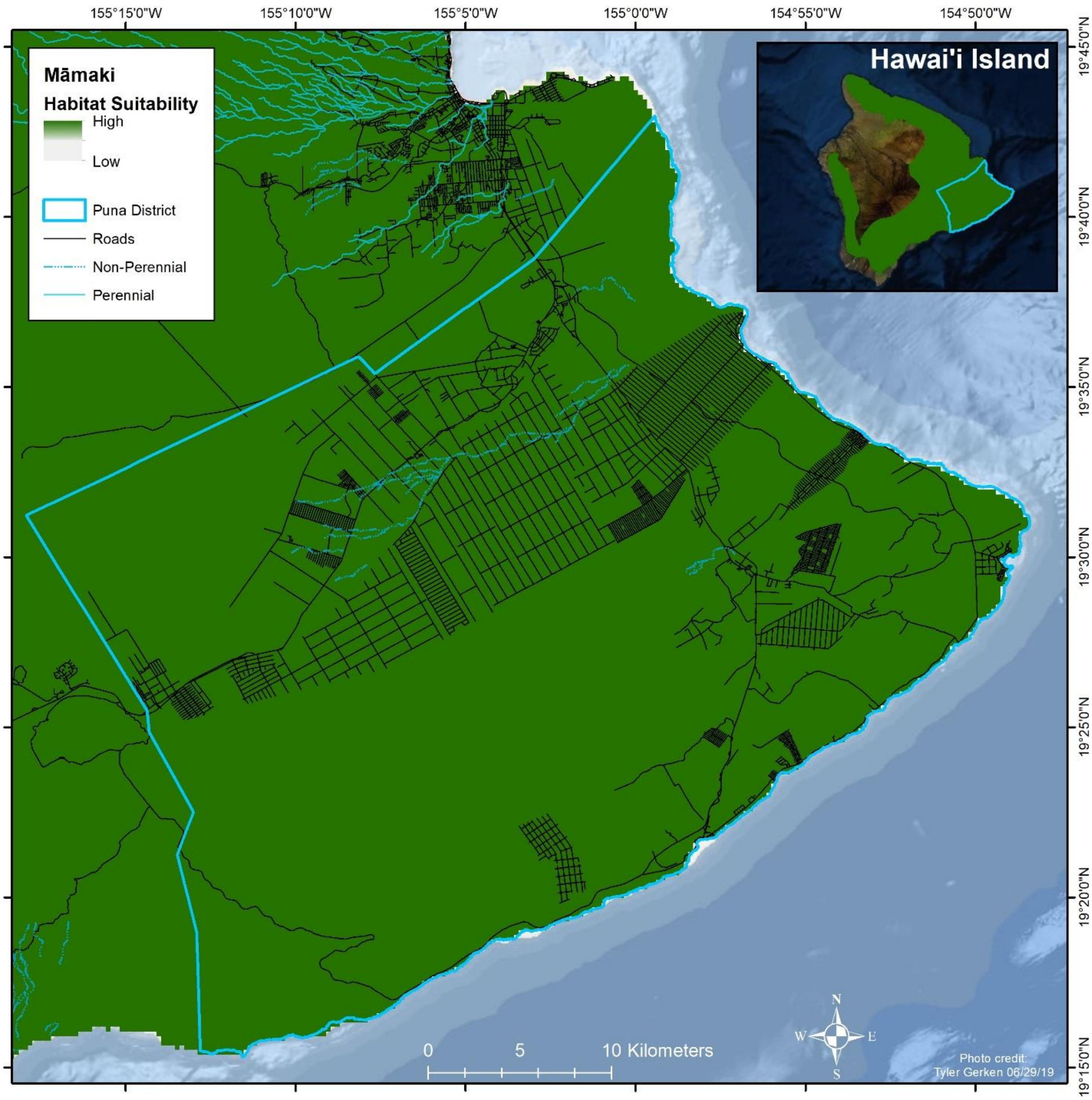

Figure 6: Species distribution model of *Māmaki* (*Pipturus albidus*) on *Hawai'i* Island, *Hawai'i*. Species Distribution Model was created using the program Maxent using data obtained via the Global Biodiversity Information Facility (GBIF) overlaid with rainfall and minimum/maximum atmospheric temperature data.

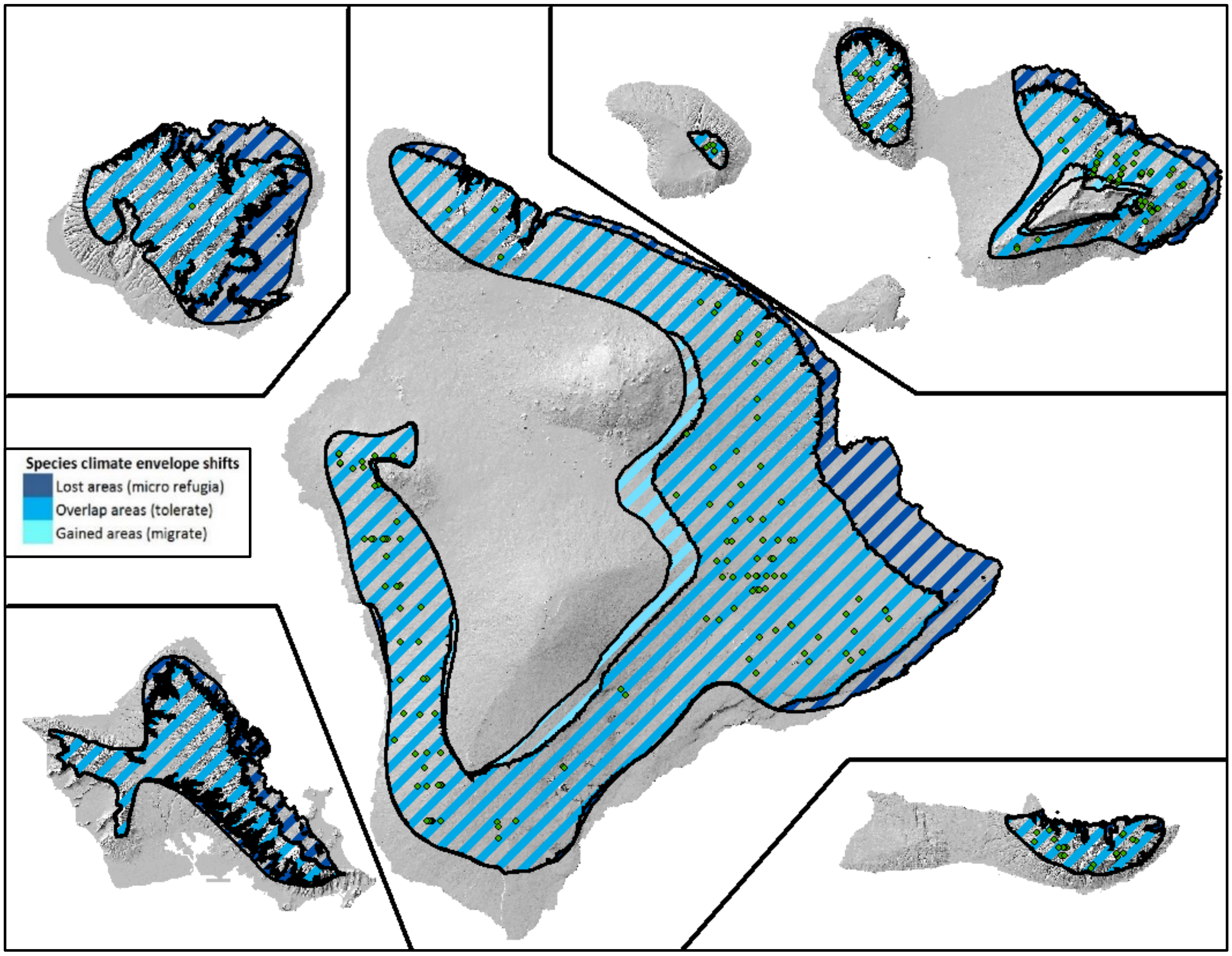

Figure 7: Projected response zones of *Māmaki* (*Pipturus albidus*) throughout *Hawai'i* based on current and future climate-compatible areas by the year 2100 (Fortini et al. 2013).

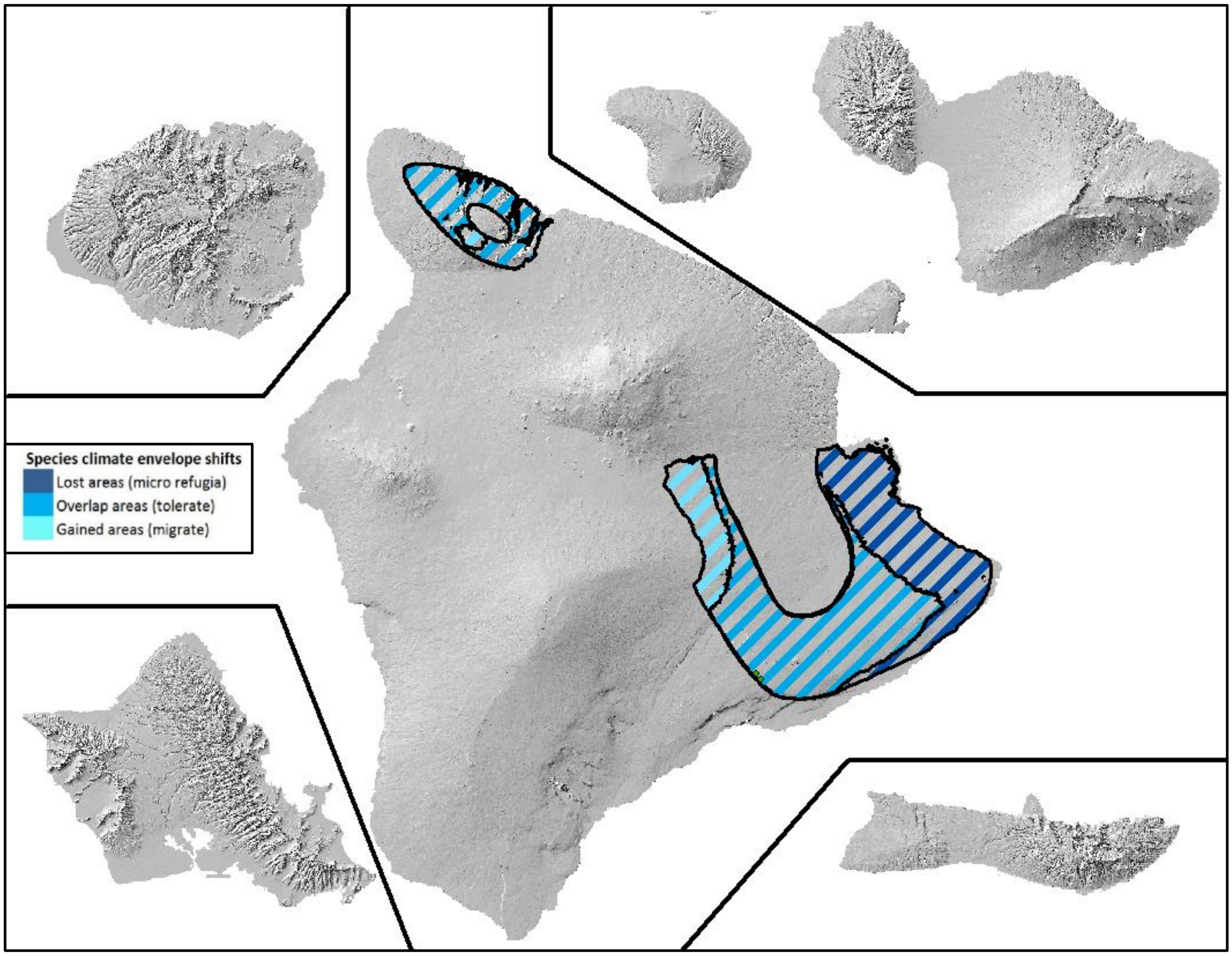

Figure 8: Projected response zones of *Ko'oko'olau* (*Bidens hawaiensis*) throughout *Hawai'i* based on current and future climate-compatible areas by the year 2100 (Fortini et al. 2013).