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Technical Report 179

The distribution of invasive plant species of concern in the Kīlauea and Mauna Loa strip areas of Hawai'i Volcanoes National Park, 2000-2010

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*The authors' use of trade names is for descriptive purposes only and does not imply endorsement by the National Park Service

ABSTRACT

Alien plant surveys conducted between 2000 and 2010 in Hawai‘i Volcanoes National Park quantified the distribution of 134 alien plant species over 87,908 ha between sea level and 4,169 m elevation. Searches were conducted by foot, vehicle and helicopter and incorporated past survey and control data. Mapping identified 33 widespread species distributed broadly across the park and 101 locally distributed species with fewer, more discrete populations. Sixteen species were incipient invaders not previously known from the park, and an additional 15 new species were identified in a separate survey by Pratt et al. Relatively high concentrations of invasive species were found along roadsides and trails, particularly in the Kīlauea summit area, `Āinahou, the Mauna Loa rock quarry and Highway 11, where heavy visitation, high traffic, and importation of road building materials likely facilitated introduction and spread of species from outside areas. A geodatabase documenting the distribution of these species was generated, and survey data were compared to previous studies (Fosberg 1966; Tunison et. al. 1992) to evaluate changes in distribution and serve as a baseline for monitoring. Relative to the last parkwide mapping of localized species completed in 1992, eight species managed to control populations were found to have increased in abundance, while 30 apparently became less abundant. Thirteen managed species could not be relocated and may be extirpated. Key management recommendations based on survey results include expanding control to 13 additional species identified during this study, quickly eradicating all newly discovered species before they spread, intensifying monitoring in high risk areas, and expanding pre-emptive measures such as sanitation, public education, and prevention of deliberate plant introductions to the park.

INTRODUCTION

Alien plant invasions are a serious threat to natural areas worldwide (Elton 1958, Vitousek et al. 1997). Invasion by plants can disrupt the biological integrity of invaded communities and reduce the abundance of native species (Meyer and Florence 1996, D'Antonio et al. 1998). Besides contributing to the extinction of plant and animal species, alien plants may alter the function of the invaded ecosystem, by changing nutrient, water and fire regimes (Vitousek and Walker 1989, D'Antonio and Vitousek 1992, Sala et al. 1996).

Alien plants threaten the biological resources of U.S. National Parks (Loope 1992) and alien plant control has become an integral component of natural resource management programs to prevent invasions, eradicate incipient populations, and mitigate the impacts of widespread species. Notoriously invasive plants, including miconia (*Miconia calvescens*), tamarisk (*Tamarix* spp.), and Brazilian pepper (*Schinus terebinthifolius*) have become illustrative of the battle against invasive alien plants in U.S. national parks and other conservation lands.

Hawai‘i’s national parks rank among the most impacted by alien plants (Loope 1992). Of the ~915 vascular plant species in Hawai‘i Volcanoes National Park (HAVO), two

thirds are alien (Higashino et al. 1988). While many of these species pose little threat to native ecosystems, over 100 alien species are managed or monitored for their potential to displace native plants or alter ecosystem properties. Included are incipient invaders whose impacts have not been evaluated.

Frequent monitoring of the distribution and abundance of invasive plants is an important component of alien plant control programs (Blossey 1999). Monitoring identifies species which impact plant communities and permits the development of control strategies based on occurrence and invasibility. Over time, monitoring data can be analyzed to detect trends in invasive plant establishment and spread, or coupled with control data to evaluate management actions and strategies. Frequent monitoring may also locate new or previously undetected weed populations that may warrant control.

Alien plant control strategies in HAVO are grouped into two different approaches, depending on the distribution of the target weed. A localized approach is used for species with discrete populations with relatively few individuals or a limited spatial extent. In these instances, the strategies are to contain or eradicate the plant. A second approach is to exclude selected species from high priority areas known as Special Ecological Area (SEAs), and is used for species that are more widespread and where parkwide control is not feasible. SEAs are selected based on attributes including representativeness, manageability, and value for research and interpretation (Tunison 1992).

The last parkwide mapping of 41 alien plant species occurred from 1983-1985 (Tunison et al. 1992), in the same area as the present study. Species targeted for mapping were those identified as localized in distribution and listed as target species of concern in the 1982 Resources Management Plan (National Park Service 1982), This information, as well as mapping of a few widespread species in separate studies (Whiteaker and Gardner 1985, Stratton 1996, Loh et al. 2000) has provided the framework for management. Since then, distributions have changed, new species have invaded the park, and overlooked populations have been identified. The present survey summarizes the distribution of 134 alien species in the Kīlauea and Mauna Loa units of HAVO (87,908ha). These include 40 of the original species mapped and 94 additional species that are considered invasive or potentially disruptive. The purpose of this study is to provide management recommendations for these species based on distribution, threats, and control efforts, and to evaluate the effectiveness of park control efforts over time. The occurrence of alien species in the recently acquired Kahuku unit (61,053ha) is summarized in a separate report (Benitez et al. 2008).

THE SURVEY AREA

The Mauna Loa and Kīlauea units of HAVO total 87,908ha, extending from sea level to 4,169 m elevation. A wide range of vegetation communities are found in these areas, including coastal strand, dry grasslands, mesic and wet forests, sub-alpine and alpine shrublands, and pioneer communities. Approximately 60% of the survey area is barren

(<10% vegetation cover) including recent (0-200 years old) lava flows and alpine environments above 2,500 m elevation where vegetation development is minimal.

The park vegetation has been characterized by six ecological zones based on climate and elevation by Mueller-Dombois (1976). These are coastal lowland, submontane seasonal, montane wet forest, montane seasonal, subalpine, and alpine (Figure 1).

Rainfall in the Hawaiian Islands is principally the result of the interaction between prevailing northeast tradewinds and the physical geography (Giambelluca and Schroeder 1998). Orographic effects result in rainfall maxima occurring along windward slopes, and leeward climates being dry. In HAVO, rainfall maxima exceeds 3,000 mm/year in the windward montane wet forest ecological zone, which includes ʻŌlaʻa and the windward section of the East Rift zone. The Kīlauea summit and the remainder of the East Rift receive less rainfall, between 2,000 and 3,000 mm/year. Rainfall decreases abruptly west of the Kīlauea summit area and across lower elevations; greater than one-half of the Kīlauea unit receives<1,500 mm/year rainfall, and the southwestern quarter of the Kīlauea unit of HAVO receives<1,000 mm/year (Hawai`i Division of Water and Land Development 1970). Alpine zones above 2,500 m elevation are also dry (<1,000 mm/year), due to the presence of a persistent inversion layer. These areas receive most of their rainfall in winter months when low pressure systems originating to the south of Hawaiʻi cause the tradewinds to fail (Giambelluca and Schroeder 1998).

The survey area is bounded by public and privately owned lands. Bordering State lands are managed by the Hawaii Department of Land and Natural Resources Division of Forestry and Wildlife (DLNR-DOFAW) and include (counter-clockwise from east) the Kahauleʻa Natural Area Reserve, ʻŌlaʻa Forest Reserve, Puʻu Makaʻala Natural Area Reserve, Mauna Loa Forest Reserve, Kapāpala Forest Reserve, and the Kapāpala Cooperative Game Management Area (Figure 2). The Office of Hawaiian Affairs (OHA) owns and manages the Wao Kele ʻO Puna reserve, which borders the park along Kīlauea's East Rift. The Keauhou Ranch, along the eastern boundary of the park's Mauna Loa unit, is owned and managed by Kamehameha Schools. The State lands, the Keauhou Ranch, and HAVO are part of the Three Mountain Alliance, a watershed management partnership encompassing over 400,000 ha on Kīlauea, Mauna Loa and Hualālai volcanoes.

Residential areas bounding the park include Volcano Village and the Volcano Golf Course Subdivision, near the Kīlauea summit area. W.H. Shipman lands also border the park here. A mixture of residential and agricultural lots can be found in Volcano Village, all others are generally residential use. Along the park's eastern boundary, the Royal Gardens subdivision has been mostly uninhabited after lava flows from Kīlauea's Puʻu `Ō`ō vent began in 1984, and other private lands comprise the remainder of the boundary.

In 2003, the Kahuku addition to HAVO (61,053ha) was acquired. This unit connects to the Mauna Loa unit near the summit area, but is otherwise disjunct from the original sectors of the park.

METHODS

Field work was largely conducted from January of 2001 to September 2003, and distributions were continually updated using control records and additional searches from 2003-2010. A variety of survey methods were used including ground, roadside, and aerial surveys. Initial surveys were conducted by foot along human transportation corridors such as roads, trails and fencelines within the older section of HAVO that included the Mauna Loa Strip and Kīlauea units (Figure 2). These surveys occasionally extended up to 500 m beyond park boundaries. The presence/absence of 40 weedy species identified by Tunison et al. (1992), as well as 94 additional species noted in HAVO Vegetation Management alien plant control databases and selected potentially invasive species was mapped (Table 1). Newly established alien species, not noted by Higashino et al. (1988), were also recorded, as were species recommended for mapping by local experts (K. Bio, L. Pratt, R. Warshauer). In a separate survey effort, many new species were discovered by (Pratt et al. *In review*) during a roadside survey, these findings are presented in the results section.

The survey areas included 137 km of roads, 120 km fences, and 175 km of trails (Figure 3). Point locations were recorded using a handheld GPS unit generally accurate to ~5 m in open areas, and ~10 m in forest. Point locations were recorded at 10-50 m intervals, and the data included the observers name, the approximate location, and the estimated precision of the waypoint. These initial surveys were designed to direct future searches and identify range extent of target species, and indicated only presence of identifiable individuals as observed from trails, roads and fences. Detailed population size or density information was not collected at this time.

Results from these surveys were input into Microsoft Excel, and plotted in a GIS (ArcView 3.x, ArcMap 8.x-9.x). This information was used to prepare preliminary distribution maps of target weeds along particular corridors, and these findings were used to direct further surveys.

Additional field work focused on resurveying previously documented alien plant populations controlled by park staff, and populations mapped by Tunison et al. (1992). Searches extended 50 to 500 m distance from the known edge of the population, depending principally on the plant's dispersal mechanism (Staples et al. 2000) or invasiveness. Additional areas with a history of frequent species introductions (e.g., park headquarters and residential areas, `Āinahou ranch) were intensively surveyed (Figure 4), and a population census was made with point locations of weeds targeted for mapping.

Field surveys located away from human transportation corridors varied by area and target species. Forty transects, totaling 79 km, were surveyed, principally on Mauna Loa, Kīlauea's East Rift, and Hilina Pali. Along transects, weed abundance was quantified in 5, 10 or 50 m wide belts in 10, 50, or 100 m segments along each transect, depending on the vegetation and visibility. Percent cover abundance of each species was estimated using modified Daubenmire percent cover classes (1 = 0-1%, 2 = 1-5%, 3 = 5-10%, 4 = 10-25%, 5 = 25-50%, 6 = 50-75%, 7 = 75-95%, 8 = >95% (Mueller-Dombois and Ellenberg 1974). Additional GPS point locations data were collected for infrequent individuals observed near transects but not within the belt, as well as elsewhere in transit to transects. This dataset was augmented by 1998 transect data from the ʻŌlaʻa unit, encompassing 19 transects spanning 61 km. These transects had segments 50 m long and 5 wide, and utilized similar modified Daubenmire percent cover classes (1 = 0-1%, 2 = 1-5%, 3 =5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-95%, 7= >95% (Mueller-Dombois and Ellenberg 1974).

Approximately nine hours of helicopter time was spent searching for alien plants in primarily open environments of Mauna Loa, coastal lowlands, and western portions of Kīlauea. Surveys targeted species with prominent aerial signatures (e.g., silk oak, olive, koa haole, fountain grass, kāhili flower, Formosa koa, faya tree). A 50 x 50 m GIS grid was developed to map invasive silk oak and koa haole along open areas.

Survey data were converted to point features in the GIS, and stored as projected feature classes in an ArcGIS Geodatabase. Aerially detected populations were occasionally sketch mapped; these maps were transferred to a GIS data layer by on-screen digitizing. Maps for all localized species were generated from the data set. Maps of selected widespread species were generated by drawing a polygon around all confirmed point locations and incidental field observations in the GIS.

Survey work includes data from January 1, 2000 through May, 2010. Control summaries include data through May, 2010. Prior to 2001, alien plant records were recorded on paper data sheets (Appendix A) and stored in a filing cabinet. In 2001, all existing control records were migrated to a Microsoft Excel spreadsheet. Subsequent alien plant control work was recorded on data sheets and filed as previously described, and the Excel spreadsheet was updated with these records. In 2003, a Microsoft Access database was designed and populated with control records from localized species (i.e., incipient invaders or those with restricted distributions). Records for control of widespread species in special management units known as Special Ecological Areas (SEAs) are recorded on separate datasheets and are maintained in Microsoft Excel file format (Appendix B).

Nomenclature presented for naturalized species follows Wagner et al. (1999), including 2003 supplemental information. Ornamental species not naturalized in Hawaiʻi follow nomenclature presented by Staples and Herbst (2005). Species not noted by Higashino et al. (1988), including 1998 supplemental data by L. W. Pratt, were considered new to HAVO. Species reported in cultivation by Higashino et al. (1988)

were considered deliberately planted and not naturalized; these were found primarily in the park's residential area, Kīlauea Military Camp (KMC) or ʻĀinahou.

RESULTS

The distribution of 134 species was mapped (Table 1). A total of 101 species had localized distributions, with relatively small, discrete populations, and 33 species were more widespread. These widespread species were not mapped in detail, but range extents were estimated from data collected during surveys, and augmented with previous mapping and control data.

Sixteen new alien species were found in the Mauna Loa or Kīlauea units of HAVO (per Higashino et al. 1988) (Table 2), all with localized distributions. Twelve of these were found <50 m from a roadside, trail, or visitor lookout and eight of these were in the Kilauea summit area. An additional 15 species new to HAVO were discovered during roadside surveys in 2001 by Pratt et al. (*In review*) (Table 3), primarily along Highway 11 and Crater Rim Drive.

Detailed species accounts for the 134 species mapped are presented below in alphabetical order by scientific name, followed by a discussion and recommendations for park management. Point location maps for all localized species and polygon range maps for selected widespread species are presented in Appendix C.

INDIVIDUAL SPECIES DISTRIBUTIONS

Abrus precatorius L. (Black-eyed Susan)

Black-eyed Susan (*Abrus precatorius*) is a leguminous vine of paleotropical origin, cultivated in Hawaiʻi for its ornamental, yet poisonous seeds (Staples and Herbst 2005). Plants are naturalized in low elevations throughout at least Niʻihau, Kauaʻi, Molokaʻi, Maui, and Hawaiʻi (Wagner et al. 1999). Motooka et al. (2003) consider black-eyed Susan a weed of pastures in Hawaiʻi on account of the poisonous seeds.

Black-eyed Susan populations were previously known from eastern HAVO below 500 m elevation. In 1978, plants were collected at the base of Kamoamoa pali by G. Clarke (HAVO # 6044), and in 1980 plants were mapped at the Waha‘ula nature trail, an unspecified location in the Kalapana extension, and an upland site along the Kalapana trail at 490 m elevation (HAVO 1980a). In 1988 Cuddihy and Kageler (HAVO # 10355) collected several plants at Kamoamoa village near sea level. The populations at Waha‘ula and Kamoamoa have since been covered by lava. Black-eyed Susan has never been controlled in HAVO.

The Kalapana trail population is apparently extant, as several plants were found in native lama/‘ōhi‘a forest at 490 m elevation during firefighting operations in 2002. Two clusters of 1-5 plants were noted, these were separated by 250 m. No additional black-eyed Susan was found elsewhere in HAVO during field surveys.

Because of recent lava flows and wildfires, a resurvey of the Kalapana trail population is recommended to determine the populations’ current extent. Relatively few plants were mapped in a rare community type and this vine belongs to a family (Fabaceae) overrepresented among natural area invaders (Daehler 1998). Therefore eradication is recommended if population size permits. Motooka et al. (2003) recommend Triclopyr based herbicides.

The common name black-eyed Susan vine is also applied to the unrelated *Thunbergia alata* (Acanthaceae) (Wagner et al. 1999), a vine naturalized at higher elevations in Volcano and elsewhere in Hawai‘i.

Acacia confusa Merr. (Formosa koa)

Formosa koa (*Acacia confusa*) is a leguminous tree with yellow flowers and phyllodial leaves native to the Philippines and Taiwan (Wagner et al. 1999). Formosa koa is cultivated throughout Hawai‘i, and naturalized in dry to mesic disturbed areas on all the major islands except Ni‘ihau (Wagner et al. 1999). Formosa koa was extensively planted in Hawai‘i for reforestation and erosion control (Little and Skolmen 1989), and was likely intentionally introduced to the park at ‘Āinahou. Higashino et al. (1988) classified Formosa koa as a disruptive weed in HAVO, found in the sub-montane seasonal zone and in cultivated areas (i.e., ‘Āinahou and park headquarters). Mapping from 1983-1985 (Tunison et al. 1992) identified a population spread across 100 ha at the ‘Āinahou Ranch and a small population along the Keauhou Trail. In 1992 an additional individual was mapped and removed from Kīpuka Kahali‘i.

Recent mapping identified less than 100 Formosa koa in HAVO. The most extensive population was located at the ‘Āinahou Ranch and consisted of mature trees and seedlings in ten disjunct clusters over 130 ha of alien grasslands and ‘ōhi‘a woodlands between 820 and 940 m elevation. Five of these clusters have been controlled annually since 1984; these had 65 seedlings and no mature individuals in 2003, and five newly discovered clusters had 17 mature plants and no seedlings. Three clusters, previously mapped in 1985 (Tunison et al. 1992) were no longer evident and are presumed extirpated.

Tunison et al. (1992) reported a similar range extent and elevation distribution (100 ha, 820-935 m) for Formosa koa at this site, but described a more continuous distribution that suggests a greater former abundance. Control work may be responsible for the observed reduction in abundance; since 1984, 4,187 Formosa koa have been removed from ‘Āinahou.

The park's lowest elevation Formosa koa population was found along the Keauhou Trail at 85 m elevation where several individuals were mapped by Tunison et al. (1992). From 1986-1997, 788 individuals were pulled at this site; and in 2007 the 13 mature trees were controlled with a basal bark application of 20 % Garlon 4 in diesel fuel oil. At the time, no new seedlings were observed, perhaps due to suppression by the dense alien grass cover surrounding the trees. In May, 2010, at least three resprouts were observed in this population.

Since 1992, individuals have been observed in new areas of the park. In 1997, an adult tree was found and removed along the HAVO/Kapāpala boundary (1,075 m elevation), and a mature individual was found and removed from Kīpuka Pepeiao (600 m elevation) in 2002. No re-growth or seedlings have been observed on annual remonitoring visits at these two sites. Also in 2002, five mature individuals were mapped from a helicopter in an unnamed kīpuka (550 m elevation) along HAVO's western boundary. Ground operations in 2007 treated 26 mature individuals at this site. Additionally, four individuals <2 m high were observed in Kīpuka Pepeiao in 2008 and a 4 m tall individual was found in the Kū`ē`ē grasslands in 2009 during vegetation surveys, but these populations were not treated as plants and were too large to be uprooted.

Additional seedlings were periodically encountered and removed along Highway 11 between the park entrance and the Ka'ū boundary (850-1,220 m elevation). Seven seedlings were pulled between 1996 and 1998 and two were pulled in 2002. The plants located along the highway were likely the result of seeds transported to the area from motor vehicles or roadside aggregates. A number of other invasive tree and herb species were encountered along roadsides in this area (e.g., melochia, fountaingrass, koa haole), and these have been controlled by pulling or chemical treatment on an annual basis.

Formosa koa is a pest plant with a localized distribution in the park. Monotypic stands have been observed and newly encountered individuals in remote areas suggest natural dispersal may have occurred. Since 1984, HAVO has been controlling this species to eradicate all populations except Keauhou, which was managed only to remove newly established individuals. Parkwide eradication efforts were expanded in 2007 to target mature individuals at Keauhou in 2007 as well as all individuals in the previously undetected and unmanaged western boundary population. Additional surveys in western kīpukas are recommended to locate any remaining undiscovered populations. Parkwide control to eradicate this species appears feasible based on the effectiveness of previous control work and the small sizes of remaining populations (<20 individuals). Seedlings can be uprooted manually and the preferred treatment for larger individuals is a frilling followed by application of 20% Garlon 4 in diesel fuel oil to the wound. Treated populations have been revisited and controlled on an annual basis. However, limiting the re-monitoring to areas of previously identified populations failed to detect new occurrences, as evidenced by the discovery of new individuals located beyond the managed populations.

The genus *Acacia* is notorious for exceptionally long lived seeds (Farrell and Ashton 1978), and evidence from controlled Formosa koa populations suggests seeds persist and remain viable >5 years in soils at ʻĀinahou, an important consideration for re-treatment and monitoring of populations. Retreatment visits should continue until the seed bank is exhausted and no new individuals are observed during multiple (3-5) consecutive annual visits. Afterwards, the monitoring interval could reasonably be relaxed to 2-4 years to reduce workloads. Should individuals be discovered in new areas in HAVO, control leading to eradication is recommended. Formosa koa has a prominent aerial signature when flowering and aerial surveys appear to be a cost effective method for detecting trees across open areas in the park.

Acacia mearnsii De Wild. (Black wattle)

Black wattle (*Acacia mearnsii*) is a leguminous tree with bipinnately compound leaves. Native to Australia, black wattle is naturalized in pastures and dry to mesic areas of all major islands except Niʻihau (Wagner et al. 1999). The name *Acacia decurrens* Wendl. De Wild. has been applied to Hawaiian black wattle plants. These two species appear to be distinct (Wagner et al. 1999), but part of a complex of closely related species. Black wattle was intentionally introduced and planted in Forest Reserves in Hawaiʻi (Little and Skolmen 1989), and was likely intentionally introduced to the park at ʻĀinahou. Fosberg (1966) did not find black wattle in HAVO, although his checklist did not include sections of the ʻĀinahou Ranch. Black wattle was noted by Higashino et al. (1988), and Tunison et al. (1992) found seven black wattle trees scattered across the ʻĀinahou Ranch, and a single individual at the research area near park headquarters. Black wattle was first controlled in HAVO in 1976, and control has been continuous since 1981.

Annual control at ʻĀinahou Ranch began in 1981, and this population remains extant. To date, 1,149 plants (mostly seedlings and saplings) have been removed. In 2003, plants were found distributed across 1.6 ha of alien grasslands and ʻōhiʻa woodlands between 820 and 850 m elevation. At that time, 23 juveniles and one mature black wattle were mapped and treated. The juveniles indicated a viable seed bank in the soil, mostly likely persisting from formerly controlled individuals as these are in discrete areas where trees were previously controlled. Nevertheless, the presence of mature trees in surrounding areas cannot be ruled out; the one mature tree discovered was in native forest, and apparently missed by control crews. Although no seedlings were discovered nearby, continued searches are warranted. No additional plants were found elsewhere in HAVO.

One individual near park headquarters was removed in 1984, and no additional plants were observed during annual monitoring visits from 1984-1991. Two additional trees were controlled outside of HAVO, near the Kapāpala Ranch boundary in 1984, and larger populations have been observed in the vicinity since, beyond park boundaries.

Black wattle is considered a serious pest in Hawaiian ecosystems (Smith 1985, Motooka et al. 2003), capable of displacing native species and difficult to control (Staples and Herbst 2005). It is also considered a noxious weed by the State of Hawai‘i (USDA-NRCS 2010a), and ranked among the world’s top 100 weeds (Lowe et al. 2000) for is negative impacts to biodiversity and agriculture. Therefore continued control work leading to eradication is recommended. Eradication is feasible because of a localized distribution, small population size, and low numbers of reproductive individuals. Expanding the search area around localized black wattle populations is important to detect outlying individuals not encountered during control work. The genus *Acacia* is well known for exceptionally long lived seeds (Farrell and Ashton 1978).

Black wattle is controlled by pulling seedlings, applying a solution of 10% Garlon 3A in water to the cut stump of saplings or applying a solution of 5-15% Garlon 4 in diesel fuel oil to the basal bark of larger trees.

Fosberg (1966) reported a silver wattle (*Acacia dealbata* Link) in the Kīlauea area, this tree was also noted by Higashino et al. (1988) in cultivation at an unspecified locality. Silver wattle is not naturalized in Hawai‘i (Wagner et al. 1999), and was not encountered during recent surveys. Silver wattle has never been controlled in HAVO, and no specimens could be found in the HAVO herbarium to confirm the identity of this tree. It is possible that the silver wattle noted by Fosberg (1966) and Higashino et al. (1988) was the black wattle referenced by Tunison et al. (1992), controlled in 1984.

***Acacia melanoxylon* R. Br. ex Aiton (Blackwood acacia)**

Blackwood acacia (*Acacia melanoxylon*) is a leguminous tree with phyllodial leaves native to Australia. In Hawai‘i, blackwood acacia is reported naturalized on Kaua‘i and Maui (Wagner et al. 1999). Higashino et al. (1988) noted blackwood acacia in HAVO, and Tunison et al. (1992) documented 20 individuals apparently naturalized near the ‘Āinahou Ranch house. Blackwood acacia has been controlled on an annual basis in HAVO since 1985.

Two discrete populations at ‘Āinahou have been controlled since 1985. A population of 19 trees 200 m to the south-southwest of the ranch house in an ‘ōhi‘a woodland was removed in 1985. A second population was controlled between 1985 and 2001, when 42 individuals were removed from 0.8 ha south of the ‘Āinahou Ranch house, using a cut stump treatment of Tordon RTU (Tunison et al. 1992).

During surveys in 2002, no plants could be found in the woodlands surrounding the former population of 19 trees. Nevertheless, the occurrence of this population suggests natural dispersal, as it was in an area unlikely to have been cultivated, and additional periodic surveys surrounding this area seem warranted to search for new individuals.

In 2002, a population of blackwood acacia was mapped in mixed alien/native vegetation at 915 m elevation just south of the ‘Āinahou ranch house. Twenty juvenile trees were observed and controlled by pulling small individuals and applying a solution

of 10% Garlon 3A on cut stumps of larger (~2 m) individuals. These plants were likely establishing from seeds deposited by blackwood trees that had been controlled in 1985, as these were in discrete areas where trees were formerly removed.

Continued control leading to parkwide eradication is recommended for blackwood acacia given its limited distribution and recognition as a serious pest capable of displacing native species (Wagner et al. 1999). Natural dispersal in the park is suggested based on past distribution, and continued monitoring and control of extant and historic populations is expected to exhaust the seed bank. The genus *Acacia*, including blackwood acacia, is notorious for exceptionally long lived seeds (Farrell and Ashton 1978). Therefore, continued monitoring should extend well beyond the last observance of seedlings at control sites.

Acca sellowiana (O. Berg) Burret (Guavasteen)

Guavasteen (*Acca sellowiana*) is a South American shrub belonging to the Myrtaceae family, sparingly cultivated in Hawai‘i (Wagner et al. 1999, Staples and Herbst 2005), valued for its edible fruits and attractive foliage. The name *Feijoa sellowiana* (O. Berg) O. Berg. is an older synonym for guavasteen (Staples and Herbst 2005). Guavasteen is also commonly known as pineapple guava. Guavasteen was collected in HAVO in 1984 by Kageler (HAVO # 7308) at ‘Āinahou, and noted by Higashino et al. (1988) at the same locality. Tunison et al. (1992) found ~15 individuals in two populations immediately south of the ranch house apparently naturalized, separated by 600 m.

Guavasteen was first controlled in HAVO in 1985 at ‘Āinahou, 75 m southwest of the ranch house. From 1985 to 1995, 24 individuals were removed. No individuals of guavasteen were found during subsequent monitoring conducted 1995-2001. A second population consisted of 2 plants removed from a site near a transect (19-W). Plants were pulled in 1985 and no additional individuals were observed at this site. No guavasteen was observed during recent surveys, and no plants have been observed since elsewhere in HAVO.

Despite evidence suggesting extirpation, additional monitoring is warranted in the ‘Āinahou vicinity to continue to search for this and other species deliberately introduced to the former ranch. Should new individuals be discovered, eradication is recommended. Guavasteen is potentially invasive because natural recruitment has been observed in HAVO (Tunison et al. 1992), and the palatable fruit with numerous small seeds suggests adaptation to bird dispersal. Further caution is warranted because an analysis of taxonomic patterns found the family Myrtaceae disproportionally overrepresented in Hawai‘i’s invasive flora (Daehler 1998).

Aechmea sp. Ruiz and Pavón (Aechmea)

Aechmea is a genus in the family Bromeliaceae, popular in the ornamental trade (Staples and Herbst 2005). In 2008, a visitor reported a single, planted bromeliad 50 m

from the Hilina Pali shelter along the Ka‘aha Trail. Though this species was not considered naturalized nor invasive (Wagner et al. 1999), the plant was a new alien plant record and was pulled in 2008 as a precautionary measure. A specific determination of this sterile plant could not be made.

Agave americana L. (Century plant)

Century plant (*Agave americana*) is a large, often variegated, succulent rosette likely native to northeastern Mexico (Staples and Herbst 2005). Century plant is cultivated throughout Hawai‘i but not reported naturalized (Wagner et al. 1999). Century plant was not noted by Fosberg (1966) within HAVO, but was noted by Higashino et al. (1988) and also Tunison et al. (1992), who reported plants at multiple locations near the Kīlauea summit. Control of century plant in HAVO began in 1985.

Tunison et al. (1992) mapped small naturalized populations near the Kīlauea summit, including Nāmakani Paio, Kīlauea Military Camp (KMC), Volcano House and park headquarters, and a population at the ‘Āinahou Ranch. These populations were controlled from 1985-1990, and were presumed extirpated.

Control was resumed in 2003 when survey work identified plants near three of the former sites. During these surveys, two mature individuals and fourteen seedlings were encountered and removed from the edge of an alien grassland and faya/‘ōhi‘a forest near KMC, at 1,220 m elevation. One mature individual and twelve seedlings were retreated a year later at this site. This population was 150 m from previously controlled individuals, and borders a SEA unit (Puaulu Buffer block 9).

Three juvenile *Agave* sp. plants, growing among alien grasses, were treated in 2003 at ‘Āinahou Ranch at 910 m elevation. Park records indicate that sisal (*A*. *sisalana*) had previously been controlled at this site. This may have been a misidentification as this population appears to be the same one described as century plant by Tunison et al. (1992). The identity of these plants could not be determined based on leaf morphology of controlled seedlings. No additional century plants were encountered elsewhere. Given the relatively small population size of this species and the invasiveness of a congeneric species (*A. sisalana*), parkwide eradication is recommended to protect native communities.

Another population of several individuals was observed in 2006 on a pali (steep slope) behind the Volcano House. One plant was noted from the Volcano House lookout, and ~10 individuals were observed during rappel operations below the lookout. Foliar applications of 50% Garlon 3A were made to several individuals, but the effectiveness of the treatment has not been evaluated due to the difficulty of accessing the plants. Because century plant is capable of vegetative reproduction through vivipary, undetected individuals likely remain below the parent plants on this pali.

Control work has been effective at locally extirpating accessible populations of century plant, but less effective at detecting new individuals outside of known populations. Additional monitoring is recommended to include expanded searches for

undetected extant populations, particularly near formerly cultivated areas throughout Kīlauea's summit. Expanded control work and surveys are recommended along the Volcano House pali, where a number of invasive taxa were discovered during rappel operations. In HAVO, the preferred control method is a foliar application of 2% Garlon 4 in water, applied to wet the entire plant's foliage.

Agave sisalana Perrine (Sisal)

Sisal (*Agave sisalana*) is a large succulent rosette native to tropical North America. Sisal has been cultivated as a fiber crop in Hawai'i, and has become naturalized on all the main islands except Ni'ihau, primarily on dry and rocky sites (Wagner et al. 1999). In HAVO, Fosberg (1966) documented several plants atop Poliokeawe Pali. Tunison et al. (1992) identified three additional populations of sisal; one large population at Waha`ula, and smaller populations along the Naulu Trail and along the Kalapana Trail.

A population of <10 seedlings was found atop Poliokeawe Pali in a small kīpuka at 655 m elevation in 2002. This population was originally described by Fosberg (1966) and mapped in 1987 (Tunison et al. 1992) with 368 individuals. Since 1987 removal and subsequent annual re-treatment have reduced numbers; 4 plants were observed and treated in 2003 and 8 seedlings were observed and pulled in 2004. No plants have been observed since.

A population at Waha'ula along the coastal lowlands previously consisting of 700 mature plants and ~500,000 seedlings spread over 8.5 ha (Tunison et al. 1992) was covered by lava between 1986 and 1990.

A population of sisal along the Naulu Trail at 655 m elevation was reported by Tunison et al. (1992) with > 1,000 plants. This population, along the edge of an 'ōhi'a dominated kīpuka with native shrubs and alien scaly swordfern (*Nephrolepis multiflora*), has been controlled since 1993. Surveys in 2003 found ~20 seedlings here, a dramatic drop likely due to control efforts at this site, and fewer than 25 individuals have been observed and removed annually since 2000.

Approximately 20 mature plants were encountered in a forested area burned by the 2002 Kupukupu fire (East Rift, ca. 800 m elevation) approximately 3.7 km northeast of the hairpin turn in Chain of Craters Road. Several plants were noted to be flowering. This population was likely mapped by Tunison et al. (1992), who observed 10 plants near the same general location. The area should be resurveyed to determine if plants are spreading or covered by recent lava flows from 2002–present.

Current control of sisal appears effective at reducing the number of individuals and limiting the population's spread. Continued parkwide control to eradicate remaining individuals is recommended due to the species' localized distribution and potential to spread and displace native plants. Sisal is considered a weed of dry areas (Motooka et al. 2003).

Sisal mature plants are controlled using a solution of 2% Garlon 4 in water applied to wet the foliage and juvenile plants are pulled.

Andropogon virginicus L. (Broomsedge)

Broomsedge (*Andropogon virginicus*) is a fire-adapted invasive bunchgrass native to southeastern U.S.A. Fire-regimes are altered where fire-tolerant grass invasions occur in HAVO's mesic and dry `ōhi`a woodlands (Smith and Tunison 1992). Though not intensively mapped, broomsedge was observed widespread in dry and mesic environments in HAVO's montane seasonal zone, the submontane seasonal zone and less frequently in coastal lowlands. Control of broomsedge is limited to small scale project areas, typically targeting a suite of non-native grass species, to restore native plant communities. A foliar application of 1 % Roundup in water is used to control broomsedge and many other grass species.

Anemone hupehensis Lemoine (Japanese anemone)

Japanese anemone (*Anemone hupehensis*) is a perennial herb native to China (Wagner et al. 1999) naturalized in Hawai'i at least in the vicinity of HAVO, where it was first collected in 1942 (Wagner et al. 1999). It was presumably introduced to the park as an ornamental; plants were noted escaping from residential gardens into forest by Fagerlund (1947) and later by Fosberg (1966) under an older synonym, *Anemone japonica* (Thumb.) Siebold and Zucc. HAVO Vegetation Management files (HAVO 1980b) document Japanese anemone from the Kīlauea summit area to Puhimau crater (~1,100 m elevation) in mesic and wet forest. Japanese anemone has never been targeted for control in HAVO.

During recent surveys, Japanese anemone was found relatively widespread in HAVO in disturbed areas and forest in mesic-wet upland habitats. Plants were found in formerly mapped areas throughout the Kīlauea summit, along fencelines near Thurston SEA (1,190 m elevation) and Puhimau (1,090-1,150 m elevation), and in new areas to ~1,000 m elevation extending below Puhimau. Along fencelines, roadsides and other disturbed areas, clusters of one to several hundred plants were found. Plants were also found throughout forest interiors. A notable infestation occurred in Thurston block 16 where dense clusters of plants exceeded 100 m^2.

In 'Ōla'a wet forest, 2002 surveys found Japanese anemone distribution variable along fencelines; plants were occasional along the fencelines of pig control units, except for New unit where pigs still remain and where plants were abundant throughout the interior of the unit. A similar distribution was noted along transects monitored in 1998; only 12 occurrences of Japanese anemone were noted in 426 stations within pig free Ag, Pu'u, Koa and Small Tract unit interiors (cover <5%). By comparison, in New unit, Japanese anemone was found in 285 out of 363 transect stations, and a greater number of these were in higher cover classes. Japanese anemone was previously mapped only in the 'Ōla'a Small Tract unit (HAVO 1980b), and no weed survey data are

available for the remainder of ‘Ōla‘a from this time period, so it remains unknown when plants became established in these other areas.

In the vicinity of Mauna Ulu, Japanese anemone was occasionally found on open, sparsely vegetated lava flows growing in small clusters of <5 plants. Japanese anemone was not observed growing in forest invaded by dense Kāhili ginger stands, and did not appear to establish well in closed canopy faya forest.

In the park’s Mauna Loa sector, Japanese anemone was uncommon between 1,180 and 1,350 m elevation. Within this range, three clusters of <5 plants were observed along transects and an additional cluster was found along a fenceline. In these drier environments, plants grew in shallow soils in open ‘ōhi‘a woodlands. Japanese anemone was not observed above 1,350 m elevation. However plants have been observed as high as 1,580 m elevation in native forest outside the survey area in the Ka‘ū district (Benitez et al. 2008).

Japanese anemone has been reported from East Rift wet forest units (Mattos pers. com) but plants were not located during ground surveys in the area in 1988-1994 (Pratt et al. 1999), and no plants were found in more recent surveys in 2003-2005. More intensive surveys are recommended to detect and map plants in these forests. The East Rift has been recently impacted by wildfires, a disturbance that could possibly contribute to the establishment of this and other invasive species.

Japanese anemone has apparently expanded its range in HAVO over the past 25 years. Infestations should be evaluated for their ability to limit native plant recruitment; and investigations conducted to determine if this weed can persist where disturbance by feral ungulates is excluded, such as in SEA fenced units in ‘Ōla‘a. Pigs are still present in New unit. Findings in support of establishment and persistence in pig free units would likely warrant strategic control of this species (e.g., SEA control in units on the periphery of the plant’s distribution).

Ardisia crenata Sims (Hilo holly)

Hilo holly (*Ardisia crenata*) is an Asian shrub naturalized in east Hawai‘i and cultivated elsewhere in the Islands (Wagner et al. 1999). The binomial *Ardisia crispa* non (Thunb.) A. DC has been applied to Hilo holly in Hawai‘i (Wagner et al. 1999). Hilo holly was noted by Fosberg (1966) and by Higashino et al. (1988) in the park residential area where it was likely planted, based on collection data cited by Fosberg.

The park’s only population of Hilo holly was previously mapped by Tunison et al. (1992) near the Volcano House (1,200 m elevation). Individuals grew among landscaped vegetation surrounded by native wet forest. Treatment of the population first began in 1985, and re-treatment of seedlings to prevent re-establishment was conducted annually until 2002. Since then, no new individuals have been observed during annual monitoring visits.

Although the Volcano House Hilo holly population appears to be extirpated, continued annual monitoring of the Volcano House surroundings are recommended to search for undetected populations and locate additional invasive taxa deliberately or accidentally introduced to the area.

Control leading to eradication of Hilo holly is warranted as a precautionary measure to remove a naturalized alien species in an early stage of invasion. Further caution is warranted since a congeneric species, *A. elliptica*, is considered one of Hawai'i's worst weeds, capable of invading and replacing native wet ecosystems (Smith 1985), and also listed as one of the world's top 100 weeds on account of its shade tolerance, aggressive growth, dispersability and germination success (Lowe et al. 2000). A cut stump treatment of 1% Garlon 4 in water has been effective at controlling Hilo holly.

Arundo donax L. (Spanish reed)

Spanish reed (*Arundo donax*) is a large perennial grass native to the Mediterranean area, naturalized on Kaua'i, O'ahu, Maui and Hawai'i (Wagner et al. 1999) capable of forming thickets at coastal sites. Spanish reed has become a weed of temperate and tropical lowland areas (Staples and Herbst 2005). Fosberg (1966) did not document this species within HAVO, but Higashino et al. (1988) noted one plant near park headquarters. Spanish reed has never been targeted for control in HAVO.

Surveys conducted between 2000 and 2004 encountered one Spanish reed in HAVO near a pipeline behind park headquarters. This individual was growing on the boundary between a landscaped area and wet native forest. No additional Spanish reed was encountered in the area surrounding this plant, or during surveys of residential and administrative areas. No evidence of recruitment was observed nearby, although the plant was fertile. Eradication is recommended due to Spanish reed's limited distribution and reported invasiveness.

Asclepias physocarpa (E. Mey.) Schlechter (Balloon Plant)

Balloon plant (*Asclepias physocarpa*) is an erect perennial herb, native to South Africa (Wagner et al. 1999). A former synonym of balloon plant was *Gomphocarpus physocarpus* E. Mey, and the genus has recently been transferred from the family Asclepiadaceae to the Apocynaceae (Wagner et al. 1999). Fosberg (1966) did not note balloon plant in HAVO. In 1974, T. Herat (BIISH #410477) collected plants near the Halapē Trail in central HAVO. Higashino et al. (1988) found balloon plant in coastal, sub-montane and montane ecological zones within HAVO. Balloon plant has never been targeted for mapping or control in HAVO.

During 2001-2004 surveys, balloon plant was found widespread in HAVO, from near sea level to 1,830 m, principally in open habitats. Most occurrences were in dry grasslands and shrublands, extending from HAVO's western boundary, east to Kīpuka Nēnē, through central HAVO, between 5 and 550 m. These areas are vegetated by alien grasses including natal red top (*Rhychelytrum repens*), thatching grass

(*Hyparrhenia rufa*), and beardgrass (*Schizacharium condensatum),* and native and alien shrubs. The populations were sparse and patchy, and dense stands were not observed throughout the plant's range. Balloon plant was less frequent in shaded environments, such as within dry ʻōhiʻa kīpukas.

In the park's Mauna Loa Strip unit, balloon plant was observed at a maximum elevation of 1,830 m and more frequently between 1,370 and 1,525 m growing on sparsely vegetated lava flows along the Keauhou/HAVO boundary fence. Though abundant, plants were not contiguously distributed. Typically found in drier environs, scattered balloon plants were observed in a recent burn in the East Rift wet forest SEA unit (Luhi blocks) at 760 m elevation. These plants were infrequent, in populations generally of 1-5 individuals.

Although balloon plant occupies a broad ecological range in HAVO, it does not form dense stands that exclude other plants. Despite a large range extent, balloon plant represents a low priority for control relative to more highly disruptive taxa (e.g., fountain grass, common mullein, strawberry guava), and no control is recommended.

It is curious that Fosberg (1966) did not note balloon plant in HAVO. If indeed it was absent at the time, its spread has been very rapid. Therefore, monitoring of changes in balloon plant abundance and spread seem justified to better understand the invasive potential of this species, and to develop a control strategy if warranted.

Banksia cf***. integrifolia*** **L. (Coast banksia)**

Coast banksia (*Banksia* cf. *integrifolia)* is a small tree native to the southeast coast of Australia. *Banksia* spp. are cultivated in Hawaiʻi (Staples and Herbst 2005) but none are reported naturalized (Wagner et. al. 1999). Coast banksia was previously unknown from HAVO (Higashino et al. 1988). Plants were first documented and controlled in 2000.

In late 2000, a mature coast banksia with numerous seedlings growing beneath it was encountered in a recently burned ʻōhiʻa woodland at 1,200 m elevation, 650 m northeast of the Nāmakani Paio campground. The species may have escaped cultivation from the Volcano Golf Course subdivision which lies 1.4 km upwind from the population, and where several flowering members belonging to the family Proteaceae were later observed in residential lots.

The tree and seedlings were removed that year. The tree trunk was cut, and treated with a Triclopyr based herbicide, Garlon 3A, in a solution of 50% herbicide and 50% water. Fifty seedlings and small saplings were manually uprooted. Seedlings were encountered and pulled again in 2003, and one was pulled during resurvey in 2004. The individuals encountered during re-inspection probably established from seeds deposited in the soil from the original tree found in 2000.

Based on previous resurvey and control efforts, the infestation site and surrounding area (~150 m from infestation origin) should be revisited at two year intervals to remove

any new individuals until the soil seed bank is depleted. Coast banksia has a conspicuous architecture and requires several years to reach maturity, thus continued control and monitoring at these intervals can reasonably be expected to lead to extirpation of this population.

A tentative specific determination was provided by Dr. Kingsley Dixon, of Kings Park and Botanic Garden in West Perth, Western Australia, based on photographs of sterile material collected in 2003. Dr. Dixon cautioned that this species is potentially weedy. In light of this warning and evidence of abundant recruitment underneath a single individual, continued control and monitoring leading to eradication is recommended at this site and elsewhere if new individuals are discovered.

A fertile branch of a related species, heath banksia (*Banksia ericifolia*) L. f., was discovered on a roadside outside of the park in February, 2009. This specimen had several flowering cones but no fruit mature was observed. Heath banksia is not known to be naturalized in Hawai‘i.

Benincasa hispida (Thunb.) Cogn. (Chinese melon)

Chinese melon (*Benincasa hispida*) is a vine native to tropical Asia, not considered naturalized in Hawai‘i, although garden cultivars have been known to escape (Wagner et al. 1999). In the park, vines were documented in the 1980's (Higashino et al. 1988) as an invasive alien that had effectively been controlled. Tunison et al. (1992) reported that Chinese melon had apparently been eradicated from HAVO, and no plants were observed during recent surveys of HAVO.

The former population of several hundred plants was first observed near the Kīpuka Puaulu picnic area, growing as two dense mats in native vegetation in 1983 (Tunison et al. 1992). These plants were intensively controlled at 2-3 month intervals between 1983 and 1984 by manual uprooting until no new individuals were observed. Annual monitoring conducted from 1985 to 1995 was discontinued because no new individuals were observed.

The apparent eradication of Chinese melon is illustrative of the strategic importance of a rapid response to an incipient weed infestation. Tunison et al. (1992) observed vines climbing on small trees and smothering the native vegetation. Intensive control prior to the establishment of larger dense stands likely contributed to lower workloads and the efficacy of control at this site. A continuation of eradication efforts is recommended if new plants are discovered at this site or elsewhere in the park.

Buddleia asiatica Lour. (Butterfly bush)

Butterfly bush (*Buddleia asiatica*) is a small Eurasian shrub, recently transferred from the family Buddlejaceae to the Scrophulariaceae. Found in mesic and wet disturbed areas and forests on O`ahu, Moloka`i, Lana`i, Maui and Hawai’i, butterfly bush occupies

a broad ecological range in HAVO, yet is relatively uncommon and does not appear to form exclusive stands. Butterfly bush has never been controlled in HAVO.

Recent surveys mapped butterfly bush most frequently in disturbed areas and grasslands between 480 and 1,220 m elevation from the Kīlauea summit to Kīpuka Nene and westward along the Hilina Pali road including the Kīpuka Nene 4WD road, generally as small groupings of 1-10 plants. Plants were also mapped in forest and along edges east of the Mothers Day lava flow at 500 m elevation. The park's densest infestations were observed along seasonal streambeds or gulches on leeward Kīlauea, such as those found along the Ka`ū desert trail and Kīpuka Pepeiao.

Though rarely encountered in closed canopy forest, five occurrences were documented along 31.5 kilometers of fenceline surveyed in the `Ōla`a unit. Butterfly bush appears to be even less abundant in the interior of the `Ōla`a unit; only a single population was observed along transect lines during survey work completed in 1998. Pratt et al. (1999) report frequencies of 17 % and 4 % occurrence in transect stations in the East Rift in 1988 and 1992 respectively.

Smale (1990) reports that a related species (*B. davidii*) is a very effective colonizer of new, nitrogen deficient surfaces, and quickly develops extensive root systems and large quantities of seed. However at present there is little evidence to suggest that butterfly bush is a threat to native plant communities in the park, and no control is recommended, although populations in key areas such as SEAs and restoration sites should be monitored to evaluate if control is required.

***Buddleia davidii* Franch. (Summer lilac)**

Summer lilac (*Buddleia davidii*) is a shrub native to China and Japan, popular in the ornamental trade and recently naturalized in Hawai‘i (Wagner et al. 1999; Staples and Herbst 2005). Little is known about summer lilac's invasiveness in Hawai‘i, but plants are reported weedy in streambeds and disturbed areas in New Zealand (Smale 1990).

In HAVO, summer lilac was first reported by Higashino et al. (1988) in cultivated areas. A single summer lilac was mapped near park headquarters in 2004 during surveys of the administrative and residential areas; this plant was fertile and apparently cultivated. No additional plants were found nearby or elsewhere in HAVO. Near the park, summer lilac was formerly known from near the Highway 11 and Volcano Golf Course area, and summer lilac plants and the congeneric smokebush (*B. madagascariensis* Lam.) occur at the Volcano transfer station and have escaped along roads in Volcano Village. Because of summer lilac's small population size, documented invasiveness elsewhere (Smale 1990) and similar biological characteristics to a widespread congener found in HAVO, eradication is recommended.

***Casuarina equisetifolia* L. (Ironwood)**

Ironwood (*Casuarina equisetifolia*) is an angiosperm which superficially resembles a pine, native to Australia, and a serious pest widely naturalized in low elevation sites throughout the Hawaiian Islands (Smith 1985; Wagner et al. 1999). In HAVO, Tunison et al. (1992) reported 2 populations at ʻĀinahou totaling 1.2 ha, and a population at Kamoamoa that has since been covered by lava. Ironwood control in HAVO began in 1981 at Kamoamoa and 1983 at ʻĀinahou.

Ironwood appears to have been extirpated from HAVO. Between 1983 and 2000, 127 plants were treated at the two ʻĀinahou populations and plants were not seen since. No new ironwood populations were identified during control operations or during recent surveys at ʻĀinahou or elsewhere in HAVO.

A former population reported by Tunison et al. (1992) at Kamoamoa consisted of ten trees and has since been covered by lava. Ironwood may occur in coastal areas east of present lava flows within the park, however these areas are difficult to access due to remoteness and ongoing volcanic eruptions, and remain unsurveyed.

Ironwood is a serious pest of native Hawaiian ecosystems because it grows rapidly, forms exclusive stands, and may produce allelopathic chemicals (Smith 1985). To ensure extirpation, continued monitoring at two year intervals is recommended to search for remaining trees surrounding formerly controlled areas. Ironwood has a conspicuous aerial signature and helicopter surveys should be considered to augment ground searches in key areas in the park (e.g., ʻĀinahou, costal lowlands in eastern HAVO). Ironwood trees located just outside of the park boundary near the Volcano Golf Course provide a nearby seed source. Park areas in the vicinity of this source should be routinely monitored to detect and eradicate new individuals that establish.

Cestrum nocturnum L. (Night cestrum)

Night cestrum (*Cestrum nocturnum*) is a white berried night-blooming shrub native to Central America. Night cestrum is naturalized in Hawaiʻi (Wagner et al. 1999) and can form dense thickets in native mesic and wet montane forest (Benitez pers. obsn.). In HAVO, night cestrum was reported in cultivation by Higashino et al. (1988) and first observed naturalized in 2001. Cultivated plants in the park were not observed during recent surveys.

The naturalized population found in HAVO in 2001 was in wet forest bordering a pasture at 1,200 m elevation. This population was within the Koa unit of the ʻŌlaʻa wet forest SEA, between transects 15 and 16, in an area intensively managed to systematically remove aggressive alien weeds. The infested area at the time of the population's discovery was approximately 200 m^2. These plants may represent a garden escape, as planted individuals have been observed in areas adjacent to the park.

The Koa unit night cestrum population was controlled shortly after discovery in 2001. Initially, 16 individuals were removed, and from 2001-2005, an additional 54 individuals were treated at this site, at intervals ranging from 6 to 16 months. Small individuals were

pulled and larger individuals controlled with a cut stump application of 10% Garlon 3A in water. Night cestrum likely reproduces clonally; extensive adventitious rooting has been observed in a population managed in the recently acquired Kahuku unit of HAVO (Benitez et al. 2008).

Night cestrum is an aggressive weed with a limited distribution in HAVO, but could develop dense thickets in native forest if left unchecked. It is a popular ornamental planted in Volcano and residential lots adjacent to HAVO, and seeds appear suited to dispersal by birds (Staples et al. 2000). For these reasons night cestrum should be regarded as a serious threat and a high priority for management. Additional surveys and monitoring are recommended in wet forest SEAs and forests bordering areas with cultivated plants. Removal leading to eradication is recommended should populations be found. A public outreach campaign to discourage cultivation of this and other disruptive invaders in adjacent residential areas would be of strategic value to limit ingress to park lands.

Chlorophytum comosum (Thunberg) Jacques (Spider plant)

Spider plant (*Chlorophytum comosum)* is an ornamental lily native to South Africa. Spider plant is commonly cultivated in Hawai‘i (Staples and Herbst 2005) but is not known to be naturalized (Wagner et al. 1999). Within HAVO, spider plant was not documented on previous flora checklists published in 1966 (Fosberg) nor 1988 (Higashino et al.).

In 2003, two spider plants were encountered in the administrative area of the park. The plants were found on the south side of the Concessions Dorm, adjacent to the Volcano House, rooted above landscaped grasses and surrounded by native rain forest. The plants were vigorous, although no reproductive structures were observed. No other spider plants were observed in a perimeter search of the area or in detailed surveys of the park residential and administrative areas. The proximity of the plants to buildings suggests that these may have persisted from past cultivation.

Though spider plant is not considered invasive, removal of these plants is recommended because this species is an exotic addition to HAVO’s flora and numbers are small.

Cinnamomum burmanni (Nees) Blume (Padang cassia)

Padang cassia (*Cinnamomum burmanni*) is a tree native to Indonesia, cultivated in Hawai‘i and naturalized on O‘ahu and more recently Maui and Hawai‘i (Wagner et al. 1999). Padang cassia is considered a pest plant in West Maui, where it forms dense stands and recruits in low light environments (Meidell et al. 1997). These infestations are considered too widespread to eradicate.

This species was previously unknown from HAVO (Higashino et al. 1988). In 2009, two saplings were found along the edge of a service road behind the HAVO RM

nursery. These plants were uprooted in 2010 as a precautionary measure, and a 0.5 ha area surrounding the plants was searched. Continued monitoring and control leading to eradication are recommended in light of the high invasive potential of this tree.

Clidemia hirta var. *hirta* (L.) D. Don (Koster's curse)

Koster's curse (*Clidemia hirta*) is an apomictic shrub native to the neotropics. Koster's curse was first collected in Hawai'i on O'ahu in 1949 (Wagner et al. 1999) and is now widespread in forest and disturbed areas on Kaua'i, O'ahu, Moloka'i, Maui and Hawai'i. Koster's curse is among the most serious weeds of wet forests in Hawai'i (Smith 1985), and also invasive on other tropical islands and in the paleotropics including Africa and Madagascar (Benitez 2010). Koster's curse is listed as a noxious weed by the Hawai'i Department of Agriculture (USDA-NRCS 2010a). A shade tolerant species where invasive (Motooka et al. 2003, DeWalt et al. 2004), dense, monotypic stands are frequent throughout the plant's range in disturbed areas and forest interiors (Benitez pers. obsn.).

Koster's curse was not known from HAVO until 2003, when a single immature individual was observed and removed from a trailside near Byron's ledge, close to the Kīlauea summit. No additional plants were noted in the area at the time. The area was not resurveyed. In 2008, 150 plants were observed and pulled at this site and in the forest interior by HAVO Interpretation staff. Surveys and control work removed an additional 154 plants. Some of these were on a steep slope west of the trail, and were accessed using rappel techniques developed to control plants on high angle slopes.

In October 2008, an additional plant was observed and later removed from a crack along the Steam Vents Trail.

In both instances, the plant's mode of ingress into HAVO remains unknown, but seeds may have been accidentally introduced by hikers or park staff. However, natural dispersal cannot be ruled out for this species. Koster's curse is found in forests and disturbed areas in the Puna and Ka'ū districts outside of HAVO, and along Highway 11 leading up to the Park. This species produces abundant small, bird-dispersed seeds which may also be transported in soil or attached to footwear or clothing. The sighting of Koster's curse in HAVO underscores the need for more intensive monitoring and control of trailsides and roadsides to prevent new establishment of invasive weeds, and strict adherence to sanitation protocols, as infestations are notoriously difficult to eradicate.

The preferred control method for seedlings and mature plants is a foliar application of 10 % Garlon 3A in water. Koster's curse appears sensitive to volcanic gases and grew poorly in a greenhouse environment in Volcano, due to attack by thrips (Thysanoptera) and perhaps suboptimal temperatures (Benitez 2010). A biological control agent, the buprestid beetle *Lius posseidon* Napp (Coleoptera: Buprestidae) was released in 1988 (Conant 2002) and has been observed at lower elevations in east Hawai`i but has not been found in the park (Benitez pers. obsn.). Control leading to eradication is recommended for this disruptive species.

Commelina diffusa N. L. Burm. (Honohono grass)

Honohono grass (*Commelina diffusa*) is an herb native to the Paleotropics, naturalized in mesic and wet environs on all Hawaiian Islands except Niʻihau and Kahoʻolawe (Wagner et al. 1999). Though not mapped in detail, Honohono grass was observed widespread along roadsides near the Kīlauea summit, and in forest and disturbed areas on Mauna Loa below 1,400 m elevation, including SEA units Kīpuka Kī and Kīpuka Puaulu, and in native plant restoration sites at Soapberry Bend. In these SEAs and restoration sites, plants may form a continuous groundcover and are selectively managed to assist native plant regeneration and prevent the buildup of larger, more disruptive populations. The preferred control method is an application of 2 % Garlon 4 in water applied to wet the foliage or manual uprooting. This species has not been mapped in wet forests including Thurston and ʻŌlaʻa, and additional surveys to better map plants in natural and disturbed areas in the park are needed. Additional mapping of this species is further recommended as the family Commelinaceae is notably invasive (Daehler 1998).

Coreopsis lanceolata L. (Tickseed)

Tickseed (*Coreopsis lanceolata*) is an herb native to central and southwestern USA, sparingly naturalized on Lānaʻi, Maui, and on Hawaiʻi (Wagner et al. 1999). In HAVO, tickseed was noted as abundant around the Kīlauea area by Fosberg (1966) and Higashino et al. (1988) reported plants in the montane seasonal zone and intentionally planted near the park residential area and Kīlauea Military Camp.

Tickseed was first controlled in HAVO in 1983, when approximately 6,000 plants were uprooted at the KMC baseball field. No additional control work has been noted since. This species was not mapped during parkwide surveys in HAVO, although occasional plants were recently observed at KMC on the outer edges of the baseball field. Tickseed was also collected in a planted location near the ʻĀinahou ranch house in 2004 and observed near the park's south boundary along Highway 11 in 2005 (L. Pratt pers. com.) Though tickseed does not appear to be invasive, relatively little is known about the plant's current distribution in HAVO, and additional surveys and monitoring are recommended to more thoroughly map the plant and develop a control strategy if necessary.

Cotoneaster pannosa Franch. (Cotoneaster)

Cotoneaster (*Cotoneaster pannosa*) is a small, bird dispersed shrub native to China (Wagner et al. 1999). Widely planted as an ornamental in Hawaiʻi, plants have recently become naturalized on Kauaʻi and Maui (Wagner et al. 1999). Plants are cultivated in the Volcano Golf Course subdivision (L. Pratt pers. com.) and sparingly naturalized near Volcano. In HAVO, Fosberg (1966) noted cotoneaster along the rim of Kīlauea Iki, and plants were collected by Poinar in 1963 near park headquarters and by Belfield and Mattos in 1996 near the Mauna Loa horse corral.

During surveys between 2000 and 2004, three cotoneaster individuals were encountered. A mature, fertile plant was controlled behind park headquarters in 2003. The shrub may have been planted or naturally occurring, and was growing among alien grasses and native shrubs near a pipeline ~10 m from a landscaped area. The cotoneaster was cut, and the stump was treated with herbicide. No juveniles were observed at the time, and none have been observed on subsequent annual monitoring visits.

Another mature, fertile cotoneaster was observed and treated 1.6 km from the previous plant, near KMC in 2003. The plant was growing among alien grasses and native shrubs, clearly removed from buildings and landscaped grounds, suggesting natural dispersal. Again, no juveniles were observed, and none have been seen during annual monitoring visits.

A third cotoneaster was observed along the west side of the Mauna Loa Rock Quarry in 2004. This juvenile plant was growing among aggregate soils and alien vegetation. The plant was uprooted, and no individuals have been seen at this site since.

Cotoneaster appears to be an incipient invader in HAVO with the potential to become weedy (Staples and Herbst 2005). Cotoneaster is dispersed through horticultural trade as well as by pigs and birds (Staples et al. 2000) including pheasants (Starr et al. 2003a) and belongs to a family with numerous invasive taxa in Hawai‘i (Rosaceae). Outside the park, shrubs have been observed establishing in closed canopy native forest surrounding the Kūlani Correctional Facility (K. Bio pers. com.). Continued monitoring of locations where cotoneaster formerly occurred and additional surveys in wet forest are recommended to prevent more widespread establishment in the park. Presently, eradication is sought and workloads to control cotoneaster are manageable but the control strategy should be re-evaluated if cotoneaster is found more widely distributed. Cotoneaster is controlled using a solution of 50% Garlon 3A in water applied to the cut stump.

***Delairea odorata* Lem. (Cape Ivy)**

Cape ivy is a fleshy, yellow-flowered invasive vine native to South Africa (Staples and Herbst 2005) naturalized in Hawai‘i (Wagner et al. 1999). Cape ivy was formerly known as *Senecio mikanioides* Otto. and the common names German or Italian ivy have been applied to these plants in Hawai`i (Wagner et al. 1999).

Cape ivy is a serious pest of high elevation forests on Mauna Loa (Motooka et al. 2003) and Mauna Kea (Wagner et al. 1999). In HAVO, Cape ivy was collected in a cultivated location in the park residential area in 1943, noted 6 m high in a tree (Fosberg 1966). Cape ivy was apparently controlled by park staff, and although records have not been located, plants have not been found during subsequent surveys that included sites of the former population in the residential area as described by Fosberg (1966). New individuals of this disruptive invader should be eradicated if found in the park.

Desmodium cajanifolium (Kunth) DC (Tree desmodium)

Tree desmodium (*Desmodium cajanifolium*) is a leguminous un-branched shrub with lavender to blue flowers native to Central and South America (Wagner et al. 1999). Tree desmodium is naturalized in the Kaʻū and Puna districts of Hawaiʻi in open forests and along roadsides (Wagner et al. 1999). In HAVO, tree desmodium has been found rarely along roadsides and in forest. Fosberg (1966) reported plants collected by Fagerlund and Mitchell in 1945 in native forest at upper ʻĀinahou, presumably from a location near a roadside. Higashino et al. (1988) reported tree desmodium from the sub-montane seasonal zone, wet forests and montane seasonal zones, although specific localities were not mentioned.

Tree desmodium was first controlled in selected areas in HAVO in 1986 and subsequently parkwide. A fertile tree desmodium was uprooted in 1986 at the steaming bluffs pullout between KMC and park headquarters. The site was monitored annually until 1993 after no additional plants were observed for several years.

From 2000-2004, tree desmodium was observed sparingly in HAVO. Two plants were observed along Highway 11 (mile markers 36 and 39) in 2001 (Pratt et al. *In review*) and an individual was observed and treated in 2002 (mile marker 30) by HAVO Vegetation Management staff. No additional plants were noted during the survey period.

The population documented by Fosberg (1966) at ʻĀinahou could not be relocated. The ʻĀinahou vicinity was intensively searched from 1984-1992 (Tunison et al. 1992), and again from 2000-2004, and no tree desmodium was observed.

Continued monitoring and control of tree desmodium leading to eradication is recommended to prevent re-establishment in HAVO. Roadsides appear likely avenues for establishment of this species, and principal roads (i.e. Highway 11, Crater Rim, Chain of Craters Road) should be monitored annually. Additional surveys, including areas near ʻĀinahou, should be undertaken to continue to search for this and other invasive species. Both manual uprooting and a solution of 10% Garlon 3A in water applied to the cut stump of tree desmodium have been effective in controlling plants.

Dicksonia fibrosa Colenso (New Zealand tree fern)

New Zealand tree-fern (*Dicksonia fibrosa*) is native to New Zealand, apparently sparingly cultivated, but not reported naturalized in Hawaiʻi (Palmer 2003). New Zealand tree-fern has not been found in HAVO but occurs in a number of residential lots in Volcano Village. Mature plants have not been observed in these areas (Tunison pers. obsn.), except for one lot where in 2006, new recruits were found establishing abundantly in areas surrounding planted trees. Later that year, at the landowner's request, these plants were removed. During two revisits to the site, in June and December, 2006, 179 and 79 individuals were removed respectively. Mature plants were controlled by uprooting or cutting and during follow up visits newly established

plants were foliar treated with herbicide. Both mechanical and chemical methods appeared to effectively control New Zealand tree-fern. Remaining control of this species was agreed to be undertaken by the landowner. A solution of 2% Roundup in water applied to the plant's foliage appears effective at controlling New Zealand tree fern.

Digitaria insularis (L.) Mez ex Ekman (Sourgrass)

Sourgrass (*Digitaria insularis*) is a robust neotropical grass, naturalized in low elevation disturbed sites on all the major Hawaiian Islands (Wagner et al. 1999, Motooka et al. 2003). Prior to 2001, sourgrass was unknown from HAVO (Fosberg 1966; Higashino et al. 1988).

Plants were first documented in 2001 at the end of Chain of Craters road, near the trailhead leading to the coastal eruption site near sea level. Less than 10 plants were observed in 2001, these were covered by lava in 2002, but an additional ten plants were observed and treated ~300 m west (downwind) of the original population in 2004. No plants were observed during a resurvey in early 2005. Plants in this population were found growing among roadside aggregates, native and alien shrubs and primarily alien grasses.

In 2002, three sourgrass plants were found 6 km downwind of the former population in previously burned grassland at Kealakomo Waena at 105 m elevation. These plants were growing among native pili grass (*Heteropogon contortus*), and alien grasses including recently established thatching grass. The population was treated at intervals of 6-13 months from late 2002 to late 2007.

Another sourgrass population was reported in 2003 near the Kamoʻoaliʻi Lava Flow at 340 m elevation, in a dry alien grassland ~20 km from the previous two populations. This population's size is unknown and remains untreated.

Sourgrass appears to be a recent invader of HAVO, although relatively little is known about the plant's distribution in the park prior to ungulate removal in the 1970's. Control and monitoring leading to eradication is recommended to halt the spread of this species in eastern HAVO. The eastern populations occur in native pili grasslands and appear relatively small and accessible, therefore control is warranted. The western (Kamoʻoaliʻi) population should be revisited to determine its range extent and to assess the feasibility of control. Sourgrass is abundant in adjacent areas of Kaʻū outside of HAVO, and it is possible that additional populations will be found. Currently, eradication is recommended parkwide, but this strategy should be changed to containment if western populations are unmanageable.

A solution of 1% Roundup in water applied to the plants foliage had previously been used to control sourgrass in HAVO, but plants occasionally re-sprouted (Benitez pers. obsn.). The efficacy of higher concentrations of Glyphosate based herbicides (e.g., 5% Roundup) should be evaluated as this ingredient is reported to be effective by Motooka et al. (2003). The current interval of 6-13 months for this grass did not halt seed

production, and a reduced interval of 2-3 months is recommended to prevent further spread of this weed.

Ehrharta stipoides Labill. (Meadow rice grass)

Meadow rice grass (*Ehrharta stipoides*) is a grass native to Australia, New Zealand and the Philippines, and naturalized in Hawai‘i on all major islands except Ni’ihau and Lāna’i (Wagner et al. 1999, Wysong et al. 2007). This grass was not mapped, though plants were observed widespread in the sub-montane, montane and sub-alpine zones, and also in seasonally dry to wet forest. Meadow rice grass was most frequent in former pastures now dominated by koa (*Acacia koa*) between 1,200 and 2,000 m elevation on Mauna Loa, where it was often a dominant groundcover. Meadow rice grass has been controlled in selected areas of SEAs Kīpuka Kī and Kīpuka Puaulu and in restoration sites on Mauna Loa to prevent the buildup of larger more disruptive populations and to permit native species regeneration. The preferred control method is a foliar herbicide application of 1% Roundup in water, although small scale trials using grass selective herbicides such as Fusilade DX are underway. No additional control is recommended for this widespread species.

Elaeagnus umbellata Thunb. (Elaeagnus)

Elaeagnus (*Elaeagnus umbellata*) is a nitrogen fixing shrub native to Asia, sparingly naturalized in Volcano, Hawai‘i, and surrounding areas. From 1984-1989, six elaeagnus were removed from the HAVO residential area, at Quarters 19 and 23. These sites were monitored until 1997, when elaeagnus was presumed extirpated after no plants had been seen for eight years. Previously, plants were documented southeast of the Nāhuku (Thurston) Lava Tube by Fosberg (1966) and later reported by park staff, who also reported plants along the south boundary of the ‘Ōla‘a SEA (HAVO 1986). No control records could be located for these sites, and individuals were not observed during recent surveys.

The ‘Āinahou Cultural Landscape Inventory (National Park Service 2004) lists Russian olive (*Elaeagnus angustifolia*) planted near the ranch house. This appears to be a misidentified olive tree (*Olea europaea* ssp. *cuspidata*) (L. Pratt, pers. com.).

Additional surveys for this weed are recommended in the Thurston SEA, and along park boundaries adjacent to the Volcano Village, where this species appears naturalized. Though sparingly naturalized, a recent weed risk assessment based on a number of biological characteristics (Daehler 2004, USFS PIER 2010) suggests a high likelihood of invasiveness for this species. Elaeagnus is declared a prohibited invasive species in many northeastern states and listed a noxious weed in Virginia (USDA-NRCS 2010b), where it invades roadsides, pastures and fields, grasslands and woodlands. In light of this designation, weedy characteristics, and evidence of naturalization in lands adjacent to the park, additional searches and control leading to eradication of any plants discovered is recommended.

***Erigeron karvinskianus* DC (Daisy fleabane)**

Daisy fleabane (*Erigeron karvinskianus*) is a sprawling asteraceous shrub native to the neotropics, naturalized on all major islands except Ni'ihau and Moloka'i from 300-1,300 m elevation in moderately wet disturbed and rocky areas (Wagner et al. 1999). Daisy fleabane is weedy in Hawai'i, capable of forming mats on forest floors that smother native plants (Motooka et al. 2003).

Daisy fleabane was documented within HAVO as early as 1944 (Fosberg 1966) from the Kīlauea area, and later by Higashino et al. (1988) from cultivated areas and wet forest in the Kīlauea summit area. In 2003, one large population and several smaller ones were located in semi-natural, landscaped and disturbed localities near the Kīlauea summit.

The park's largest population of daisy fleabane was found along a pipeline in wet forest at 1,200 m elevation. This population covered a ~100 m^2 area, on a relatively open exposure, growing among alien grasses and invasive knotweed (*Persicaria capitata*), surrounded by native trees.

Fifteen smaller clusters of daisy fleabane were mapped in the park residential and administrative areas in 2003. These ranged in size between 1 and 10 m^2, on landscaped grounds, stone walls, rock outcroppings and roadsides. Most plants were observed growing terrestrially in open areas. Exceptions were one plant observed on a native hapu'u tree-fern trunk near the Volcano House, one plant 5 m inside a native 'ōhi'a wet forest bordering an open landscaped area, and one plant in dense native vegetation edging Highway 11.

Three of the populations mapped in 2003 were at the Volcano House growing along a rock wall overlooking Kīlauea crater. Observations in 2008 and 2009 suggest these populations are expanding along the wall and down the pali (cliff). Recently, new small populations of <2 m^2 have also been noted along trails surrounding the Volcano House. These plants were not noted in 2003, and likely represent newly established individuals.

Daisy fleabane has never been targeted for control within HAVO, but the plant's localized distribution, small population size, and potential for spread suggest parkwide control leading to eradication is feasible and warranted. Daisy fleabane is a common weed in New Zealand along rock walls, stony places, roadsides and scrub (Roy et al. 2004), and considered a pest plant regulated under the New Zealand National Pest Plant Accord (New Zealand Government 2008), which bars it's sale, propagation and distribution. Casual observations suggest daisy fleabane is expanding from known populations near the Volcano House and park administrative areas, and unchecked spread may threaten native plants, particularly on rocky sites. Eradication efforts should target roadsides, trailsides, and the steep slopes where plants were found and continued searches to locate new individuals are also recommended.

***Eriobotria japonica* (Thunb.) Lindl. (Loquat)**

Loquat (*Eriobotria japonica)* is a rosaceous tree native to China cultivated throughout Hawai‘i for its attractive foliage and edible fruits. Plants occasionally escape cultivation and become naturalized (Wagner et al. 1999). Fosberg (1966) documented loquat from HAVO in the Kīlauea vicinity, and Tunison et al. (1992) mapped several planted individuals near the Kīlauea summit, and a large naturalized population at the ‘Āinahou Ranch. Loquat has been controlled in HAVO since 1984.

No loquat could be found within the former population described by Tunison et al. (1992) at ‘Āinahou. This population, surveyed in 1984, contained an estimated 7,000 seedlings and saplings surrounding the ranch house. Between 1984 and 1985, 7,328 seedlings and saplings were removed by park staff. From 1985 to 1993, 1-50 individuals were controlled annually. Only two trees were found during recent surveys in 2002, 300 m from the edge of the former infestation. These sterile trees were growing in seasonally dry forest and woodland at 880 and 940 m respectively, and were treated using a solution of 50 % Garlon 3A in water applied to the tree’s cut stump. A 100 m radius was searched around the trees, and no additional plants were noted.

Tunison et al. (1992) found loquat trees planted at the Volcano House and park headquarters (1,220 m elevation), planted or naturalized at Nāhuku (Thurston) Lava Tube (1,170 m elevation), and Keanakāko‘i Crater (1,120 m elevation). These individuals were controlled between 1984 and 1998, and no loquat was observed at any of these locations during recent surveys (2000-2004). Loquat appears to be naturalized outside of the park in the vicinity of Volcano Village, Hawaiian Ocean View Estates subdivision, Manukā State Park and Wood Valley (Benitez pers. obsn.).

Due to loquat’s limited population size and distribution, parkwide eradication appears feasible and is recommended. Dense stands and abundant recruitment have been observed, and dispersal appears vectored by birds. Additional surveys in the vicinity of the ‘Āinahou Ranch house are necessary to locate any remaining individuals from the former population. If plants are found these should be controlled and the area plus surroundings revisited annually until no new plants are discovered

Eucalyptus globulus **Labill. (Blue gum) and** ***Eucalyptus robusta*** **Sm. (Swamp mahogany)**

Eucalyptus (*Eucalyptus* spp.) is a large genus of Australian trees in the family Myrtaceae. Eucalyptus are widely cultivated in Hawai‘i with over 90 species introduced and more than 30 species naturalized (Wagner et al. 1999). In HAVO, Fosberg (1966) described blue gum (*E. globulus*) and swamp mahogany (*E. robusta*) in the vicinity of the old Volcano House. More recently, Higashino et al. (1988) noted blue gum and swamp mahogany cultivated or intentionally planted near the Kīlauea summit and the ‘Āinahou Ranch. Tunison et al. (1992) noted blue gum naturalized in HAVO, and mapped a 2.5 ha population at Nāmakani Paio, four small populations at ‘Āinahou comprising 0.5 ha total plus a single individual above Kealakomo. Tunison (1992) did not report swamp mahogany distribution.

Blue gum has been controlled in selected areas in HAVO since 1983. Control records do not distinguish between the Eucalyptus species, though blue gum is the principal species currently in the park.

The park's largest population of blue gum was found at the Nāmakani Paio campground along Highway 11 at 1,200 m elevation. This population extended over 3 ha and consisted of many large mature trees over 40 m tall, considered part of the historic cultural landscape. New individuals that establish beyond this area have been controlled annually. Since 1983, 219 individuals have been removed.

Blue gum was formerly known from ʻĀinahou near the ranch house in ʻōhiʻa and faya forest and woodlands (Tunison et al. 1992). Control of plants began in 1983. No plants have been encountered at this location since 1989 and this population appears to have been extirpated.

Approximately 20 mature swamp mahogany trees were found near the HAVO rainshed at 1,230 m elevation. A juvenile swamp mahogany was found behind park headquarters approximately 200 m from this population in 2003. No other swamp mahogany was noted in the vicinity. Plants at the HAVO rainshed have never been controlled.

A mature unidentified *Eucalyptus* species was encountered in 2000 along the Waldron Ledge. This tree was treated using a solution of 50 % Garlon 3A in water applied to the frilled base of the tree. No additional plants have been observed in the vicinity since treatment. It is uncertain how the tree became established at this site.

Vegetation Management files document *Eucalyptus* control of a single plant along the Chain of Craters Road at 600 m elevation, and several individuals along Highway 11 near the Kaʻū boundary at 820 m elevation. The former plant was likely the blue gum mapped by Tunison et al. (1992), and the latter plants were an undetermined species. No plants were encountered at either site during recent surveys.

Parkwide monitoring and control to extirpate blue gum, swamp mahogany and other *Eucalyptus* species from areas outside of the cultural historic landscape should be continued. Containment of the Nāmakani population by removing individuals that establish beyond the historic cultural landscape has been effective at checking blue gum spread into surrounding dry ʻōhiʻa woodland natural areas. The HAVO rainshed population should likewise be monitored and any new plants removed. All other individuals parkwide should be controlled to eradicate if populations are discovered. Even if cultural concerns regarding their removal can be addressed, eradication of the two populations of *Eucalyptus* at Nāmakani and HAVO rainshed may be complicated because of the size of the trees and their proximity to structures. Nevertheless, eradication should be considered as this genus is invasive and serves as an alternate host for the pathogen guava rust (*Puccinia psidii* Winter), which may also threaten native ʻōhiʻa (*Metrosideros polymorpha*) trees.

***Falcataria moluccana* (Miq.) Barneby and Grimes (Albizia)**

Albizia (*Falcataria moluccana*) is a fast growing large tree native to the Moluccas, New Guinea, New Britain and the Solomon Islands (Wagner et al. 1999). In Hawai‘i, albizia has been introduced for reforestation and shade, and has become naturalized in low elevation disturbed sites on all islands except Ni’ihau (Wagner et al. 1999). On the island of Hawai‘i, albizia is conspicuous in disturbed environments below 600 m throughout the Puna and Ka‘ū districts (Benitez pers. obsn.).

Albizia was not documented by Fosberg (1966), but Higashino et al. (1988) reported albizia established along disturbed areas in the park, though no specific locations were given. Tunison et al. (1992) found one individual along Chain of Craters road; this tree was controlled in 1985. One individual was later found and controlled in 2000 along the KalapanaTrail in eastern HAVO. Resurveys of these areas found no additional plants.

Surveys conducted between 2000 and 2004 mapped 19 albizia trees growing in open areas including alien grasslands and sparsely vegetated pāhoehoe lava fields between 275 and 580 m elevation in the southwestern section of the Kīlauea area. The largest occurrence was 14 albizia scattered across 450 ha of alien grasslands and sparse native shrubs in Kīpuka Pepeiao. Although many trees appeared mature, no fertile material was noted. In 2004, all fourteen individuals were treated with a solution of 15% Garlon 4 in diesel fuel oil applied to the basal bark of the trees. While this treatment effectively killed most trees, two large trees did not die. A wildfire occurred in the area six months later, and though the two mature individuals were found persisting in 2008, no seedlings were observed.

West of Kīpuka Pepeiao, four mature albizia were found during ground searches and helicopter surveys. These plants were in alien grasslands, sparse shrublands and sparsely vegetated lava flows, at 270-580 m elevations, and have not been controlled.

In the East Rift, one albizia was found and controlled in a mesic-wet forest burned by wildfires between 2002 and 2003. No additional albizia were found in subsequent surveys of the area between 2004 and 2005.

Albizia is a serious pest in Hawai‘i (Smith 1985). Trees form exclusive stands and are capable of altering succession and ecosystem function in invaded areas through their ability to fix nitrogen (Hughes and Denslow 2005). The ability to fix nitrogen is an important trait of many natural area invaders worldwide (Daehler 1998).

Because of albizia’s disruptive nature, potential for spread, limited distribution, and detectability, parkwide eradication and increased monitoring to locate new individuals are recommended. Discovery of albizia in new areas in HAVO is probable given the likelihood of seeds dispersing by wind, birds or possibly water from trees located outside the park or undetected individuals within HAVO (Staples et al. 2000). Expanded monitoring by helicopter is feasible because albizia has a prominent aerial signature,

and occurs primarily in open areas. Such surveys could be done in conjunction with semi-annual surveys currently underway to remove invasive fountain grass.

Albizia is controlled in HAVO using a solution of 15% Garlon 4 in diesel fuel oil applied around the lowest 20 cm of the basal bark of the tree. This treatment was not effective on several exceptionally large trees in HAVO (dbh >80 cm), and the efficacy of higher concentrations of Garlon 4 (i.e., 50%) is being evaluated.

Albizia's nomenclature has been strenuously revised, with recent treatments including *Adenanthera falcataria* L., *Albizia falcata* sensu auct., non. (L.) Backer, *A. falcataria* (L.) Fosb., *A. mollucana* Miq., and *Paraserianthes falcataria* (L.) I. Nielsen (Wagner et al. 1999). While several other species of *Albizia* (*sensu lato*; including *Albizia*, *Falcataria* and *Paraserianthes*) are cultivated and/or naturalized in Hawai'i (Wagner et al. 1999; Staples and Herbst 2005), these have not been observed in the park, though *Albizia chinensis* is frequent along Highway 11 below approximately 500 m elevation (L. Pratt pers. com.)

Ficus macrophylla Desf. ex. Pers. (Moreton bay fig), *F. carica* L. (common fig) and *F. pumilla* L. (creeping fig)

Moreton bay fig (*Ficus macrophylla*) is a large tree native to Australia recently naturalized in Hawai'i (Wagner et al. 1999, Oppenheimer and Bartlett 2000). In HAVO, a Moreton Bay fig was found apparently planted at the 'Āinahou Ranch. This 10 m tall tree was treated in 2007 using a basal bark application of 15% Garlon 4 in diesel fuel oil, as a precautionary measure to prevent the new establishment of this potentially invasive tree. Like other *Ficus* spp, Moreton bay fig depends on a single symbiotic wasp species for pollination. The wasp pollinator for Moreton bay fig was deliberately introduced to Hawai'i in 1921 and both the plant and the wasp appear naturalized (Wagner et al. 1999).

Two other species of *Ficus* (*F. carica* – common fig, and *F. pumilla* – creeping fig) are known from HAVO (Higashino et al. 1988). A common fig population was controlled near Kīpuka Puaulu SEA between the picnic area and the trailhead from 1983-1986. This population was monitored until 1996, and was presumed extirpated because no additional plants were observed at this site, including surveys in 2003-2004. Common fig was also reported from the 'Āinahou Ranch, although no control work was noted, and plants were observed in 2004 in areas cultivated surrounding the ranch house (L. Pratt, pers. com). The common fig has not been reported naturalized in Hawai'i, though the pollinating fig wasp for this species was introduced to the islands in 1909 (Wagner et al. 1999).

Creeping fig was controlled from 1985-1992 near park administrative areas. From 1992-1996, no plants were observed, and the species was presumed extirpated. No additional plants were found during a monitoring visit in 2002, and plants were not noted elsewhere in HAVO. In 2008 and 2009 small vines were observed on a rock wall near the park hula platform. The symbiotic wasp pollinator of creeping fig is absent from

Hawai‘i (Wagner et al. 1999). Considering the relatively small population sizes and potential invasiveness, a continuation of previous control efforts is recommended leading to eradication of all *Ficus* species in the park.

Fraxinus uhdei **(Wenzig) Lingelsh (Tropical ash)**

Tropical ash (*Fraxinus uhdei*) is a tree native to Mexico, widely planted in Hawai‘i for silviculture and reforestation purposes (Little and Skolmen 1989). Tropical ash is naturalized and considered a serious weed capable of forming monospecific stands in Hawai‘i (Smith 1985). Hawai‘i State Forestry records document over 300,000 American ash (*F. americana* L.) trees planted in Hawai‘i, though the correct identity of these trees is *F. uhdei* (Wagner et al. 1999) and American ash is apparently absent from Hawai`i. From 1982-2000, 1,686 plants, mostly seedlings and saplings, were controlled at ‘Āinahou Ranch, and subsequently 4 mature plants and numerous seedlings were mapped by Tunison et al. (1992), principally near the ranch house. These plants were subsequently controlled.

Although tropical ash has not been observed in the survey area since 2000, continued monitoring in and around ‘Āinahou is warranted because of the invasive nature of this tree. Because seedlings were formerly abundant in the area, it is possible that a seed bank persists at ‘Āinahou, or that individuals may have been missed during the previous control cycle. Control leading to eradication is recommended should new individuals be discovered.

Fuchsia magellanica **Lam. (Hardy fuchsia),** ***F. hybrida*** **Hort. ex Siebold and Voss. and** ***F. paniculata*** **Lindl.**

Hardy fuchsia (*Fuchsia magellanica* Lam.) is a shrub native to South America, naturalized in mesic to wet forest on Kaua‘i, Maui and Hawai‘i. Fosberg (1966) reported hardy fuchsia (*F. magellanica* var. *discolor* Bailey) naturalized in the Kīlauea area and Higashino et al. (1988) reported hardy fuchsia in the park residential areas and naturalized in wet forest.

The distribution of hardy fuchsia in HAVO was mapped in 1985 (HAVO Vegetation Management Files 1985) when five dense roadside populations were identified. These populations were mapped along Crater Rim Drive, from the park research area to Pu‘u Puai. An additional 32 smaller populations were mapped elsewhere in the Kīlauea summit area. Within the larger roadside populations, cover of hardy fuchsia was estimated at 23-73% along the ten 11-29 m transects sampled.

Tunison et al. (1992) report a similar distribution of hardy fuchsia in HAVO. Populations were noted mainly along Crater Rim Drive, from Pu‘u Puai to Thurston SEA, and along the Escape Road. Tunison et al. (1992) noted that the spread of hardy fuchsia appears to be mainly vegetative, as no viable seeds were found during a two-year period.

During 2000-2004 surveys, the distribution of hardy fuchsia was noted along roadsides and trailsides in areas formerly mapped near the Kīlauea summit. These areas include the Crater Rim Drive, the Escape Road, the park residential areas, and Thurston SEA. Additional plants were noted in ʻŌlaʻa along a fenceline in the Koa unit SEA, an area where plants had not previously been mapped. A more detailed investigation, comparing the present distribution of fuchsia relative to the 1985 data set (HAVO 1985) and mapping by Tunison et al. (1992) is recommended to evaluate the changes in hardy fuchsia distribution and abundance. Presently, control of this species is recommended in SEA units and project sites due to previous findings of dense infestations suggesting invasive potential.

Other fuchsia species and varieties are found in HAVO. Fosberg (1966) reported *F. arborescens* (Sims) and *F*. *hybrida* (Voss) in the park residential area, and Higashino et al. (1988) reported *F. paniculata* Lindl, which is more recent synonym of *F. arborescens* (Sims), in cultivated areas and naturalized in rain forest, and *F*. x *hybrida* Hort. ex Vilm. in the park residential area. Plants formerly reported as *F. hybrida* (Fosberg 1966) and *F*. x *hybrida* (Higashino et al. 1988) are treated as *F. hybrida* Hort. ex Siebold and Voss. (Wagner et al. 1999), and likely represent a variable horticultural hybrid with *F. magellanica* as one of the parents (Wagner et al. 1999). These species are less widespread than *F. magellanica*, though control leading to eradication is also recommended.

Grevillea banksii R. Br. (Kāhili flower)

Kāhili flower (*Grevillea banksii*) is a small tree native to Australia naturalized in dry to wet disturbed areas from 75-400 m elevation on all the main Hawaiian islands except Lānaʻi and Kahoʻolawe (Wagner et al.1999). The Hawaiʻi Department of Agriculture lists kāhili flower a noxious weed (USDA-NRCS 2010a) and Motooka et al. (2003) consider kāhili flower invasive in pastures and natural areas. In HAVO, kāhili flower was not noted by Fosberg (1966) or Higashino et al. (1988).

Kāhili flower was first found in 2002 when approximately nine mature and 70 juvenile trees were discovered along the park's western boundary. The population was distributed across 0.3 ha of sparse shrubs and alien grasses, and has not been controlled. A second population, with 35 mature plants, was mapped 3 km to the south in the Kū`ēʻē grasslands. This population was initially controlled in 2007. No additional plants were observed elsewhere in HAVO. Outside the park, infestations were found in the Kaʻū district, including the adjacent State owned lease lands near the Kapāpala Ranch, and cultivated and sparingly naturalized in Ocean View (Benitez 2004).

Kāhili flower is a newly established invader in HAVO. This population was in a remote location far removed (>2km) from the nearest known plants, suggesting an effective wind dispersal mechanism consistent with reports by Staples et al. (2000). Control leading to eradication is recommended and additional searches and monitoring in the vicinity of plants are warranted to map occurrences and limit the establishment of this

potentially disruptive weed. Motooka et al. (2003) reported effective control with a Triclopyr ester based herbicide at 2.5% concentration in diesel fuel oil.

Kāhili flower is known locally as bottlebrush, a name also applied to unrelated ornamental trees in the genus *Callistemon* R. Brown. These latter ornamentals are popular but not naturalized in Hawai`i (Wagner et al. 1999).

Grevillea robusta A. Cunn. ex R. Br. (Silk oak)

Silk oak (*Grevillea robusta*) is a large tree with wind-dispersed seeds native to Australia, considered a serious weed in Hawai‘i (Smith 1985; Staples et al. 2000). Introduced around 1880 and planted extensively for reforestation purposes, silk oak is found on all islands except Ni’ihau and Moloka’i (Wagner et al. 1999). Silk oak was documented in HAVO as early as 1944 (Fosberg 1966) near the Volcano House and along the park’s western boundary. Tunison et al. (1992) mapped silk oak in 13 populations across 300 ha below 1,000 m elevation west of the ‘Āinahou Ranch. Mapping in 2000-2004 found silk oak more widespread, with individuals concentrated in three core areas (western boundary, Kīpuka Pepeiao, Ka‘ū Desert Trail) and several outliers that occurred in ‘Āinahou and Keamoku SEA. Selected individuals in core and outlying populations have been controlled in HAVO since 1985.

HAVO’s largest silk oak population was found along the park’s western boundary at ~700 m elevation. A central core of >1000 silk oak was mapped among sparse native and alien trees, shrubs, grasses, and mostly pāhoehoe lava flows. This core was calculated to cover 104 ha in 2002, and was surrounded by sparser silk oak between 640 and 800 m elevations. Based on sub-sampling, an estimated 625 individuals occupied 438 ha of surrounding ‘ōhi‘a dominated kīpukas, open shrublands and lava flows, and a range of size classes observed gave evidence that the population was recruiting and increasing in size. Plants in these areas were generally found in groupings of 1-20 individuals, but up to 198 individuals were found in a single cluster. Further south at lower elevations, silk oak became sparser, with typical clusters of 1-4 plant separated by distances as much as 3.8 km. An exception was a 45 ha area containing 55 individuals in a woodland near 550 m elevation. In these sparser infestations, populations were mapped from a helicopter, so small plants may remain undetected. The edges of the large core population and surrounding areas were initially treated in 2010 by the park’s Exotic Plant Management Team (EPMT) as part of a containment strategy based on these mapping efforts; and 2,368 trees were controlled over 62 ha. At that time, mortality and defoliation of trees presumably due to volcanic gas emissions from Kīlauea caldera was observed, as was newly established trees since mapping in 2002.

In Kīpuka Pepeiao, an estimated 420 individuals were mapped in 2002, distributed across 104 ha of alien grasslands, sparse shrublands and ‘ōhi‘a kīpukas between 580 and 640 m elevation. Control work to eradicate this population began in 1999 and has since removed approximately 729 individuals. A wildfire burned this Kīpuka in late 2004.

No follow-up surveys have been done to determine if individuals established after the burn.

Between Kīpuka Pepeiao and Hilina Pali road, silk oak occurred occasionally within very dense clusters near the Kaʻū Desert Trail. The largest mapped population consisted of 286 individuals. At this site, 673 individuals had been previously controlled in 1999. An additional 300 trees were scattered in clusters of 1-50 individuals along the Kaʻū Desert trail.

Elsewhere in the park, two silk oaks were found and treated at the ʻĀinahou Ranch in 2003. One of these was in a former population described by Tunison et al. (1992) and subsequently treated. In the Keamoku SEA, 28 individuals were found and treated in 2004. No silk oak had previously been reported from this area. Outside of HAVO, silk oak forms dense stands on adjacent lands in dry sparse ʻōhiʻa woodland and pasture including lower elevation Kapāpala Ranch (Benitez pers. obsn.). These populations likely are an important source of silk oak propagules into the park.

Silk oak is a tenacious pest of native Hawaiian ecosystems (Smith 1985), widespread in HAVO and adjacent lands. Eradication of trees in the park's western boundary appears prohibitive due to large population sizes and remoteness. Instead, containment to prevent new establishment and control trees outside of the large core population is recommended as a continuation of control efforts led by EPMT in 2010. Similarly, containment is recommended to exclude plants from areas east of Hilina Pali road, and within SEAs Keʻāmoku and Kaʻū Buffer to stop the eastward spread in the park. Removal of silk oak from Kīpuka Pepeiao appears feasible due to smaller population sizes and relatively accessible terrain. Such work would complement ongoing restoration efforts to rehabilitate this burned area. A logical continuation of these efforts is control of populations along the Kaʻū Desert Trail extending to Hilina Pali road. Silk oak appears extirpated at ʻĀinahou, but these sites should be monitored to remove additionally encountered individuals and prevent re-establishment. Silk oak is controlled by applying a solution of 15% Garlon 4 in diesel fuel oil to the basal bark (i.e., lowest 20 cm) of the tree. Monitoring is warranted to further investigate the response of silk oak populations to volcanic gas exposure.

***Hebe speciosa* (A. Cunn) Cockayne & Allan (Hebe)**

Hebe is a purple flowered shrub native to New Zealand recently naturalized in Hawaiʻi and in HAVO (Shannon and Wagner 1996). Hebe was collected in 1938 near the Old Volcano House (Fosberg 1966) presumably planted and latter noted by Higashino et al. (1988) in cultivated areas near the Kīlauea Summit. Hebe appears deliberately introduced to the park as an ornamental, and has never been controlled.

Hebe was found sparingly in disturbed habitats of the park residential, administrative and rainshed areas. Plants were found in grassy areas surrounding the park rainshed, along a pipeline in wet forest running through the park administrative area, and behind the maintenance building in wet forest. Though this genus was recently reassigned to

the family Plantaginaceae (Wagner et al. 1999), the plant's former family Scrophulariaceae was well represented with 21 alien naturalized species including the herb common mullein (*Verbascum thapsus*), targeted in costly control programs in HAVO. Due to affinities shared with this family, and in light of recent evidence of naturalization, eradication of the relatively small populations of hebe are recommended as a precautionary measure while workloads remain manageable.

***Hedera helix* L. (English ivy)**

English ivy is a Eurasian climbing vine, popular with the horticultural trade because of its attractive foliage and hardiness. Plants readily escape cultivation, and English ivy is widely naturalized in temperate and tropical zones (Staples and Herbst 2005). In the Hawaiian Islands, vines are sparingly naturalized on Kaua'i, O'ahu, Maui, and Hawai'i (Wagner et al. 1999). In HAVO, Fosberg (1966) found English ivy in the residential area, and Higashino et al. (1988) noted English ivy vines in the sub-montane seasonal zone ('Āinahou Ranch) and wet forest including the park residential area. Tunison et al. (1992) mapped populations at 'Āinahou and the park residential area, and a small population at the Nāhuku (Thurston) Lava Tube. English ivy has been controlled since 1983 at 'Āinahou and since 1985 at the park residential area.

English ivy was most abundant in the park residential area, where 11 discrete groupings of 1-50 plants were mapped. Vines were distributed across 16 ha of landscaped grounds adjacent native wet forest at ~1,220 m elevation. Prostrate and climbing habits up to 12 m were noted, as were newly established seedlings suggesting potential for spread from seed. An additional population of <10 individuals was mapped near the park entrance station, approximately 500 m away. Control of park residential populations has been continuous since 1985, and newly discovered individuals are removed as they are discovered. Populations are re-visited at 6-12 month intervals to prevent range expansion. No new populations were discovered during surveys in the residential area or elsewhere in HAVO.

A small population of English ivy was mapped and controlled at 'Āinahou Ranch (910 m elevation) in alien/native vegetation in 2002. Several vines were found near the ranch house and the plant nursery among 'ōhi'a, Cook pine (*Araucaria columnaris*) and pine (*Pinus* sp.) trees. A larger population (~50 m² in 1987) formerly occurred at this site, but was controlled in 1987. No English ivy has been observed at 'Āinahou since 2002.

Another small English ivy population was found in the 'Ōla'a Small Tract SEA unit at 1,160 m elevation in wet forest. Numerous plants were in a nearby residential lot and were found trailing across the boundary fence into the park. No seedlings were noted, but plants had adventitious roots and were establishing among the native vegetation. The gross infested area occupied by plants on the HAVO side of the boundary fence was estimated at ~400 m^2. A former population located at the Nāhuku (Thurston) Lava Tube could not be relocated during the 2002 survey.

Continued control of English ivy leading to eradication is recommended due to this species' localized distribution and high invasive potential. This strategy has been effective in halting the spread of English ivy in the HAVO residential area, ʻĀinahou and Nāhuku populations. Continued monitoring is recommended at these sites to ensure extirpation and to search for new individuals, as recruitment from seed has been observed. Continued control of encroaching vines in ʻŌlaʻa is recommended and the park should work with residential owners to remove plants along the boundary. English ivy is controlled using a foliar solution of 2% Garlon 4 in water.

Hedychium gardnerianum Sheppard ex Ker-Gawl (Kāhili ginger)

Kāhili ginger (*Hedychium gardnerianum*) is a coarse herb with showy and fragrant flowers, native to the Himalayan region (Wagner et al. 1999) and regarded as one of the most disruptive pests of wet forests in Hawai'i, where it forms monotypic stands which prevent native species regeneration (Smith 1985). Kāhili ginger rhizomes and plants are sold throughout the Islands in gift shops, nurseries, and the Honolulu airport. Plants produce fragrant blossoms in the summer months.

In HAVO, Kāhili ginger was found widespread; distributed over an estimated 3,000 ha of upland wet and mesic forest near the Kīlauea summit, lower Mauna Loa strip, and ʻŌlaʻa wet forest. Throughout much of this range, Kāhili ginger dominates the understory of native forest, and crowds out native understory species. To limit these impacts, plants are controlled in SEA units surrounding the Kīlauea summit and in ʻŌlaʻa.

The occurrence of kāhili ginger was mapped along roadsides, trailsides and fencelines, and along transects from 1998-2004. Plants were found at a maximum elevation of 1,300 m on Mauna Loa in Kīpuka Kī SEA, and at a minimum elevation of 750 m in the East Rift. The densest infestations noted were in forested areas near the Kīlauea summit, where monospecific thickets were frequent. In ʻŌlaʻa wet forest, monitoring along transects in 1998 found kāhili ginger more abundant in the southern half of the unit.

Additional searches found a sparser distribution with decreasing elevation and precipitation. Infestations of few scattered plants were found around 900 m elevation near ʻĀinahou, and an apparently isolated but dense infestation was found around 750 m elevation in the East Rift, in wet forest east of the Nāpau campground in 2009. No plants had been noted in the East Rift previously by Pratt et al. (1999), or during previous surveys of this area's trails and fencelines, or in systematic sweeps of East Rift SEA units from 2000-2005, though the area where plants were discovered was not visited during these surveys.

Kāhili ginger is controlled by cutting stalks and spraying exposed rhizomes with a solution of 1g Escort per liter of water. Stalks may be sprayed several days after cutting. Plants are controlled most intensively in SEA units and special project sites near the Kīlauea summit. A biological control agent, *Ralstonia solanacearum*, is currently being investigated as a biological control agent.

Because of the severe threat to native plant communities, a continuation of control efforts in SEA units is recommended, including expanded control in other contiguous wet forest areas if resources permit. Additional mapping of the plant and control efforts would be of strategic value to better prioritize new control sites. A summary of research and control could also be of value to park managers and interpreters to communicate the disruptive effects of this and other escaped ornamental species, and how the park manages such threats.

Heterocentron subtriplinervum (Link and Otto) A. Braun and C. Bouché (Pearl flower)

Pearl flower (*Heterocentron subtriplinervum*) is a shrub belonging to the family Melastomataceae, native to Mexico and Guatemala and naturalized in Hawai‘i (Wagner et al. 1999). Pearl flower was noted in disturbed areas of Kīlauea by Fosberg (1966), and two populations were later mapped by Tunison et al. (1992) along Crater Rim Drive below the Nāhuku (Thurston) Lava Tube, and near Pu‘u Puai. Tunison et al. (1992) described additional plants near the park administrative and residential areas and near the Volcano House and along Hwy 11.

In 2003, dense populations of pearl flower were encountered along Crater Rim Drive in areas previously identified by Tunison et al. (1992). Additional searches away from the roadside and ~100 m into the forest interior found no plants, suggesting that pearl flower has not become established in the forest interior.

Plants previously noted by Tunison et al. (1992) were remapped at the Volcano House and near park’s administrative areas. Evidence of new recruitment from seed was observed at the Volcano House, where new plants were found growing among alien and native vegetation on the edge of a pali (cliff) behind the house. New recruitment from seed was also reported by Tunison et al. (1992).

In 2006, the populations along Crater Rim Drive were controlled using a foliar solution of 5% Roundup in water. These populations have been re-visited at yearly intervals to retreat re-sprouting plants and to remove newly established individuals. Expanding control parkwide to eradicate all individuals including those at the park’s administrative area and Volcano House, where new plants are establishing, is recommended because of the high invasive potential of the family Melastomataceae. Included in this family are some of the most disruptive species (e.g., *Clidemia hirta*, *Miconia calvescens*, *Tibouchina* spp.) found in Hawai‘i and other tropical island ecosystems.

Heterotheca grandiflora Nutt. (Telegraph weed)

The malodorous herb telegraph weed (*Heterotheca grandiflora*) is native to California, Arizona and Baja California, Mexico. In Hawai‘i, plants are commonly found in dry disturbed areas up to 2,270 m elevation (Wagner et al. 1999). In HAVO telegraph

weed was previously known from a roadside population located near Mauna Ulu in 1986. This population was controlled in the late 1980's, and plants were observed as late as 1993 (Pratt, pers. com.). No plants have been seen since, and the population is believed extirpated. In 2001 a new population along Highway 11 at ~1,030 m elevation was found and plants have since been controlled here.

The Highway 11 roadside population occurs from 880 to 1,220 m elevation. Plants are found in two 500 m long clusters, centered near mile-markers 31 (1,030 m elevation) and 35 (1,220 m elevation). Telegraph weed grows in gravel, aggregates and among alien grasses and herbs within 5 m of the road pavement's edge. Plants have not been observed forming a continuous cover and no establishment beyond roadsides has been noted. Telegraph weed was not found elsewhere in HAVO during recent surveys that included the vicinity of the formerly controlled population near Mauna Ulu.

Since control began in 2001, 849 individuals have been removed along Highway 11. Sites are revisited at 4-6 month intervals, with 8 to 377 individuals removed during each visit. Telegraph weed is controlled by manually uprooting plants or by applying a solution of 2% Roundup in water to the plant's foliage. Seed set has been observed at least twice since control was initiated.

Because of the limited distribution of telegraph weed in HAVO and past effectiveness of control in eliminating individuals, continued control leading to parkwide eradication is recommended. Routine monitoring of principal roadsides in HAVO is also recommended because these areas appear to be a primary corridor for the dispersal and establishment of telegraph weed; outside of HAVO, dense infestations have been observed along Highway 200 (Saddle Road) between 1,500 and 2,000 m elevation (Benitez pers. obsn.).

Seed set observed between control cycles suggests the need to shorten the retreat interval to 3-4 months to exhaust the seed bank and prevent recruitment of new individuals. Telegraph weed produces abundant seed at relatively short intervals, a trait considered important to invasive success (Rejmánek and Richardson 1996).

Hyparrhenia rufa (Nees) Stapf (Thatching grass)

Thatching grass (*Hyparrhenia rufa*) is a C_4 African grass naturalized in many tropical areas worldwide (Wagner et al. 1999). In Hawai'i thatching grass is common along roadsides and cultivated fields between 10 and 660 m elevation on all major islands except Lāna'i, Kaho'olawe, and Ni'ihau (Wagner et al. 1999). In HAVO thatching grass is a dominant grass in coastal lowlands west of Chain of Craters Road. Thatching grass has not been observed in coastal lowlands east of Chain of Craters Road. These areas are notable for extensive stands of the native grass pili (*Heteropogon contortus*).

Since 1989 a containment strategy has been in place to check the spread of thatching grass into areas east of Chain of Craters road. Plants along roadsides, and up to 50 m away are controlled at six-month intervals using a foliar solution of 1-5%

Roundup in water. Monitoring in 2007 to assess the efficacy of this containment strategy searched for thatching grass along two transects (total combined length was 4 km) located in native pili grasslands and no plants were detected. These findings support continuation of control of thatching grass to contain and prevent establishment in the pili grasslands east of Chain of Craters Road.

Ipomea triloba L. (Little bell)

Little bell (*Ipomea triloba*) is a vine in the family Convovulaceae, native to the West Indies, naturalized in low elevation sites on Midway atoll and Kaua'i, O'ahu and Maui, and recently reported from Hawai`i (Wagner et al. 1999). Little bell was previously unknown from HAVO (Fosberg 1966; Higashino et al. 1988). In 2005, 10 plants were found along the Sulphur Banks Trail, a popular visitor attraction. The plant was uprooted, and the area was later searched for additional plants, but none were found.

Contaminated fill used in a recent trail construction project may have been responsible for the introduction of little bell to HAVO. This occurrence underscores the need for continued monitoring of principal areas of human activities, because these are avenues for new plant introductions. Little bell is not known to have a high invasive potential, however, continued monitoring of this site is recommended to prevent the establishment of this species.

Jasminum humile L. (Jasmine)

Jasmine (*Jasminum humile*) belongs to a genus of shrubs in the family Oleaceae, native to the Paleotropics and popularly cultivated for their fragrant flowers (Staples and Herbst 2005). Approximately 11 jasmine species are cultivated in Hawai‘i, yet only *J. fluminese* is known to be naturalized. In HAVO, Higashino et al. (1988) noted two species, *J. humile* and *J. multiflorum*, in cultivated areas. HAVO control records also note an unknown species of jasmine controlled in 1992, south of the Volcano House.

In 2002, one species of jasmine was encountered at the park rainshed. This jasmine had yellow flowers and pinnate leaves, determined as *J. humile*, known locally as pīkake melemele. No evidence of vegetative spread or spread from seed was noted in the vicinity and this individual remains. In 2009, a mature *J. humile* was treated in the Mauna Loa horse corral. No additional jasmine was noted in the vicinity or elsewhere in HAVO during parkwide surveys.

Though jasmine does not appear to be spreading in HAVO, caution is warranted due to the invasive nature of genera in the family Oleaceae (e.g., *Jasminum, Ligustrum*, *Olea*) and removal of the extant plant as well as continued monitoring is recommended. Nevertheless, this species appears to be a relatively low priority relative to more disruptive species, as natural recruitment has not been observed and jasmine plants are generally self incompatible (Staples and Herbst 2005) and many of the cultivated varieties are clones which rarely produce seed.

Justicia betonica L. (White shrimp plant)

White shrimp plant (*Justicia betonica*) is a shrub native to Asia, cultivated throughout Hawai‘i, and naturalized on Kaua‘i, O‘ahu, Moloka‘i, Lāna‘i, Maui and Hawai‘i (Wagner et al, 1999). The older synonym *Nicoteba betonica* (L.) Lindau has been applied to this species. In pastures and woodlands, white shrimp plant can form dense stands (Motooka 2003). The first Hawaiian collection of this plant was made in the HAVO residential area in 1943 (Fosberg 1966; Wagner et al. 1999). Higashino et al. (1988) reported plants in cultivated areas but not naturalized in HAVO.

Thirty mature plants were found in HAVO's coastal lowlands in 2003. These plants were located along the Chain of Craters road at an elevation of 100 m, distributed over ~0.1 ha, near a scenic viewing area, among boulders, exposed pāhoehoe lava rock and shallow soils with alien grasses and lantana (*Lantana camara*) shrubs. Plants did not appear cultivated. No additional white shrimp plant was observed in HAVO, including surveys of the park residential area.

The Chain of Craters population was initially controlled in 2004 using a foliar solution of 5% Roundup in water, and subsequently monitored at three-month intervals. No plants were found in a resurvey in 2006, although from 2007 to 2009, 10 plants were treated.

White shrimp plant is a potentially serious weed (Neal 1965), which escapes cultivation and forms dense thickets in Hawai‘i (Wagner et al. 1999). Because of this, continued monitoring and control leading to eradication of the Chain of Craters population and additional surveys to search for new individuals are recommended. Additional populations, if encountered in the residential area or elsewhere in HAVO, should also be eradicated.

Kalanchoë pinnata (Lamarck) Persoon (Air plant)

Air plant (*Kalanchoë pinnata*) is a succulent herb of unknown origin (Wagner et al. 1999). Disagreement exists over the generic placement of this species; the most commonly applied synonym of air plant is *Bryophyllum pinnatum* (Lamarck) ‘Oken. This species is naturalized and sometimes very abundant in low elevation disturbed habitats on all the main islands except Kaho‘olawe and Ni‘ihau. Fosberg (1966) did not find air plant in HAVO, and Higashino et al. (1988) noted air plant in the park residential area. Although this air plant population could not be relocated, five new populations were found during recent surveys in the park. Control of air plant in HAVO began in 2002 in the coastal lowlands and was subsequently expanded as new populations were discovered.

In 2002, a 60 m² air plant population was mapped at a scenic pullout at 100 m elevation on Chain of Craters road. This population contained an estimated 90 mature plants on the north side of the road and 10 mature plants on the south side. Seedlings and immature plants were abundant. Chemical control using a foliar application of 5%

Roundup in water began in February 2002, and the site has been revisited at four-month intervals to remove any new individuals.

Also in 2002, an estimated 35 mature plants and numerous seedlings and immature plants were found close to the viewing area overlooking Pauahi Crater. Several plants were also found underneath the viewing area and near the crater's edge. Plants were growing in an island of alien scaly sword fern (*Nephrolepis multiflora*) and native māmaki (*Pipturus albididus*) shrubs. Control of this population began in 2002, and plants have not been observed at this site since 2005.

In 2003, a small roadside (2 m²) population was encountered and treated along Hwy 11. The population was uprooted and bagged, and no new plants have been observed since.

In 2005, an 18 m² population was found near the Kīpuka Nēnē fuel break, growing principally among alien grasses. This population was initially treated in 2006. That same year, a 15 m² population was discovered in the Puaulu Buffer SEA, Block 6, near the Volcano Golf Course. Plants were growing on shallow soils among alien and native vegetation in an ʻōhiʻa woodland. This population was the only one found in HAVO a considerable distance from a roadside or trailside. Treatment of this population began in 2005. Air plant may also occur at ʻĀinahou although plants have not yet been mapped. The ʻĀinahou Cultural Landscape Plan (National Park Service 2004) mistakenly identifies a population of *K. pumilla* J.G Baker as air plant.

Air plant is an invasive weed, found primarily along roadsides in HAVO. Because it can form dense stands in dry and mesic natural areas, is adapted to arid environments and extensively reproduces by vegetative means, air plant establishment should be considered a threat to the park's native plant communities. Parkwide control leading to eradication is recommended, and roadsides, which appear to be a principal corridor of air plant establishment, should be monitored at least annually, to detect and remove newly established populations. A foliar application of 5% Roundup in water is an effective control method.

Numerous other succulents belonging to the Crassulaceae are cultivated in Hawai`i. Notable in HAVO is *Kalanchoë waldheimii,* found at the ʻĀinahou Ranch, occupying close to 50 m² of mostly landscaped habitat, spread into three clusters. This plant does not yet appear to be naturalized, but continued monitoring is warranted to evaluate possible invasive tendencies.

***Kalanchoë tubiflora* (Harv.) Raym.-Hamet (Chandelier plant)**

Chandelier plant (*Kalanchoë tubiflora*) is a small succulent plant native to Madagascar (Wagner et al. 1999). There is considerable disagreement over the taxonomic arrangement of this genus and species (Staples and Herbst 2005). Chandelier plant is recognized by some botanists as *Bryophyllum tubiflorum* Harvey, or less commonly *Bryophyllum delagoense* (Ecklon & Zeyher) Schinz, *Kalanchoë*

delagoensis Ecklon & Zeyher or *Kalanchoë verticillata* Scott-Elliot (Staples and Herbst, 2005). Naturalized in low elevation dry disturbed habitats on Kauaʻi, Oʻahu, Lānaʻi, Maui and Hawaiʻi, Fosberg (1966) reported chandelier plant was collected in HAVO's residential area by Fagerlund and Mitchell and was later noted by Higashino et al. (1988) from the same locality. This population could not be relocated in 2003, but two new populations were found elsewhere in the park.

In 2002, approximately 50 chandelier plants were found on the southwest side of the Kealakomo parking lot (650 m elevation) off the Chain of Craters road. Plants were growing on rocky substrates with sparse alien grasses and ferns. The plants were uprooted at the time and a subsequent search of the surrounding vicinity discovered no other plants. The site was not revisited until summer of 2004, when nine plants were uprooted. Since then, the site has been revisited at four-month intervals, and individuals are removed when found.

In December 2006, a chandelier plant population was found along Hwy. 11 near the Foot Prints trailhead. Less than ten individuals were pulled along with other roadside weeds targeted for control.

Chandelier plant can reproduce vegetatively and is adapted to dry areas and plants should be considered potentially weedy. Though the former residential area population was likely not an optimum growing environment, the dry locations of the two most recent discoveries may be more conducive to chandelier plant establishment and spread. As with other recently established weeds in HAVO (e.g., telegraph weed, fireweed), areas of high visitor traffic such as roads, trails and parking lots represent likely avenues of introduction, and these sites should be more intensively monitored. The efficacy of chemical control has not been evaluated for this species in HAVO. A solution of 5% Roundup in water applied to the foliage effectively controls the related air plant (*Kalanchoë pinnata*) and this method should be tested for control of chandelier plant. Eradication of all populations is recommended to prevent the buildup of larger more disruptive populations.

***Lantana camara* L. (Lantana)**

Lantana is a shrub perhaps native to the West Indies naturalized and invasive throughout much of the tropics and sub-tropics (Wagner et al. 1999). Characterized by a complex of cultivars owing to centuries of horticultural selection and cross breeding (Thomas and Ellison 2000), lantana is considered one of the world's top 100 invasives for its impacts to agriculture and native ecosystems (Lowe et al. 2000). In Hawaiʻi, lantana is one of the most serious weeds in dry to mesic environments (Smith 1985; Wagner et al. 1999). In HAVO, lantana is found principally in the coastal lowland and sub-montane zones below 1,000 m elevation, where removal is limited to SEA's, including Naulu, where it is one of the most disruptive plants. During 2002-2005 surveys, lantana was not found on Mauna Loa, wet forest SEA units of Ōlaʻa, Thurston, nor park residential and administrative areas. Few individual plants were found in wet forest near the Kalapana Trail in Kīlauea's East Rift around 500 m elevation. A notable

infestation was identified along the Poliokeawe Pali, below the ʻĀinahou Ranch, among alien grasses, mixed shrubs and alien faya tree (*Morella faya*) and olive (*Olea europea*).

Lantana appears too widespread for control in HAVO beyond SEA units, and no additional control is recommended. Lantana is controlled manually by uprooting small plants, and chemically with cut stump or basal bark applications of Triclopyr based herbicides. At least 24 biological control agents have been released to control lantana in Hawai`i (Thomas and Ellison 2000), though the distribution of these agents and their efficacy in HAVO has not been evaluated, and the plant continues to be a pest. Lantana varieties, as distinguished by thorn morphology and flower color, have not been mapped in the park, but casual observations suggest the dominant morphotype conforms to *L. camara* var. *aculeata sensu* Moldenke (Benitez pers. obsn.). During surveys, no varieties with homogenously white, orange, pink, or purple heads were noted in the park.

Lathyrus odoratus L. (Sweet pea)

Sweet pea (*Lathyrus odoratus*) is an annual pea species, native to Italy and Sicily, cultivated in Hawaiʻi (Staples and Herbst 2005). In HAVO, sweet pea was found in residential gardens by Fosberg (1966) and by Higashino et al. (1988) in cultivation areas and also in the sub-montane seasonal zone.

During 2003 surveys one sweet pea plant was encountered in the park residential area. The plants referred to by Higashino et al. 1988 in the sub-montane zone likely occurred at the ʻĀinahou Ranch, where sweet pea was controlled between 1983 and 1984. Sweet pea may also persist at ʻĀinahou, as plants were noted near the greenhouse in 2004 (L. Pratt, pers. com). No sweet pea vines were noted elsewhere in HAVO.

Sweet pea appears to have a low invasive potential in HAVO, and has not been described as naturalized (Wagner et al. 1999). However, removal of the individual near park headquarters and ʻĀinahou will lead to the eradication of this alien species from HAVO, and is recommended as a precautionary measure. Further caution is warranted because the family Fabaceae is overrepresented among natural area invaders (Daehler 1998).

Leucaena leucocephala (Lam.) de Wit (Koa haole)

Koa haole (*Leucaena leucocephala*) is a small neotropical tree ranked among the world's top 100 invasive species (Lowe et al. 2000), naturalized principally in dry, lowland disturbed areas throughout Hawaiʻi (Wagner et al. 1999). In HAVO, both Fosberg (1966) and Higashino et al. (1988) reported koa haole from lowland environments. Tunison et al. (1992) identified three major infestations; Keauhou-Halapē, Puʻu Kaone, and the Kalapana trail. Recent mapping identified dense infestations at two of these sites, and smaller surrounding satellite populations which appeared recently established. Previously unmapped individuals were also located at

‘Āinahou and along Highway 11. Mostly small, satellite koa haole populations have been controlled since 1984.

Koa haole was found abundant in the coastal lowlands, with a total infested area estimated at 1,120 ha extending from Pu‘u Kaone, to Halapē Iki, along the coast to Keauhou, and up the Keauhou trail to 420 m elevation. Fifteen large, dense clusters, ranging from 1.2 to 29.1 ha were mapped in this area, and numerous smaller groupings of 1-100 individuals located during foot and aerial surveys. Many of the dense clusters were monotypic koa haole stands, some of these were also infested by invasive guinea grass (*Panicum maximum*), which otherwise is uncommon in the park’s coastal lowlands. Former populations along the Kalapana trail and at Lae ‘Apuki appear to have been covered by recent lava flows.

In 2004, a large koa haole population ranging over 14 ha was mapped below the Chain of Craters Road at 90 m elevation. Included was a dense 1 ha stand, with numerous smaller clusters to the west. Closer to the Kīlauea summit, 20 koa haole were observed along and between the Peter Lee Road and Highway 11. These individuals have been controlled and newly established individuals are periodically removed from this site.

Koa haole is an aggressive pest of Hawaiian ecosystems cited by Smith (1985) as one of the most disruptive to natural areas. Its potential for spread is high in lowland ecosystems in Hawai`i (Smith 1985), plants may alter soil chemistry through nitrogen fixation, and observations suggest infestations may facilitate the establishment of invasive guinea grass. Relative to previous mapping by Tunison et al. (1992), the area infested by dense populations of haole koa has increased, and plants have established in new areas. Plants are too widespread to eradicate, and control is recommended for special project sites to protect sensitive resources such as coastal strand, turtle nesting sites, or rare plants. Koa haole is preferably controlled with a cut stump application of 30% Garlon 4 in water applied to the tree’s cut stump.

Ligustrum sinense Lour. (Chinese privet) and *L. ovalifolium* Hasskarl (California privet)

Chinese privet *(Ligustrum sinense)* is a shrub native to Southern China, widely cultivated, and often escaping cultivation. The binomial *Ligustrum vulgare* was a formerly misapplied name for *Ligustrum sinense* (Staples 2005). In Hawai‘i, Chinese privet is recently naturalized (Wagner et al. 1999), and sparingly naturalized in HAVO; Fosberg (1966) reported Chinese privet in a natural setting near the summit of Kīlauea, and Higashino et al. (1988) reported Chinese privet in cultivated areas and in wet forest. Chinese privet is controlled in SEA’s and localized populations in HAVO.

In HAVO, scattered individuals of Chinese privet were found near the Kīlauea summit. Between 2000 and 2004, 77 plants were removed from wet forest SEA units Thurston and ‘Ōla‘a during systematic sweeps by ground crews to remove a suite of invasive weeds. Three additional privets, detected by Vegetation Management staff,

were controlled in landscaped and natural areas near the Kīlauea summit between 2000 and 2004.

No privet was encountered along roads, trails or fences throughout HAVO during surveys conducted in 2002-2006. Undetected plants likely occur in wet forest at the summit and ʻŌlaʻa based on recent incidental discoveries by park staff. Continued control is recommended in SEAs, and additional surveys outside of these areas are warranted to locate and eradicate all individuals. A solution of 10% Garlon 3A in water applied to the cut stump is effective in controlling privet. Chinese privet is a popular ornamental and naturalized in adjacent Volcano Village, and these plants may represent a seed source for the park.

A related species, the California privet (*Ligustrum ovalifolium* Hasskarl) occurs near park headquarters (Higashino et al. 1988, Benitez pers. obsn.) and elsewhere in Hawaiʻi (Staples 2005) but does not appear to be naturalized. These plants have not been controlled near park headquarters, but eradication is recommended as a precautionary measure. The family Oleaceae, which includes the genus *Ligustrum*, has been cited as invasive in natural areas (Daehler 1998, Staples and Herbst 2005), and many species are likely spread by bird dispersed fruits (Staples et al. 2000). Included is a congeneric species, *L. robustum*, cited as one of the world's top 100 invasive species (Lowe et al. 2000).

Lonicera japonica Thunberg. (Japanese honeysuckle)

Japanese honeysuckle (*Lonicera japonica*) is a vine with fragrant, white-yellow flowers, native to Asia, cultivated in temperate and tropical areas including Hawaiʻi. Vines are sparingly naturalized in mesic to wet areas on Kauaʻi, Maui, and Hawaiʻi (Wagner et al. 1999; Wagner & Herbst 2003). In HAVO, honeysuckle was collected as early as 1938 by Olsen (Fosberg 1966) presumably from cultivated material. Higashino et al. (1988) noted honeysuckle in the park residential area and naturalized in wet forest.

In 2003, a similar distribution of honeysuckle vines was mapped throughout the park residential area and in wet forest at the ʻŌlaʻa Small Tract unit. In the residential area near the Kīlauea summit, vines were found growing in clumps 1-20 m², in landscaped areas and native forest, spread over 24.7 hectares. Honeysuckle had not been previously mapped in detail in the park, thus little is known about the rate of spread here, but observations from 2001-2010 suggest clumps have become larger and established in new areas within the mapped range (Benitez pers. obs.). While many of the clumps identified were near buildings and likely planted, the distribution of vines in more forested areas away from landscaped areas suggests some dispersal by either vegetative or sexual means is possible.

A smaller population was found in the ʻŌlaʻa Small Tract unit, in closed canopy native wet forest at 1,250 m. This population appeared to be spreading vegetatively from an adjacent private property. Honeysuckle was not found beyond this site in wet forest

units of ʻŌlaʻa or Thurston SEAs, nor elsewhere in HAVO, and no additional vines were detected or controlled in systematic sweeps of these units.

Honeysuckle has never been targeted for control in HAVO. This self-incompatible species is a serious weed of mainland USA forests (Motooka 2003), but presumably has not become problematic in Hawaiʻi because of either unfavorable environmental conditions or because the introduced cultivars have low genetic diversity, resulting in low levels of fruit production and seed set (Wagner et al. 1999, Kilkenny pers. com.). In light of a high invasive potential, control work leading to eradication is recommended. Additionally, new introductions of cultivars of this species to the park and adjacent communities should be actively discouraged by the park.

Lophospermum erubescens D. Don (Roving sailor)

Roving sailor (*Lophospermum erubescens*) is a vine native to Mexico. In Hawaiʻi, roving sailor is naturalized in dry forest, shrublands and alien grasslands on Oʻahu, Maui and Hawaiʻi (Wagner et al. 1999; Wagner & Herbst 2003). Recent synonyms for roving sailor include *Asarina erubescens* (D. Don) Pennell, *Maurandya erubescens* (D. Don) A. Gray and *Maurandya scandens* (D. Don) A. Gray var. *erubescens* (D. Don) Voss. Both *Lophospermum* and *Maurandya* have recently been transferred from the family Scrophulariaceae to Plantaginaceae (Wagner et al. 1999). In HAVO, Fagerlund and Mitchell collected roving sailor at the Volcano House (Fosberg 1966) and this population was apparently also noted by Higashino et al. (1988).

In 1987, roving sailor plants were found near a stone wall behind the Volcano House and along the caldera floor directly beneath it. All accessible portions of this population have been regularly treated from 1987-1993 and from 2000-present. A small (<30 m^2) population was found at the base of the pali and a another small population was found 300 m to the south. Based on the occurrence of newly established individuals on the caldera floor, it is apparent that uncontrolled reproductive plants persist on the pali above. Roving sailor was not observed elsewhere in the survey area between 2000 and 2003.

Continued control leading to eradication is recommended for this species. Control has been effective at reducing population sizes. Additional surveys to locate and control undetected individuals should be conducted along steep slopes behind the Volcano House using rappelling techniques. This species has been controlled using a solution of 2% Garlon 4 in water to wet the foliage.

Luculia gratissima Sweet (Luculia)

Luculia (*Luculia gratissima*) is an ornamental shrub native to Asia. Luculia is occasionally cultivated in Hawaiʻi (Staples and Herbst 2005), including areas adjacent to HAVO, but not reported naturalized (Wagner et al. 1999; Wagner & Herbst 2003). Luculia was found in HAVO in 1944 (Fosberg 1966) near park headquarters, and by Higashino et al. (1988) in cultivated areas and presumably escaped in wet forest.

Luculia control began in 1985, and plants have been treated parkwide annually since 1991.

Luculia was previously known from four sites within HAVO. In 1985, a mature luculia was treated in Thurston SEA block 1. This tree was located 50 m NNW from the exit of the Nāhuku (Thurston) lava tube. From 1991-1996, 122 plants were treated at the Kīlauea Iki overlook, although precise location data was not found for this site. Resurveys of the general area discovered no plants at either site. A third location was discovered in 1996, and a mature luculia was treated near the Nāhuku (Thurston) lava tube parking area, in closed canopy native wet forest at 1,150 m elevation in Thurston SEA block 8. Approximately 35 seedlings have been removed annually since discovery, and in 2004, an additional mature tree previously missed was discovered and controlled at this site. HAVO Vegetation Management files document a fourth location of luculia between the Volcano House and Quarters 15. This plant could not be relocated, and no records of control were found.

A previously undetected mature luculia was found and treated near the HAVO research area dog kennels in 2005. The site was monitored annually, and no seedlings were observed in the most recent inspection in 2009. No additional Luculia was located during recent surveys of HAVO that included all cultivated localities near the Kīlauea summit and areas surrounding former populations.

Continued control of luculia leading to eradication is recommended. Mature trees are controlled using a solution of 15% Garlon 4 in water applied to the tree's cut stump, and seedlings are pulled. Luculia has a limited distribution in HAVO and plants occur in residential areas and SEAs where new individuals are more likely to be discovered. Luculia's occurrence and establishment in wet forest suggests the potential for spread into new areas if plants are left uncontrolled. Because of the recent incidental discovery of mature individuals, intensive surveys are recommended within luculia's potential range to ensure all plants are discovered and controlled. Cultivated individuals outside of the park may represent a seed source for future ingress, as natural recruitment has been observed among controlled individuals.

***Lupinus hybridus* Lem. (Lupine)**

Lupine (*Lupinus hybridus*) is a hybrid perennial herb of uncertain origin and parentage, known in Hawai'i only from Volcano, Hawai'i (Wagner et al. 1999). Fosberg (1966) previously encountered an undetermined species of lupine (*Lupine* spp.) in residential gardens at HAVO. However, the first plants identified as *L. hybridus* were not collected until 1984 (K. Nagata 2956 HLA, US) (Wagner et al. 1999). Higashino et al. (1988) noted lupine in the sub-montane seasonal zone of HAVO. Lupine was formerly known from a roadside site near the HAVO/Volcano Golf Course boundary, on the north side of Highway 11 near the Volcano golf course, at 1,300 m elevation. This population had been controlled until 1994 and the population was presumed extirpated. In 2001, plants were again discovered at this location, and control was resumed.

In 2002, a newly discovered lupine population was found ~8 km away from the former population at 1,370 m in the park's Mauna Loa unit bordering Kapāpala Ranch. Four mature plants and 250 immature plants were found in a dry native shrubland, with alien and native grasses distributed over a 200 m² area that straddled the park boundary fence. Several plants in pastures outside the park were also found, these had been browsed by cattle. Shortly after discovery, the population was manually uprooted and new plants subsequently removed from the site at 2-6 month intervals. Seed set has been observed at least once since control work was initiated.

Continued monitoring of the former population and control to eradicate the current population is recommended because lupine is a localized weed whose invasive potential is unknown. New individuals should be controlled if found elsewhere in the park. Control work should also target the adjacent ranchlands. Species belonging to this genus are nitrogen fixers, several are considered invasive in continental systems (Valtonen et al. 2006), and the family Fabaceae is overrepresented among natural area invaders (Daehler 1998). The genus *Lupinus* may be notable for the longevity of its seeds (Pielou 1991); this could complicate eradication efforts if populations are considered extirpated prematurely. Lupine's mode of dispersal remains unknown, and a better understanding of the dispersal vectors would aid in the search and control of remaining populations. Additionally, shorter retreatment intervals are recommended to prevent seed production in controlled populations. Pulling plants and bagging fruits of mature individuals is the preferred control method for this species.

***Macaranga* cf. *tanarius* (L.) Müll. Arg. (Parasol leaf tree)**

Parasol leaf tree (*M. tanarius*) is a tree in the family Euphorbiaceae, native to Malaysia, naturalized in Hawai'i on Kaua'i, O'ahu, and Maui (Oppenheimer et al. 1999, Wagner et al. 1999), and recently naturalized on Hawai'i (Parker and Parsons 2010). One other species of this genus is naturalized in Hawai'i; bingabing (*M. mappa*) on O'ahu and Hawai'i. Neither have previously been reported from the park.

In 2006, a seedling, apparently parasol leaf tree, was found in the rock quarry near the Mauna Loa Strip road. This plant was uprooted, and a search of the area was conducted. This site has been routinely monitored and treated at 6-12 month intervals to remove other alien species.

The determination of parasol leaf tree was made using the uprooted seedling. This occurrence represents a new addition to the park's flora. Bingabing is abundant in low elevations of Hawai'i, including the Hilo and Puna districts, but *Macaranga tanarius* is recently naturalized, and has a more restricted distribution (Wagner et al. 1999, Parker and Parsons 2010). Additional occurrences of either species should be mapped and controlled to eradicate populations from the park.

***Marrubium vulgare* L. (Common horehound)**

Common horehound (*Marrubium vulgare*) is a Eurasian wooly mint with compact axillary inflorescences. In the Hawaiian Islands, it is naturalized in disturbed habitats from 150-1,920 m elevation on Lānaʻi and Hawaiʻi (Wagner et al. 1999). Common horehound was first documented in HAVO in 2003; it was not noted by Fosberg (1966) or Higashino et al. (1988) in previous surveys of the park.

In 2003, one plant, covering <1 m² was found behind Quarters 16, in the park residential area at 1,220 m elevation. The plant was growing in a landscaped lawn at the edge of a native wet forest. The area surrounding the population was searched, and no additional plants were observed.

Removal of this plant and any new plants discovered is recommended to eradicate and prevent spread of this species in the Kīlauea and Mauna Loa strip areas of HAVO. The invasive potential of this plant has not been evaluated, however, common horehound was found frequently in sub-alpine grasslands disturbed by ungulates in the newly acquired Kahuku unit to HAVO (Benitez et al. 2008).

***Melaleuca quinquenervia* (Cav.) S. T. Blake (Paperbark)**

Paperbark (*Melaleuca quinquenervia*) is a tree with spongy exfoliating bark, native to eastern Australia, New Guinea and New Caledonia (Wagner et al. 1999). Paperbark trees have been extensively planted throughout Hawaiʻi, and naturalized populations are found on Kauaʻi, Oʻahu, Molokaʻi, Maui and Hawaiʻi (Wagner et al. 1999). Fosberg (1966) did not report paperbark in HAVO, although his surveys did not include the ʻĀinahou Ranch, where Tunison et al. (1992), documented six trees. Paperbark was initially controlled in HAVO from 1983-1985, when 38 trees were cut and treated with herbicide. Two additional trees were discovered and removed, one each in 1990 and 1996. Paperbark was not been observed in HAVO since 1996, despite subsequent searches in the vicinity of the former population and the larger ʻĀinahou Ranch area.

Paperbark is a serious pest in Hawaiʻi (Smith 1985) and leaves may contain allelopathic substances. Furthermore, paperbark belongs to one of the most invasive families in Hawaiʻi, the Myrtaceae (Daehler 1998), and this species is invasive elsewhere in the tropics and subtropics. In Florida's everglades, it is one of the most serious pests (Motooka et al. 2003, Franks et al. 2008) and forms dense thickets which alter hydrologic regimes. Although paperbark appears extirpated in HAVO, continued monitoring is recommended as a precautionary measure. Newly discovered populations should be promptly eradicated and areas surrounding these should be intensively searched.

Additional monitoring is warranted because of the potential for new ingress of paperbark into HAVO. Paperbark is abundant outside of the park, where planted and perhaps naturalized individuals are found in Volcano Village. Because paperbark seeds are small and easily transported by wind or vehicles, monitoring should emphasize boundary areas as well as roads and trailsides. The preferred control method is to pull

seedlings and treat larger individuals with a basal bark application of 15% Garlon 4 in diesel fuel oil.

Melinus minutiflora P. Beauv. (Molasses grass)

Molasses grass (*Melinus minutiflora*) is an African C_4 grass (Baruch et al. 1985) widely naturalized in tropical areas. In Hawai‘i, molasses grass is common in dry to mesic disturbed, open areas on all the main islands except Ni’ihau (Wagner et al. 1999). Considered a serious pest capable of choking out or preventing native plant growth (Smith 1985; Wagner et al. 1999; Motooka et al. 2003), plants also have a high chemical content that promotes the spread of wildfire, and readily colonizes and outcompetes native plants in the post burn environment (Hughes and Vitousek 1993, Tunison et al. 1995, D'Antonio et al. 1998).

Molasses grass was found widespread in HAVO, in dry to wet habitats, principally in open areas. The distribution of molasses grass was not intensively mapped, but plants were noted from near sea level to approximately 2,000 m elevation along the Mauna Loa Strip road. At these higher elevations, molasses grass was occasional, in small patches of <5 m² primarily along roadsides. At lower elevations, molasses grass became more dominant and exclusive stands of >100 m² were commonly observed.

Molasses grass has been controlled along roadsides on Mauna Loa, to prevent the buildup of larger populations that could spread into natural areas, and a continuation of these efforts is recommended. The invasive potential of this grass warrants a more detailed study to map the distribution in HAVO. This mapping will allow resource managers to monitor changes in distribution and abundance of this disruptive invader, to assess the efficacy of control efforts on Mauna Loa, and to examine if additional control measures are required. A 1% Roundup in water foliar solution is the preferred control method for this grass.

Melochia umbellata (Houtt.) Stapf (Melochia)

Melochia (*Melochia umbellata*) is a small tree native to southwestern Asia, naturalized and abundant at least in the Hilo and Puna districts of Hawai‘i Island (Wagner et al. 1999). Melochia has recently undergone a familial re-classification; formerly in the family Sterculiaceae, the genus is now assigned to the Malvaceae (Wagner et al. 1999). In Waiākea, within the Hilo district, melochia was reportedly aerially seeded in 1928 after a fire (Wagner et al. 1999), and also planted extensively in forest reserves around that time (Little and Skolmen 1989). In HAVO, Fosberg (1966) did not note melochia, and Higashino et al. (1988) noted melochia as one of the roadside alien taxa being controlled. Tunison et al. (1992) did not include melochia in their invasive plant distribution reports. Though melochia was not found along survey transects of the East Rift in the 1990’s (Pratt et al. 1999), in 2003-2005 plants were found beginning to invade recently burned mesic and wet forests in Kīlauea’s East Rift. Elsewhere in the park, surveys found melochia occasionally distributed along principal roads.

Since 1983, 522 individuals have been discovered and removed, mostly by pulling, during annual weed monitoring of roadsides including Crater Rim Drive, Highway 11 and the Mauna Loa quarry in HAVO. These plants were likely established by seeds deposited by passing vehicles, or accidentally introduced with roadside aggregates brought into HAVO from the Puna and Hilo districts. No melochia was encountered along other roads.

Melochia was more recently found in burned areas of Kīlauea's East Rift. In 2004-2005, eight individuals were found and removed during systematic sweeps to control target weeds in a 60 ha area of the East Rift SEA (Luhi blocks). Melochia was previously unknown from this area, and the plant's mode of ingress remains unknown. Propagules may have arrived via natural wind or animal dispersal from populations outside HAVO. Human aided dispersal is also a possibility, as extensive firefighting operations occurred in the area in 2002-2004. Melochia was not encountered on trails and fencelines, or elsewhere in HAVO during recent surveys.

Parkwide control to eradicate melochia is recommended by removing new establishment along roadsides. Additional surveys are recommended to map the distribution and remove melochia throughout Kīlauea's East Rift, where the plant appears to be at the early stages of invasion. Surveys should include aerial searches to locate individual plants and determine if larger populations exist in HAVO or on adjacent lands. If populations found in the East Rift or elsewhere are too large to eradicate, then either exclusion from SEA units and/or containment should be considered as control strategies.

Morella faya (Aiton) Wilbur (Fayatree)

Fayatree (*Morella faya* – formerly *Myrica faya*) is an invasive tree native to the Canary Islands, Madeira, and Azores (Wagner et al. 1999). In Hawai'i, faya tree is found on Kaua'i, O'ahu, Lāna'i, Maui and Hawai'i in wet to mesic forests, reportedly between 150 and 1,310 m elevation (Wagner et al. 1999). Plants have been found recently in the Ka'ū district between 1,690 and 2,280 m elevation (Benitez et al. 2008). Within the park, Fosberg documented a single tree along Crater Rim Trail in 1961 (Fosberg 1966). Higashino et al. (1988) found faya tree abundant in the sub-montane seasonal zone, wet forest and montane seasonal zone, and categorized faya tree as one of the most disruptive alien weeds in HAVO.

Fayatree expanded rapidly in the late 1970s and early 1980s in HAVO. In 1977 plants were known from 600 ha in small populations located between Nāmakani Paio Campground to Pānau Nui ahupua`a in the eastern portion of the park between 670 m and 1,200 m elevation. In 1985 plants ranged over an estimated 12,200 ha, a 20-fold increase (Whiteaker and Gardner 1985). By 1992, fayatree had expanded its range by 3,700 ha and infested approximately 15,900 ha of Hawai`i Volcanoes National Park (park unpublished data).

Fayatree remains widespread in dry, mesic and wet forests, woodlands and shrublands between 450 and 1,700 m elevation in the Mauna Loa Strip and Kīlauea sectors of the park. At upper elevations, two mature trees were found and removed near 1,500 m elevation in the Mauna Loa Upper SEA. Because plants may have deposited seeds in the soil, the area is revisited annually to monitor seedling recruitment, though no plants have been found. Findings of plants at elevations up to 2,280 m elevation in the Kahuku addition suggest faya tree remains a serious threat on Mauna Loa's upper vegetated slopes.

Fayatree was found at a minimum elevation of 450 m, on the Poliokeawe Pali on the flats below ʻĀinahou Ranch in sparse ʻōhiʻa woodlands. Less than 40 trees were observed from a helicopter in 2002. A fayatree was reported and removed from the Puʻu Loa pullout along the Chain of Craters Road in 2006 at ca 30 m elevation by HAVO Interpretation staff.

Three mature fayatree were found in Kīpuka Pepeiao (~750 m elevation), and individuals recently found along the Highway 11 near the park boundary represent the westernmost individuals. The easternmost plants were observed along the Kalapana trail at approximately 800 m elevation, 23.5 kilometers from Kīpuka Pepeiao.

A range extent for fayatree within HAVO was estimated at 30,495 ha, of which 15,700 ha represent relatively dense infestations. The remainder consists of smaller outlying populations, and suggests potential for continued range expansion.

Control of fayatree began with the removal of trees from the central and more accessible populations in the 1970s. Park-wide control was abandoned in 1980 when park staff realized they could not eradicate faya. A control program was revived in 1985 with a focus on eradicating faya tree populations in SEA's. Continued control in SEA units and outlying populations is recommended to check faya tree expansion and exclude this pest from high value sites in the park. Faya is killed by manually uprooting small individuals, and treating larger individuals with a solution of 10-50% Garlon 3A in water applied to a cut stump or girdled trunk.

***Muehlenbeckia complexa* (A. Cunn.) Meisner (Wire vine)**

Wire vine (*Muehlenbeckia complexa*) is a small-leaved, branched vine native to Australia and New Zealand, from habitats including coastal lowlands, lower montane forest and open and rocky places in the North, South, and Stewart Islands of New Zealand. Although fertile material has not been examined, it appears that the name *Muehlenbeckia axilaris* (J.D. Hook.) Walp. is a formerly misapplied name to wire vine cultivars found in HAVO (Staples and Herbst 2005). Wire vine is not known to be naturalized in Hawaiʻi (Wagner et al. 1999). In HAVO, plants were collected in 1943 in HAVO's residential area (HAVO 7371 - G.O.F. and A.L.M. 750) and Fosberg (1966) found plants along roadsides and the park residential area. Tunison et al. (1992) identified three populations of wire vine; two along Crater Rim Drive, and one in the park residential area. The Crater Rim populations were suspected to represent an incipient

natural infestation (Tunison pers. com.). Wire vine control began in 1983, and plants have not been observed since 1996.

During 2003-2005 surveys, no wire vine was encountered, and the populations controlled at the residential area and Crater Rim Drive from 1983 to 1996 are presumed eradicated. The apparent eradication of wire vine is illustrative of the strategic importance of a rapid response to an incipient weed infestation, yet a cautionary approach is recommended, as individuals may have escaped detection, or remain as seed dormant in the soil. Therefore crews working in rain forest near former populations should be trained to recognize this species and to report any new sightings. Should plants be found, a continuation of eradication efforts is recommended.

Nephrolepis brownii (Desv.) Hovenkamp & Miyam. (Scaly sword fern)

Scaly sword fern (*Nephrolepis brownii*) is an invasive fern, native from India to tropical Asia (Palmer 2003). The recent synonym *Nephrolepis multiflora* (Roxb.) F.M. Jarrett ex C. V. Morton has been widely applied (Imada 2007). The distribution and abundance of scaly sword fern in HAVO was not intensively mapped, but scaly sword fern was found widespread. Scaly sword fern was noted infrequently in dry environments, and more frequently in transitional mesic and wet environments, including recent lava flows, woodlands and forests. Large areas of transitional mesic forest along Kīlauea's East Rift have been invaded by scaly sword fern. These areas now support dense 1-2 m high swards that dominate the understory. The dried rachis, papery fronds and litter that accumulate within the swards are capable of supporting large wildfires in the park. This fern has only been controlled in relatively small restoration areas in Kīlauea's East Rift, totaling less than 10 ha, using foliar applications of Roundup in water, and continued control is recommended only in selected project areas.

Because of the potential of scaly sword fern invasion to alter fire regimes and successional trajectories, additional studies are recommended to map the species' distribution and abundance in greater detail. These maps will permit the evaluation of relevant control strategies, and permit the updating of existing fuels maps used for fire management. Scaly sword fern is currently being investigated for its ability to alter fire regimes and successional trajectories in invaded areas (Ainsworth and Boone Kauffman 2009).

Olea europaea L. subsp. *cuspidata* (Wall. ex G. Don) Cif. (Olive)

A tree native to the Mediterranean region, olive (*Olea europaea* subsp. *cuspidata*) is widely cultivated in tropical and temperate areas. Olive was formerly known as *Linociera ligustrina* in Hawai'i (Higashino et al. 1988, Wagner et al. 1999), and also *Olea europaea* subsp. *africana* (L. Pratt, pers. com). Naturalized on the islands of Kaua'i, Maui and Hawai'i (Wagner et al. 1999), olive was cited as an aggressive pest of Hawaiian ecosystems by Smith (1985). In HAVO, olive was noted by Fosberg (1966) at

the ʻĀinahou Ranch. The distribution of olive was mapped in greater detail by Tunison et al. (1992), who found the plant infesting over 750 ha in the ʻĀinahou vicinity.

During 2003-2005 surveys, olive was found distributed over approximately 1,400 ha in HAVO and formed monospecific stands across portions of this range. The densest infestations were found at ʻĀinahou where olive may have been originally planted for a windbreak. Olive was mapped in areas far beyond the range identified by Tunison et al. (1992). The most distant outliers were found in a koa haole grove at Puʻu Kaone, a distance >6 km from the closest previously mapped plants in 2004. To prevent further range expansion, in 2010 three olive trees were removed below Poliokeawe Pali along the Keauhou trail by the park's EPMT crew using a solution of 50 % Garlon 4 in water applied to the trees cut stump. These three trees were the only individuals encountered below the pali. Parkwide, olive is considered too widespread for eradication, and continued removal of outliers and removal from SEA units is recommended.

Opuntia ficus-indica (L.) Mill. (Prickly pear)

Prickly pear (*Opuntia ficus-indica*) is a cactus most probably native to Mexico (Wagner et al. 1999). Prickly pear was not noted within HAVO by Fosberg (1966), but much of the ʻĀinahou Ranch was not included in his survey as these lands were not yet part of the park. Higashino et al. (1988) documented prickly pear from the sub-montane seasonal zone and also in cultivation, though precise localities were not cited. Tunison et al. (1992) reported seven populations of prickly pear, ranging in size from one to dozens of individuals distributed over 19 ha near the Poliokeawe Pali.

Surveys in 2004 found plants in the mapped former range, and identified plants further down slope to 275 m elevation in central HAVO. The largest population of prickly pear was found below the Poliokeawe Pali at ~640 m elevation, in alien grassland with scattered native shrubs. This population contained approximately 35 large individuals and numerous smaller plants distributed over 4 ha. Plants observed generally did not appear vigorous and yellowing and contorted growth patterns were observed. Two groupings of five individuals each were mapped on the edge of a koa haole grove near the Keauhou Trail at 300 m elevation. These plants were growing among alien grasses including natal redtop (*Melinus repens*) and guinea grass (*Panicum maximum*). Further upslope, less than five prickly pear plants were mapped at the ʻĀinahou Ranch. No prickly pear was found elsewhere in the park, including the residential areas.

Prickly pear populations at Poliokeawe were controlled chemically in 1980 using Tordon 22K. In 1985, two biocontrol agents, the moth *Cactoblastis cactorum*, and the cochineal insect *Dactylopius opuntiae* were released at that site. No additional control work has been performed since. Biocontrol agents appear to have checked the spread of this alien species (Davis et al. 1992), and no additional management beyond monitoring is recommended.

Paederia foetida L. (Maile pilau)

Maile pilau (*Paederia foetida*) is a malodorous vine native to eastern Asia, naturalized on Kaua‘i, O‘ahu and Hawai‘i from sea level to 1,830 m elevation in disturbed mesic forest, coastal sites, dry forest and subalpine woodland (Wagner et al. 1999). The synonym *Paederia scandens* (Lour.) Merr. has been applied to this species in Hawai‘i. Fosberg (1966) did not note maile pilau within HAVO, while Higashino et al. (1988) documented maile pilau as a roadside species.

In HAVO, a single population of maile pilau was found near the Puhimau hotspot at 1,100 m elevation. Vines grew among alien grasses and sparse shrubs. Efforts to eradicate the vine have been continuous since 1985, when vines covered an estimated 500 m². The twice yearly treatments appeared successful in reducing the population size to an estimated 10 m² in 2003. Eradication has not been achieved because vines root adventively and have been difficult to detect among the loose substrate and alien grasses. Plants were originally controlled using Tordon 22k and in 1991 either Roundup or Garlon 4 were used. Since 1998, vines have been treated exclusively using a foliar application of 2% Garlon 4 in water, as this herbicide appeared most effective.

Based on the limited distribution and designation as a pest species (Motooka et al. 2003), continued control and monitoring is recommended leading to eradication. Additional perimeter searches of the infested area and nearby woodlands and forests are recommended to ensure all individuals are discovered. Alternative treatments should also be considered to remove recalcitrant plants, including manual control, more intensive searches and use of other herbicides.

Panicum maximum **(Jacq.) (Guinea grass)**

Guinea grass (*Panicum maximum*) is a robust C_4 bunchgrass native to Africa. Various synonyms have used for this widely distributed species, including *Megathrysus maximus* (Jacq.) B. K. Simon & S. W. L. Jacobs and *Urochloa maxima* (Jacq.) R. Webster. An important forage grass, guinea grass is naturalized and common on all the main Hawaiian Islands (Wagner et al. 1999). In HAVO, Guinea grass was documented by Fosberg (1966) from the Keauhou vicinity, around 460 m elevation. Higashino et al. (1988) noted this species in the park’s coastal lowlands and sub-montane seasonal zones.

In 2004, surveys found guinea grass invading HAVO’s coastal lowlands and upland roadside areas. Guinea grass was most abundant in the park’s coastal lowlands, where plants often grew near or within koa haole groves as well as in open areas. The largest guinea grass patch was in a large koa haole grove at Keauhou, and covered greater than 50% of the 16 ha grove. Smaller populations were also found commonly primarily east of the Keauhou trail along the coastal plain. Further upslope (210-420 m elevation) populations were systematically mapped over a 206 ha area along the Keauhou Trail, and an infestation totaling 5.1 ha was identified, with 106 populations between 1 and 400 m² totaling 0.3ha and two larger populations in koa haole groves of 1.1 and 3.7 ha.

In 2004, 35 recently established guinea grass plants were controlled along Highway 11. These plants were growing along the side of the road among alien grasses, herbs, and roadside aggregates to a maximum elevation of 1,220 m. Many of the plants were fertile. In 2005, surveys were conducted to examine if guinea grass was spreading from the Highway 11 population. This search included 600 ha of `ōhi`a woodlands, bounded by Highway 11, the HAVO/Kapāpala boundary, the Broomsedge Burn (Puaulu Buffer SEA), and Peter Lee Road (ca. 1050-1150 m elevation), but no plants were found.

Plants along Highway 11 were initially treated using a solution of 5% Roundup in water applied to the foliage. In late 2004, an outlying population of guinea grass was controlled 0.2 km south of the park boundary along Highway 11 to prevent seed dispersal along this corridor. Continued exclusion of guinea grass along Highway 11 to prevent establishment in the park's ʻōhiʻa woodlands is recommended. In 2010, the park's EPMT crew led initial and follow-up control treatments of guinea grass populations totaling 2.8 ha. These populations were distributed over 556 ha below the Poliokeawe pali along the Keauhou trail (0-500 m elevation), and control work was performed during extreme drought conditions using primarily a solution of 5% Roundup in water. Monitoring later that year indicated treatments were effective, although follow up treatment is recommended to eradicate this species from the park.

Passiflora edulis Sims (Purple granadilla)

Purple granadilla (*Passiflora edulis*) is a vine native to South American montane forests cultivated in Hawaiʻi and naturalized in mesic forest and shrubland from 80-1,220 m elevation on Kauaʻi, Oʻahu, Lānaʻi, Maui and Hawaiʻi (Wagner et al. 1999). In HAVO, purple granadilla was noted as rare in the vicinity of Kīlauea by Fosberg (1966), and as present in the montane seasonal zone by Higashino et al. (1988).

In 2003-2004, individual purple granadilla vines were found occasionally in mesic forest on Mauna Loa, and in forests near the ʻĀinahou Ranch. Denser infestations were identified in disturbed mesic and wet forests and along fencelines in Kīlauea's East Rift, where purple granadilla appeared widespread. An attempt to control purple granadilla following a wildfire in the East Rift (Luhi blocks) in 2005-2006 was abandoned. Infestations were deemed too widespread to be manageable and additional monitoring was needed to determine if dense infestations could persist without continued disturbance. Previously, Pratt et al. (1999) reported a 15 % frequency in transect stations in the East Rift.

Two forms of this species reportedly occur in HAVO; *P. edulis* f. *edulis* was observed on Mauna Loa, and in forest on Kīlauea's East Rift (Benitez pers. obsn.), this form is also known locally as purple poka. Another form, *P. edulis* f. *flavicarpa*, was reported by Higashino et al. (1988) from the sub-montane seasonal zone and wet forest in HAVO, though these plants were not found during the present surveys. This yellow form is commonly called lilikoʻi or passion fruit in Hawaiʻi. Species in the genus *Passiflora* warrant caution because many naturalized species are damaging to native ecosystems (e.g., *P. edulis*, *P. tarminiana*, *P. suberosa*) (Motooka et al. 2003; Wagner et al. 1999).

No control is recommended for this species, though continued monitoring to evaluate impacts to native communities is warranted, especially in the East Rift areas recently disturbed by fire.

Passiflora tarminiana Coppens and Barney (Banana poka)

Banana poka (*Passiflora tarminiana*) is a neotropical vine, among the most disruptive forest invaders in Hawai‘i (Wagner et al. 1999, Smith 1985). In the park, plants are widespread in the ‘Ōla‘a wet forest units (3,920 ha) between 975 and 1,340 m elevations. Banana poka plants were previously misidentified as *Passiflora mollissima* (Kunth) L.H. Bailey (Wagner et al. 1999), and perhaps also *P. tripartata*.

Transect data collected in 1998 from ‘Ōla‘a quantified banana poka cover within units managed to exclude weeds and pigs as well as unmanaged units. The greatest abundance of banana poka was found in the Ag unit (162 ha), where plant cover was estimated at 1-5 %. Plants were not controlled at the time, but initial control in 2007 removed 64,455 plants from this unit. Transect data from the Pu‘u unit (245 ha) and the New unit (761 ha) found cover of 1-5 % in these units as well. The Pu‘u unit was initially controlled in 2003, when 3,193 banana poka vines were removed from 155 ha, but the New unit remains unmanaged for weeds. The remaining units in ‘Ōla‘a were mapped with less than 1 % cover of banana poka. Banana poka was least frequent in the 356 ha Small Tract unit; though plants have been occasionally found, no vines were found during systematic sweeps in 2005.

In 2004, a population was discovered in mesic koa forest in the Mauna Loa Strip at 1,430 m elevation. This was the park’s first discovery of banana poka outside of ‘Ōla‘a. Between 2005-2007, intensive efforts to eradicate this population assisted by the park’s EPMT crew led to the removal of 3,704 plants using Roundup or Garlon 3A herbicides, although large plants in the canopy proved difficult to control. In 2009, tests were performed using the previously mentioned herbicides and an Imazapyr-based formulation (Arsenal). This herbicide appeared effective in controlling vines, and was reportedly weak on legumes, an important consideration in koa forest. The first aerial treatment cycle in 2009-2010 used 240 liters of 2% Arsenal in water applied to an estimated 0.5 ha of vines in the koa canopy distributed over 36 ha. An area of 124 ha surrounding the treatment area was aerially searched and no additional plants were detected. Based on field observations from the herbicide tests, control operations, and additional mapping, continued aggressive treatment of this population is recommended using aerial and ground sweeps, and periodic (e.g., 2 year) surveys beyond the infested area are also warranted.

The biological control agent *Septoria passiflorae* was released in Hawai‘i in 1996, and between 1996-1998, this agent was reported responsible for a 90% reduction in cover at sites free of acid rain on Hawai‘i Island (Trujillo et al. 2001). In June, 2002, spores on infected leaves were collected from the Blair Road field site in Laupahoehoe and released in the park at two sites in the Ag unit, where mature vines were common. While unusual mortality and defoliation of vines was reported by field workers in 2004,

no *S. passiflorae* was found during a re-visit to the release site in 2009. It is unknown if drought, acid rain, or control efforts affected the establishment of this pathogen, or if other factors were responsible, but given the reported success of *S. passiflorae* elsewhere in Hawai'i, further releases and more intensive monitoring are recommended.

Banana poka was found too widespread in ʻŌlaʻa to eradicate, and a continuation of the current control strategy is recommended, where plants are removed from SEA units managed to exclude invasive. The population on the Mauna Loa strip should be eradicated, as should any new populations if they are found outside of ʻŌlaʻa.

***Pennisetum clandestinum* Chiov. (Kikuyu grass)**

Kikuyu grass (*Pennisetum clandestinum*) is a pasture grass native to Africa, introduced to Hawaiʻi for cattle grazing. Kikuyu grass is a serious pest (Wagner et al. 1999), capable of smothering native vegetation and preventing seedling establishment.

In HAVO, kikuyu grass was widespread near the Kīlauea summit and throughout the Mauna Loa Strip, below 2,000 m elevation. Kikuyu populations were not intensively mapped, but this grass was found most abundant in formerly grazed koa forest on Mauna Loa, often as the dominant understory species.

Control of kikuyu is limited to koa reforestation experiments in Lower Mauna Loa, Kīpuka Kī and Kīpuka Puaulu SEAs. Grasses are subject to several treatments of 1% Roundup followed by recruitment of native trees either naturally or assisted with plantings by park staff. Alternative control methods using Imazapyr and Fluazifop based herbicides are also being researched in the park as strategies since these have less non-target effects to native tree seedlings and shrubs.

***Pennisetum purpureum* Schumach. (Elephant grass)**

Elephant grass (*Pennisetum purpureum*) is a stout perennial bunch grass native to Africa. In Hawaiʻi, plants are naturalized along fields, roadsides and pastures, in mesic to wet sites from 10-1,220 m elevation on Kauaʻi, Oʻahu, Lānaʻi, Maui and Hawaiʻi. In HAVO, Fagerlund (1947) documented plants at ʻĀpua and at about 800 m elevation near the eastern boundary of ʻĀinahou, and Fosberg (1966) reported a similar distribution and also plants at an unspecified location in the Kīlauea region. Tunison et al. (1992), reported nine small populations at ʻĀinahou totaling 2.8 ha, and 0.1 ha populations at Waha'ula and Kīpuka Nēnē. Elephant grass had not been controlled in HAVO prior to 2010.

Twelve elephant grass populations between 3-60 m² in area were mapped along roadsides at ʻĀinahou Ranch at 850-930 m elevation, these totaled 305 m², and may be the populations referenced by Fosberg (1966). Plants were found mostly along open roadsides among alien grasses and native shrubs and on the edges of native/alien forest. A separate population of elephant grass previously described by Tunison et al.

(1992) totaling 0.1 ha was mapped along the Kīpuka Nēnē fire break road, surrounded by alien grasses. The former population described by Tunison (1992) at Waha‘ula has since been covered by lava, and no plants were found at ‘Āpua.

New elephant grass populations were mapped in the park during the present surveys. A population estimated at 100 m² was mapped from a helicopter in 2002 near the park’s western boundary; this population has not been controlled. Four populations totaling 80 m² were mapped along the Keauhou trail in 2002; these plants were initially controlled by the park’s EPMT crew in 2010, with a foliar application of 2% Arsenal and 5% Roundup, which appeared to be an effective control method for this species.

Parkwide eradication of elephant grass is recommended, first targeting more accessible populations at ‘Āinahou, Keauhou trail and Kīpuka Nēnē to prevent the spread of plants into adjacent areas. These populations are small and localized, and this species is a documented pest. Subsequently, control efforts should be expanded to populations along the park’s western boundary. The genus *Pennisetum* is notoriously invasive in Hawai‘i.

***Pennisetum setaceum* Schumach. (Fountain grass)**

Fountain grass (*Pennisetum setaceum*) is an African C_4 bunchgrass, highly invasive in dry areas of Hawai‘i (Smith 1985) and a dominant species in lowland areas of leeward Hawai‘i Island. In HAVO, Tunison et al. (1992) found fountain grass in two major infestations over ~8,000 ha, and smaller populations throughout the park. Because of the increased fire risk and colonization of otherwise intact primary successional sites on recent lava flows, fountain grass has become one of the most intensively managed species in HAVO. Control efforts began on outlying populations in the mid-1960s along roadsides, and were expanded in the late 1970s and early 1980s to reduce the range in the park. By the early 1990s, efforts expanded to parkwide control with treatment of a core infestation at Kamo‘oali‘i (400 ha). Since then, twice yearly surveys and control to treat plants have been carried out across nearly 25,000 ha in the southwest area, and along roadsides in the park. The number of plants discovered has dropped dramatically with control from over 11,000 individuals in 1996 to fewer than 1,000 individuals in 2005 throughout the older units of HAVO. The current control method for fountain grass is to manually uproot individuals, while larger plants and more widespread infestations are treated with a foliar solution of 5% Roundup in water to wet the foliage. Manually clipping and bagging seed heads is done to limit dispersal. A combination of Roundup and the preemergent herbicide Velpar L. appear effective at limiting re-establishment in dry, rocky sites, and this method should be considered especially in areas of the park such as remote locations where re-visit costs are high. A continuation of control efforts to eradicate this species from the park is recommended.

***Persea americana* Mill. (Avocado)**

Avocado (*Persea americana*) is a tree native to Central America, widely cultivated for its edible fruit (Wagner et al. 1999) and as a shade tree or windbreak (Staples and Herbst 2005). Avocado is naturalized in Hawai‘i (Wagner et al. 1999) and cultivated fruits can produce viable seed. In HAVO, avocado was noted by Higashino et al. (1988) in cultivated areas, and naturalized in lowland wet forest and the montane ecological zone. Avocado is controlled in HAVO along roadsides and SEAs.

Individual avocado trees were found sparingly near park residential and administrative areas, many of these were likely planted and/or cultivated. Seedlings were rarely observed in the vicinity of mature trees, suggesting a relatively low invasive potential of these plants. Avocado was found sparingly in more natural settings, including managed forested SEA units (e.g., Kīpuka Puaulu, Thurston), and along roadsides above 600 m elevation. Human assisted dispersal of the large seed appears to be the most likely vector for plants along roadsides. Avocado seedlings can be pulled, and larger trees can be cut and treated with a solution of 50% Garlon 3A.

Although avocado plants appear to have a low invasive potential, continued control in SEAs and along road and trailside locations is recommended to preclude more widespread establishment. Avocado trees are typically dependant on cross pollination for reproduction (Staples and Herbst 2005), and continued control may prevent the establishment of new individuals that could serve as pollinators or seed sources. For these reasons, removal of avocado trees in the residential and administrative areas and SEAs appears warranted as a cautionary measure, though these represent a relatively low priority compared to other invasives found near the Kīlauea summit. An additional consideration is that in forest and woodlands, the large size of mature avocado trees presents a challenge to remove the tree without damaging adjacent vegetation, thus control of smaller individuals is cost effective and minimizes damage to native plant communities.

***Persicaria capitata* (Buch.- Ham. ex D. Don) Masam. (Knotweed)**

The prostrate invasive herb knotweed (*Persicaria capitata*) is native to the Himalayas and western China (Wagner et al. 1999). Knotweed was formerly described as *Polygonum capitatum* F. Ham. and the common name polygonum is still used locally. Plants occur in Hawai‘i in a very wide range of habitats, from forest to open lava flows (Wagner et al. 1999). Knotweed was first collected in or near HAVO along Highway 11 and Chain of Craters Road in the 1960s (Fosberg 1966). Today plants are found along roadsides, on lava fields, and in forests, from 550 to 2,050 m elevation, and plants have been observed near sea level outside of the park. Knotweed has been intensively managed since 2002 along roadsides and in selected SEA units near the Kīlauea summit, using a solution of 3 % Garlon 3A in water. Knotweed is shade tolerant and capable of establishing in closed canopy native forest.

Knotweed has apparently spread rapidly in the park and shows a very wide ecological tolerance, suggesting further expansion is likely. Accordingly, additional mapping is warranted to evaluate the efficacy of control programs and to develop a

more comprehensive strategy to contain this species in HAVO. Species in the family Polygonaceae are overrepresented among agricultural weeds (Daehler 1998), and many are also disruptive invaders in tropical and temperate natural areas (Oliver 1996). Herbicide trials using a 2 % Arsenal solution appear to provide superior control over current methods and should be further investigated.

Philodendron sp**. Schott (*Philodendron*)**

Philodendron is a genus of ~700 species of climbers and vines native to the Americas (Staples and Herbst 2005). In HAVO, an undetermined philodendron persists along the Sandalwood trail, below the Volcano House. This population was initially controlled from 1988-1991, when nine plants were removed using a foliar herbicide application. Between 1991 and 1993 no plants were observed, and philodendron was presumed to be extirpated. In 2002, four philodendron plants were re-discovered at this site, and control was resumed using the same treatment. Philodendron does not appear to reproduce sexually in HAVO, as no flowers nor fruit have been noted by park staff. Continued control leading to eradication is warranted given the small, manageable population size.

Four other species in the family Araceae are known from HAVO (Higashino et al. 1988). The most conspicuous of these is monstera (*Monstera deliciosa* Liebmann), found sparingly in cultivation in the park residential area, and in a larger population along a rock face on the north side of Highway 11, near the HAVO/Volcano Golf Course boundary. This large population suggests the potential to displace native plants, and monstera should be monitored to evaluate invasive tendencies.

Phoenix dactylifera **L. (Date palm) and *P. robelenii* O'brien (Dwarf date palm)**

Date palm (*Phoenix dactylifera*) is a paleotropical palm with an extensive history of cultivation worldwide (Staples and Herbst 2005). Plants are cultivated throughout Hawai‘i, and although not reported naturalized by Wagner et al. (1999), seedlings appear at coastal sites away from adult trees (L. Pratt pers. com). In HAVO, Fosberg (1966) did not encounter date palm, but Higashino et al. (1988) found date palm in coastal lowlands. Date palm has been controlled parkwide since 1985, and plants have been principally found along the central coast extending from Ka‘aha to ‘Āpua, and also at Pu‘u loa and an upland site near Keanakāko‘i.

Along HAVO's central coast, date palms have been found near Halapē. In 1985, five mature plants and nine seedlings were treated near the Halapē campsite using Tordon RTU. An additional 19 mature plants and two seedlings were controlled between 1986 and 2004 from coastal strand vegetation, a coconut grove at Halapē, and eastward between the shoreline and the Puna Coast trail. Plants have not been observed at these sites since 2004.

Individuals have also appeared at five other coastal locations in HAVO. These are Pu‘u loa, near the horse hitching rail (1 plant, 1989), east of the Keauhou-Halapē pali (1

plant, 1993), ʻĀpua (1 plant, 1995), Kaʻaha (1 plant in 1995, retreated in 2002) and Halapē Iki (1 plant, 1997). In 1989, one date palm was discovered and removed near Keanakākoʻi crater (1,100 m elevation). This was the furthest upland a plant has been discovered.

Date palm's occurrence mostly near campsites and along hiking trails suggests humans are dispersing seeds. However, oceanic dispersal may be possible for this species' appearance at coastal sites.

Continued parkwide monitoring and control leading to eradication is recommended due to a limited occurrence in HAVO, and the potential for plants to spread in coastal strand, an important habitat for a number of rare and threatened species. Where plants cannot be uprooted, a solution of 2% Garlon 4 in water applied to the foliage appears to effectively control date palm.

The taxonomic status of HAVO date palm is uncertain. Morphologically similar cultivated Canary date palms (*P. canaierensis*) are found in Hawaiʻi, and these may form a hybrid complex (Staples and Herbst 2005). Vegetative material examined from Halapē had prominent petiolar spines indicative of date palm, but a definitive species determination could not be made. A related dwarf date palm (*P. robelenii*) is cultivated at the ʻĀinahou Ranch, where it does not appear to be spreading.

***Phormium tenax* J.R. Forster and G. Forster (New Zealand flax)**

New Zealand flax (*Phormium tenax*) is a large acualescent perennial herb, native to New Zealand and Norfolk Island. This genus has recently been transferred from the family Agavaceae to the Hemerocallidaceae. New Zealand flax is cultivated in Hawaiʻi, and reported naturalized on Kauaʻi and Molokaʻi (Wagner et al. 1999). Cultivated plants are found in Volcano, however adventive plants have not been found in adjacent areas of the park including SEA units. Smith (1985) considers New Zealand flax a serious pest in Hawaiʻi because it can form dense thickets in moist environments.

In HAVO, Fosberg (1966) found New Zealand flax growing in clumps or as individual plants along an unspecified roadside in forest. Higashino et al. (1988) reported New Zealand flax in cultivated areas and in wet forest. Tunison et al. (1992) documented 3 small roadside populations of New Zealand flax located along Crater Rim Drive. These plants may have been planted, as no evidence of naturalized individuals has been observed in the park (L. Pratt, pers. com.). New Zealand flax was controlled at these three sites from 1982-1988, when 139 plants were treated using a foliar solution of 3% Roundup in water. An additional plant was treated in 1988 at Quarters 19 in the park residential area. No new plants were found during recent surveys, which included former infested sites and roadsides in HAVO. Although New Zealand flax appears to be extirpated within HAVO, continued monitoring of former populations is recommended as a precautionary measure. If new populations are discovered, control efforts leading to eradication should be reinitiated.

Phyllostachys cf. *nigra* (Lodd.) Munro (Bamboo)

Bamboo (*Phyllostachis* cf. *nigra*) is a large woody perennial grass native to China. In Hawai‘i, bamboo is extensively cultivated and spreads vegetatively in areas below 400 m elevation on O‘ahu, Moloka‘i, and Maui (Wagner et al. 1999). Bamboo was not documented by Fosberg (1966) in HAVO, but Higashino et al. (1988) noted bamboo in cultivated areas, and Tunison et al. (1992) described three bamboo populations near the Kīlauea summit.

In 2005, the largest bamboo population covered a 400 m² area adjacent to the Volcano House (1,220 m elevation). This population was bordered by structures, native forest, landscaped grounds and a steep slope (pali) with native and alien vegetation. Within the infestation, a few native tree ferns and an overstory of native ‘ōhi‘a trees remain. The bamboo population appears to be spreading vegetatively by rhizomes, and more recently established bamboo plants can be found on the edge of the pali.

Two populations historically documented from the Sulphur Banks and Steam Vents areas (Tunison et al. 1992) were presumed extirpated in 1983, following control with Garlon 4, but three patches were rediscovered and treated at these sites in 2001. No bamboo was found at these areas or elsewhere in HAVO besides the Volcano House during 2004 surveys. Additional periodic monitoring is recommended at Steam Vents, to ensure that any remaining plants are found and controlled.

Bamboo is notoriously difficult to control by chemical and mechanical means (Motooka et al. 2003). Tunison et al. (1992) report this species did not consistently respond to the herbicide treatments tested and Motooka et al. (2003) recommend a combination of mechanical clearing and herbicide treatment to control bamboo, citing Glyphosate and Fluazifop (Fusillade DX) or Imazapyr (Arsenal, Habitat) as potentially effective chemicals on a related species. If effective chemical treatments are found, parkwide control of bamboo is recommended to halt its spread and protect native plant communities. In 2007, park staff initiated chemical trials testing the efficacy of Glyphosate, Fluazifop and Hexamine based herbicides on the Volcano House bamboo population. Though these trials are ongoing, treatments using Fluazifop appear most effective. Once a suitable control method is developed, control of this remaining population leading to eradication is recommended.

Pinus caribaea Moreler (Slash Pine)

Slash pine (*Pinus caribaea*) is an evergreen tree cited as a serious pest of Hawaiian ecosystems (Smith 1985). In HAVO, plants were originally cultivated along the driveway to the historic ‘Āinahou Ranch house (National Park Service 2004). Tunison et al. (1992) mapped the distribution of slash pine at ‘Āinahou, and found naturalized plants distributed over approximately 17 ha between 840 and 920 m elevation. Plants appeared to be spreading into nearby forest and pastures. Efforts to contain the spread of slash pine by removing new individuals establishing at ‘Āinahou began in 1983. To

date, 254 individuals have been removed. Larger individuals are left untreated during the interim while the cultural landscape treatment for this area is developed.

In 2004, an undetermined pine species, perhaps slash pine, was found growing in dry ʻōhiʻa woodland near the Kīlauea summit (Puaulu Buffer block 4 SEA). This plant and one other were removed in 2005. No additional pines were found in HAVO during 2002-2005 surveys.

No native gymnosperms occur in Hawaiʻi (Wagner et al. 1999). Four introduced pine species are known from the original HAVO section of the park; slash pine appears most invasive based on observations at ʻĀinahou. Loblolly pine (*P. taeda* L.), an undetermined *Pinus* sp, and the Monterey pine (*P. radiata* D. Don) have been observed in cultivated areas (Higashino et al. 1988). Monterey pine shows evidence of natural reproduction surrounding planted individuals at the Kahuku unit of HAVO (Benitez et al. 2008).

Continued control of slash pine leading to eradication is recommended at ʻĀinahou. In addition to removal of newly established individuals, efforts should be expanded to remove the larger individuals which are an important seed source. Felled slash pine trees are not known to re-sprout (Tunison et al. 1992), and this method has been effective in controlling plants in HAVO.

***Pittosporum undulatum* Venten. (Orange pittosporum)**

Orange pittosporum (*Pittosporum undulatum*) is a small tree with undulating margined leaves, native to Australia (Wagner et al. 1999). In Hawaiʻi, orange pittosporum is declared a noxious weed (USDA-NRCS 2010a), naturalized in disturbed mesic forests between 500 and 1,200 m elevation on Lānaʻihale, Lānaʻi and Hawaiʻi. In HAVO, Fosberg (1966) documented orange pittosporum from the park residential area. Higashino et al. (1988) found orange pittosporum in the sub-montane seasonal zone, lowland and montane wet forest, and cultivated areas. Tunison et al. (1992) described individuals sparingly distributed near the Kīlauea summit and the ʻĀinahou rainsheds. Plants near the Kīlauea summit were distributed along trailsides, and near the Volcano House.

Since 1985, plants have been removed parkwide. Between 1985 and 1994, 29 orange pittosporum were removed near Kīlauea Iki, and 8 trees were removed at ʻĀinahou. In 2000, a tree was treated near Kīlauea. In 2001, one mature orange pittosporum was discovered in Kīpuka Kahaliʻi (850 m elevation), this plant was growing among native ʻōhiʻa and native shrubs, in sparse vegetation on cinder. Shortly after discovery, the plant was treated with a solution of 10% Garlon 3A applied to the cut stump of the tree. In 2010, one mature tree and approximately 20 seedlings were treated between the Volcano House and park headquarters. Subsequent surveys did not encounter plants at these former sites or elsewhere in the park.

Continuation of eradication efforts is recommended in HAVO. Orange pittosporum has a high risk for invasiveness based on a recent weed risk assessment (Daehler et al. 2004), which evaluated characteristics such as adaptation for bird dispersal of seeds (Staples et al. 2000) and the presence of large, naturalized populations. Outside of the park, a notable population occurs in mesic forest and woodlands throughout Ocean View, adjacent to the Kahuku unit of the park, and this infestation may provide a nearby source for seed introduction to this area of the park (Benitez et al. 2008). More intensive surveys are recommended to locate undetected individuals near formerly treated populations and in other areas in HAVO where ingress may be likely.

Two additional alien *Pittosporum* have been noted in HAVO (Higashino et al. 1988); Japanese pittosporum (*Pittosporum tobira* (Thunb.) Ait. f.) and an undetermined *Pittosporum* sp*.* These ornamentals do not appear to be naturalized. Two other potentially invasive pittosporum, *P. pentandrum* (Blanco) Merrill and *P. viridifolium (*Sims) are cultivated in Hawai‘i (Staples et al. 2000) but have not been found in the park. Five endemic *Pittosporum* spp*.* occur in HAVO (Higashino et al. 1988).

***Plumbago auriculata* Lam. (Plumbago)**

Plumbago (*Plumbago auriculata*) is a shrub with blue or white flowers native to South Africa, cultivated in Hawai‘i and recently reported naturalized on East Maui (Wagner et al. 1999). In HAVO, plumbago was not noted by Fosberg (1966), but Higashino et al. (1988) reported the plant in cultivated areas.

In 2006, one mature plumbago was found and treated in Kīpuka Puaulu SEA. The plant was growing in mesic forest dominated by native trees, shrubs and ferns.

Plumbago is not considered invasive in Hawai‘i, and it is unknown how the plant became established in Kīpuka Puaulu. This plant was growing in a specially managed area where weeds are intensively controlled. As a precautionary measure to prevent a potential buildup of larger populations, the plant was treated with a foliar solution of 2% Garlon 3A in water, and continued eradication efforts are recommended for this species. No additional plumbago was noted elsewhere in HAVO, and plants have not been observed at the site since. The indigenous congener ‘Ilie‘e (*P. zeylandica*) is a sprawling shrub which formerly occurred in the coastal lowlands of HAVO (L. Pratt, pers. com.), and this common name is sometimes also used for plumbago.

***Prosopsis pallida* (Humb. and Bonpl. ex Willd.) Kunth (Kiawe)**

Kiawe (*Prosopsis pallida*)**,** is a leguminous tree native to northwestern South America (Wagner et al. 1999), naturalized and common in coastal sites and degraded lowland dry forest and grasslands on all the main Hawaiian Islands except Ni‘ihau. In HAVO, Fosberg (1966) reported kiawe trees at Keauhou, and Tunison et al. (1992) found 17 kiawe individuals or small populations with up to 19 individuals each at coastal sites near Keauhou and Halapē. Many populations mapped by Tunison (1992) reportedly contained a number of dead trees, presumably from control work prior to 1985.

During 2002-2005 surveys, thirteen kiawe trees were found; eleven of these were mature plants at a coastal site 1 km east of Keauhou. This population was surrounded by anchialine pools and primarily alien grasses and shrubs, and apparently has never been controlled. One additional mature and one juvenile kiawe tree were found at Keauhou among coastal vegetation dominated by koa haole and alien grasses, these appear to be remnants of the larger kiawe population described by Tunison et al. (1992). From 1985 to 1999, 299 individuals were controlled at this site, and individuals may have also been controlled prior to 1985 (Tunison 1992).

Kiawe is considered a damaging pest in dry Hawaiian lowland communities (Smith 1985), and continued removal of all mapped individuals appears warranted to prevent buildup of larger populations. Continued monitoring of lowland areas in the park seems warranted to detect persistent or newly established individuals, and parkwide eradication of kiawe in HAVO seems feasible given the small population size and past successes of control work.

Prunus serrulata Lindley (Japanese flowering cherry)

Japanese flowering cherry (*Prunus serrulata*) is a tree native to Asia, belonging to a genus of over 100 tree species native to north temperate regions. Many species are cultivated for their fruit, seeds, or flowers, and edible species were early introductions to Hawai‘i, many prior to 1825 (Staples and Herbst 2005). The distribution of Japanese flowering cherry has never been mapped in the park, although Fosberg (1966) noted peach (*Prunus persica* (L.) Batsch) locally adventive in kīpukas of the Kīlauea region, and Higashino et al. (1988) noted this species naturalized in the montane zone and in cultivated areas. Higashino et al. (1988) also noted sour cherry (*P. cerasus* L.) in cultivated areas.

Since 2000, Japanese flowering cherry trees, saplings and seedlings have been found occasionally in wet forest SEA units in primarily native vegetation. From 2000-2007, 341 prunus trees, saplings and seedlings were discovered and removed during systematic ground sweeps from Koa (215 ha), Pu‘u (155 ha) and Small Tract (144 ha) SEAs in ‘Ōla‘a wet forest. Mature prunus trees remain along the south boundary fences of Small Tract and Koa units, and on adjacent private pastures.

A sapling, presumably also Japanese flowering cherry, was found in wet forest in Thurston SEA (block 20) in 2006. Prior to this sighting, this species was previously unknown from this unit. No additional trees were found in wet forest elsewhere in HAVO.

Outside of the park, Japanese flowering cherry is common in residential lots and woodlands dominated by native and alien trees in the Volcano Golf Course subdivision. A related species, the peach (*P. persica*) has been reported from mesic forest in Kīpuka Puaulu and Kīpuka Ki, but plants were not observed during 2003-2005 surveys, though these plants persist (L. Pratt, pers. com).

Japanese flowering cherry is not generally regarded as highly disruptive in Hawai‘i, yet this species’ occurrence in native forest is consistent with reports of bird dispersed fruits (Staples et al. 2000) suggesting continued spread is likely surrounding known populations. Furthermore, the family Rosaceae (Daehler 1998) is notable for being highly invasive in Hawai‘i and consideration should be given to increase efforts to control plants along the south boundary fences of Small Tract and Koa units in ‘Ōla‘a, and if possible to work with landowners to remove plants on adjacent pasture lands as these likely represent an important seed source to the park.

***Psidium cattleianum* Sabine (Strawberry guava)**

Strawberry guava is a small tree native to lowland and montane Atlantic wet forests between 0 and 1000 m in Brazil and Uruguay (Pedrosa-Macedo et al. 2007). Strawberry guava is cultivated throughout the tropics, apparently first introduced to Hawai‘i in 1825 (Nagata 1985) and now regarded as one of the most invasive pests of wet and mesic forests (Smith 1985; Wagner et al. 1999). Strawberry guava is widespread in HAVO and was not intensively mapped, but plants were seen frequently along transects, trails, and interiors of wet to mesic forests and woodlands between 420-1,400 m elevation. Based on these observations, a range extent of dense strawberry guava was estimated at 10,700 ha, with individual plants scattered over an additional 3,240 ha. Notable dense infestations included the ‘Ōla‘a Koa unit, the Tree Molds area on lower Mauna Loa, and areas within the East Rift of Kīlauea. Since 1985, efforts to control strawberry guava have been focused in SEAs and restoration sites.

Transects sampled between 1998 and 2005 were used to estimate cover of strawberry guava in portions of ‘Ōla‘a, East Rift, Mauna Loa SEAs, and ‘Āinahou. Strawberry guava was widespread in ‘Ōla‘a, becoming increasingly prominent within the southeastern half of Ōla’a Tract with denser, often monotypic stands, suggesting that a strawberry guava invasion front is advancing northwest. In other areas of ‘Ōla‘a (Ag, Pu‘u and the western portion of Koa unit), strawberry guava was rarely encountered.

On the Mauna Loa Strip, strawberry guava was mainly concentrated in wetter koa forests, east of Kīpuka Puaulu along the HAVO/Keauhou boundary, where dense infestations grew among alien grasses. The largest infestation had 10-25% cover across an area of 17.4 ha and a denser infestation was also noted in the Tree Molds area, where cover was estimated to exceed 50 % underneath a koa canopy. Elsewhere on Mauna Loa, strawberry guava was infrequent in koa forests below 1,400 m, occurring at less than 1% cover, whereas no strawberry guava was found in ‘ōhi‘a woodlands and shrublands above 1,250 m. The Tree Molds population was controlled in 2008, by cutting trees and treating the stumps with a solution of 50 % Garlon 3A in water, and the cut trees were chipped on site.

At ‘Āinahou Ranch strawberry guava occurred sparingly at less than 1% cover in mesic forests and woodlands dominated by ‘ōhi‘a and faya tree, and alien grasses.

Strawberry guava appears to represent a lesser threat in these drier environments, and plants have never been controlled at this site.

In the East Rift wet forest, strawberry guava was widespread. Strawberry guava was controlled in 143 ha of the East Rift SEA, where 69,310 plants were removed between 2000 and 2007. Below these areas, strawberry guava was mapped in a closed ʻōhiʻa and lama dry-mesic forested kīpuka (extending down to 400 m elevation) now covered by lava. Consistent with reports of adaptation to disturbance (Huenneke and Vitousek 1990) resprouting and new seedling recruitment appeared abundant in areas burned by 2002-2003 wildfires. However, this area is directly downwind of the Puʻu ʻOʻo volcanic gas steam plume, and casual observations suggest strawberry guava is sensitive to prolonged gas exposure, as plants are typically less abundant and vigorous in these areas than in surrounding forest further away from the plume. The distribution of strawberry guava in the East Rift is discussed in greater detail by Pratt et al. (1999)

Strawberry guava's dispersability, rapid growth, and shade tolerance warrant continued, aggressive control to exclude this species from SEA units and other priority sites. More detailed range maps would be of strategic benefit to park resource managers and allow for more effective prioritization of removal and containment strategies, particularly in ʻŌlaʻa and the East Rift. Three strawberry guava forms are recognized in Hawaiʻi (Wagner et al. 1999), although these have not been specifically mapped in HAVO. The Brazilian gall forming insect *Tectococcus ovatus* Hempel (Heteroptera:Eriococcidae) is a specialized natural enemy of strawberry guava, and a potential biological control agent in Hawaiʻi (Vitorino et al. 2000), though this agent has not yet been released.

***Psidium guajava* L. (Common guava)**

Common guava is a small tree native to tropical America and widely cultivated in the tropics including Hawaiʻi (Staples and Herbst 2005). In HAVO, common guava is widespread in costal lowlands, the submontane seasonal zone and wet forest (Higashino et al. 1988).

Common guava was not intensively mapped; however a range extent was estimated at 18,615 ha based on data points collected along roads, trails, fencelines and transects between 2001 and 2005. With a few exceptions common guava occurred at fairly low densities throughout this range, and plants were not found in wet, closed canopy forest. Though rare, dense infestations exceeding 25% cover were noted near the park's southwest boundary and the Kapāpala Ranch, and also in an alien grassland near Kamoʻoaliʻi, Common guava was observed at a maximum elevation of 1,200 m in koa/ʻōhiʻa montane mesic forest, and at a minimum elevation near sea level in central and eastern sections of HAVO. A solution of 10 % Garlon 3A in water applied to the tree's cut stump is used to control common guava.

Common guava is a disruptive weed in Hawaiʻi (Wagner et al. 1999, Motooka et al. 2003, Staples and Herbst 2005). Because common guava is widespread, parkwide

eradication is not feasible and control is limited to excluding plants from dry and mesic SEA units (e.g., ʻĀinahou, Kīpuka Kahaliʻi, Nāulu). A continuation of these efforts is recommended to protect resources in SEAs. Plants are occasionally discovered and controlled in wetter SEA units, but the congeneric species strawberry guava (*P. cattleianum*) is more often found in these areas and is considered a greater threat to Hawaiian ecosystems (Smith 1985).

Pterolepis glomerata (Rottb.) Miq (Pterolepis)

Pterolepis (*Pterolepis glomerata*) is a neotropical herb or subshrub in the family Melastomataceae, naturalized but not cultivated in Hawaiʻi (Staples and Herbst 2005). A population of 62 plants was uprooted in 1983 along the Nāpau Trail, near Makaopuhi Crater in Kīlauea's East Rift wet forest. This area was intensively surveyed in a separate study in 1992-1994 (Pratt et al. 1999) and no plants were found. Follow-up surveys to determine if plants still remained were conducted again in 2002, when based on the early control notes, the general area of the original infestation and all trailside's throughout Kīlauea's East Rift were surveyed for this and other invasive weeds. Although no plants were found, continued monitoring is recommended because of the invasive nature of this species, and the uncertainty of the exact location of the original population. This caution is warranted because the family Melastomataceae is represented by some of the most ecologically disruptive invasive species in Hawaiʻi (Smith 1985, Baruch et al. 2000). New occurrences of this weed should therefore be eradicated if discovered.

This plant was formerly misidentified by park staff as *Arthrostemma ciliatum* Pav. ex D. Don (L. Pratt, pers. com.). No *Arthrostemma latifolia* has ever been found in HAVO.

Pueraria montana var. *lobata* (Willd.) Maesen & S. Almeida (Kudzu)

Kudzu (*Pueraria montana var. lobata*) is a fast growing, nitrogen fixing herbaceous vine native to southeast Asia (Wagner et al. 1999, Mitich 2000), where it has been cultivated for over two millennia. Kudzu is a federally listed noxious weed (Mitich 2000), reported naturalized in disturbed areas in Hawaiʻi below 700 m elevation on Kauaʻi, Oʻahu, Maui and Hawaiʻi (Wagner et al. 1999). In HAVO, kudzu was not documented by Fosberg (1966), however his surveys did not include ʻĀinahou Ranch, where Tunison et al. (1992) mapped four populations distributed over approximately 0.5 hectares between 910 and 935 m elevation. Two varieties are recognized in Hawaiʻi, with HAVO plants assigned to *P. lobata* var. *lobata* (Wagner et al. 1999).

During 2003 surveys, three small populations of kudzu were found at ʻĀinahou in sites formerly mapped by Tunison et al. (1992) in ʻōhiʻa/faya forest, woodlands and landscaped grounds. Four vines were found in a 100 m² area in ʻōhiʻa/faya forest, and three plants were found in a 400 m² area in open native dry woodland. Two plants were growing in an open area dominated by alien grasses on the southeast side of a nursery. All plants were treated with a cut stump application of 5% Garlon 3A in water soon after discovery.

Since 1984, a variety of control methods have been used to control kudzu. In 1984 and 1985, 1,253 and 876 individuals respectively were treated using a 2% Roundup foliar treatment. From 1988 to 1991, less than 70 individuals were treated with Tordon or uprooted. Between 1991 and 1996, 23 plants were uprooted, and from 1996 to 2006, 23 individuals were treated with foliar or cut stump applications of Garlon 3A or Garlon 4. No control of kudzu occurred between 2006 and 2009. Kudzu is reportedly difficult to control manually and chemically (Mitich 2000), and past efforts appear successful in containing and reducing population sizes, but not eradicating all infestations. Primarily vegetative reproduction is suggested since no new populations have been located at ʻĀinahou or elsewhere in HAVO since mapping by Tunison et al. (1992) and fruits have not been observed by control crews.

Kudzu is an extremely aggressive weed in southeastern United States, and expensive control programs are dedicated to limiting the spread of vines, which spread mainly by vegetative expansion and occasionally by seed. Control of kudzu leading to eradication should be continued until the species is extirpated from HAVO, and alternative chemical treatments should be considered to remove persistent rootstocks.

***Pyracantha crenatoserrata* (Hance) Redher, and *Pyracantha koidzumii* Redher (Firethorn)**

Firethorns (*Pyracantha* spp.) are thorny shrubs in the family Rosaceae, native to Eurasia, cultivated in warm temperate areas worldwide and naturalized in higher elevation mesic sites at Kōkeʻe on Kauaʻi, East Maui, and Volcano on Hawaiʻi (Wagner et al. 1999, Staples and Herbst 2005). In HAVO, firethorn was noted by Fosberg (1966) naturalized in the Kīlauea region, and by Higashino et al. (1988) in wet forest and cultivated localities. Since 1999, firethorn has been controlled parkwide. Firethorn plants in HAVO were previously misidentified as *P. angustifolia* (Franch.) C.K. Schneid. In the park, *P. crenatoserrata* appears more common (L. Pratt pers. com), but *P. koidzumii* is also present.

During 2003-2005 surveys, mostly small infestations were mapped in mesic and wet, often disturbed areas including woodlands and forest near the Kīlauea summit. These areas included the Mauna Loa horse coral, the park residential and administrative areas, the dog kennels at the park research area, Puaulu Buffer SEA, and KMC. All known populations have been controlled on approximately six month intervals, using a variety of chemical treatments (e.g., foliar Triclopyr or Glyphosate applications, cut stump Triclopyr applications). Continued parkwide control work leading to eradication is warranted given the invasive tendencies of these plants, including high fecundity, adaptation to bird dispersal, and aggressive growth in Volcano. Since this species is well established in areas adjacent to the park, continued ingress can be expected. The family Rosaceae is notably invasive in Hawaiʻi, and although this notoriety is primarily due to the genus *Rubus* (Daehler 1998), Staples and Herbst (2005) urge caution with this species due to a high invasive potential. Accordingly, efforts to limit cultivation of

this species in Volcano should also be encouraged by the park to limit additional ingress.

Ricinus communis **L. (Castorbean)**

Castorbean (*Ricinus communis*) is a small tree native to Africa and perhaps India (Wagner et al. 1999), naturalized in Hawai‘i prior to 1819 and now found in disturbed habitats below 500 m elevation on all islands (Wagner et al. 1999). In HAVO, Fosberg et al. (1966) found castorbean established at low elevations, and Tunison et al. (1992) mapped 11 populations of castorbean growing on talus slopes, cracks or collapsed lava tubes at low elevations, and commented populations were capable of prolific regeneration from seed following disturbance. At least three of the populations mapped by Tunison et al. 1992 have since been covered by lava. Parkwide castorbean control began in 1978.

Between 2000 and 2009, small castorbean populations were mapped in areas previously identified by Tunison et al. (1992) at Halapē Iki, Kealakomo Waena, Hōlei Pali, Kūkalau‘ula Pali, Kīpuka Pepeiao and the Mauna Loa rock quarry. A new population of two mature plants was identified 100 m south of the Kalapana trail in 2002 and two plants were mapped along the northwest side of a large koa haole population at Pu‘u Kaone in alien grasses in 2009. Outside the park, a castorbean population was found along Hwy 11, 100 m beyond the HAVO southwestern boundary in an aggregate rock pile in 2000, and these plants were controlled to remove seed sources near the park. A foliar solution of 1 % Garlon 4 in water has been used to control castorbean plants in the park.

Continued parkwide control of castorbean is recommended to eradicate this species since it is a disruptive invader which threatens native plant communities. Control should continue on individuals adjacent to the park, and additional monitoring should be undertaken to discover and remove undetected plants in HAVO. The seed coat of the castorbean plant contains the powerful cytotoxin ricin, which can be toxic to animals including humans if released following ingestion (Wedin et al. 1986).

Rosa spp **L. (Rose)**

Roses (*Rosa* spp.) are shrubs comprising ~150 species primary from north temperate regions (Staples and Herbst 2005). In HAVO, Fosberg (1966) noted four rose species, with Cherokee rose (*R. laevigata* Michx.) and polyantha rose (*R. polyantha* Hort.) in cultivation, and multiflora rose (*R multiflora* Thunb.) and redleaf rose (*R. rubrifolia* Vill.) naturalized in the Kīlauea area. Additionally, Fosberg (1966) made note of an unspecified number of rose species persisting from cultivation. Higashino et al. (1988) noted the four rose species described by Fosberg (1966) and an additional, unidentified rose species. Tunison et al. (1992) did not map the distribution of any rose in HAVO. Roses are cultivated in Hawai‘i; Cherokee rose (Nagata, 1995) and *Rosa* x *damascena* Mill. are recently naturalized.

In 2003, an undetermined pink flowered rose (*Rosa* spp A) was mapped along roadsides near the Kīlauea summit. This species was first controlled in 2004, and 504 individuals were removed from Thurston wet forest SEA (Block 18, 30 ha) through 2009. This rose appears naturalized because seedlings and mature plants were found in areas removed from cultivated locations and roadsides. Two additional rose species were found during 2003 surveys of park residential and administrative areas. No roses were found elsewhere in HAVO.

Additional work is recommended to update the distribution of these roses and determine specific identities. The family Rosaceae is notably invasive in Hawai‘i, although this notoriety is chiefly on account of the genus *Rubus* (Daehler 1998). Nevertheless, the invasive tendencies of this genus should not be taken lightly, as a number of rose species are serious pests in the continental United States, including two species known from HAVO, the Cherokee rose (Rosene 1950) and multiflora rose (Underwood et al. 1996). Accordingly, control leading to eradication of these and other rose species is recommended as a precautionary measure. Based on evidence of naturalization, control of *Rosa* spp A is the highest priority for the park.

***Rubus argutus* Link (Florida Prickly blackberry)**

Florida prickly blackberry (*Rubus argutus*) is a thorny shrub native to central and eastern USA. In Hawai‘i, Florida prickly blackberry is an extremely serious weed of disturbed habitats, on the Hawai‘i noxious weed list (USDA-NRCS 2010a). Plants are found in mesic to wet forest and subalpine shrubland from 200-2,300 m elevation on Kaua‘i, O‘ahu, Moloka‘i, Maui and Hawai‘i. Fosberg (1966) noted Florida prickly blackberry abundant in open areas and in disturbed forest on Kīlauea.

Florida prickly blackberry was found widespread in sub-montane and montane forests, woodlands and open areas. Along transects on the Mauna Loa unit plants were frequent, occurring in 21% (n=828) of transect stations sampled in 2003, with 5% of all stations (n=43) exceeding 10% cover. Plants were found most abundant over 1,500 ha between 1,190 and 1,620 m elevation, with a core infestation of 752 ha in koa forest from 1,190 to 1,430 m elevation where large, dense thickets (250 m² area) became increasingly frequent at lower elevations. In ‘ōhi‘a woodlands and open shrublands where soils were shallow, plants were less common, and generally covered less than 5 m². No plants were noted above 1,620 m elevation, but plants were recently found at 1,850 m elevation in the Kahuku addition of the park (Benitez et al. 2008). Down slope, Florida prickly blackberry was found in Puaulu Buffer SEA, where plants have been controlled every two years during systematic sweeps of the area. Intensive control of this species occurs in Kīpuka Ki and Kīpuka Puaulu.

Relative to the Mauna Loa infestation, Florida prickly blackberry was less abundant in Ōla‘a units, mapped in 9% (n=1227) of the 50 m² sampling units read along transects in 1998. All but four of these occurrences were at <1% cover. Elsewhere, Florida prickly blackberry was not observed in forests surrounding ‘Āinahou or Kīlauea’s East Rift during the present surveys. No plants were noted in the East Rift by Pratt et al. (1992).

Florida prickly blackberry is controlled in wet and mesic SEA units (e.g. Koa, Pu‘u, Small Tract, Thurston, Kīpuka Puaulu and Kīpuka Kī). Outside of SEAs, Florida prickly blackberry is controlled in experimental restoration plots in former pasture and koa forest on Mauna Loa. During sweeps to control multiple species in wet forest units, cut stump applications of 10% Garlon 3A provide good control, but the preferred method for this species in dense stands is a foliar application of 0.5% Garlon 3A in water.

Florida prickly blackberry is too widespread for parkwide eradication, but nevertheless is disruptive to native plant communities and warrants intensive control. Continued control in SEA’s and experimental restoration sites is warranted to protect unique native plant communities, and to develop control techniques which may be applied at larger scales (i.e., landscape level). Additional research is warranted to better understand the environmental and ecological conditions that may limit its abundance. Continued monitoring is also required to prevent establishment in new areas such as the East Rift and ‘Āinahou, where favorable conditions for the establishment of this plant likely exist. In light of the widespread distribution and negative environmental impacts of this plant, it is a candidate for biological control research.

Rubus ellipticus Sm. (Yellow Himalayan raspberry)

Yellow Himalayan raspberry is an thorny shrub native to southern Asia (Wagner et al. 1999) introduced to Hawai‘i at the University of Hawai‘i Volcano Agricultural Experimental Station in 1961 (Jacobi and Warshauer 1992). In Hawai‘i, large infestations are now found in forests, disturbed areas, pastures, roadsides and residential lots in the Volcano vicinity (Benitez pers. obsn.). Smaller infestations are known from the North Kona, Ka‘ū, and North Hilo districts. Plants are not yet known from other Hawaiian Islands (Stratton 1996, Wagner et al. 1999) except O‘ahu where a roadside population was recently discovered presumably introduced as contaminants on landscape plants (Frolich and Lau 2007). In HAVO, yellow Himalayan raspberry is found primarily in ‘ōhi‘a wet forest and occasionally in mesic koa forest between 914 and 1,340 m elevation. Since 1985, control of plants has been focused in SEAs.

Infestations of yellow Himalayan raspberry were highest in ‘Ōla‘a wet forest where plants occurred in 57 % (n=1227) of the 50 m² sampling units read along transects in 1998. Cover abundance ranged between 0 and 25% and eastern units appeared more infested; a maximum cover value of 2.81% was estimated for managed Koa unit and a minimum 0.08% for Pu‘u unit.

In Kīlauea’s East Rift, plants were reported restricted to Kane Nui o Hamo, with a frequency of 5.8% along transects in 1992 (Pratt et al. 1999). The range of this species has apparently expanded since, as 32 plants were discovered and removed from a 143 ha weed managed area between 2002 and 2005 in an area previously surveyed by Pratt et al. (1999).

Elsewhere in the park, yellow Himalayan raspberry occurred at a maximum elevation of 1,340 m in Kīpuka Kī, a native montane mesic forest with many rare and endangered plant species, and at a minimum elevation of 910 m at ʻĀinahou, where several large plants were mapped during a survey in 2003 in mesic ʻōhiʻa/faya forest.

Yellow Himalayan raspberry is an extremely disruptive weed in HAVO and elsewhere, where it forms exclusive stands and displaces native species in upland wet forests (Stratton 1996). Continued control in SEA's is recommended to protect these native plant resources, and additional surveys in Kīlauea's East Rift are recommended to map the extent of invasion and identify a containment or exclusion strategy that will prevent more widespread establishment.

***Rubus glaucus* Benth. (Andean raspberry)**

Andean raspberry is a thorny shrub with glaucous stems native from Mexico to Ecuador. In Hawaiʻi, Andean raspberry was introduced in the early 1960's at the University of Hawaiʻi Volcano Agricultural Experimental Station, in Volcano, Hawaiʻi (Tunison et al. 1992), and escaped cultivation shortly thereafter. Andean raspberry is now found in native forest, agricultural lots and disturbed areas in Volcano and has recently been documented from Maui at elevations above 1,200 m (Starr et al. 2003b). In HAVO, Higashino et al. (1988) documented Andean raspberry from wet forest, and Tunison et al. (1992) documented four populations of Andean raspberry in the ʻŌlaʻa tract, behind the UH Volcano Agricultural Experimental Station. Andean raspberry has been controlled in SEA wet forest units in HAVO since 1989, using a solution of 10 % Garlon 3A applied to the plant's cut stump.

Andean raspberry is distributed primarily within the ʻŌlaʻa Ag wet forest unit, which lies directly adjacent to the UH Volcano Agricultural Experimental Station, and where small thickets may cover an area of up to 50 m² within native wet forest. Plants are most abundant nearest the Agricultural Station, however plants are also scattered throughout the unit's interior.

Andean raspberry appears to expanding its range, as the current distribution appears more widespread relative to mapping by Tunison et al. (1992) and continued spread is expected, as evidenced by recent sightings and control work by ground crews during cyclic weed removal work in Koa unit SEA. Although plants have not yet been noted in the Small Tract Unit of ʻŌlaʻa nor elsewhere in HAVO, continued monitoring and control in SEA units is recommended for this weed as plants in this genus are notably invasive in Hawaiʻi.

***Rubus rosifolius* Sm. (Thimbleberry)**

Thimbleberry (*Rubus rosifolius*), a shrub native to Asia, is a common weed in Hawaiʻi (Wagner et al. 1999), and an aggressive invader in the Society Islands (Meyer 2004). Thimbleberry populations were not intensively mapped, but presence/absence points collected along transect lines, roadsides, fencelines indicate a widespread distribution

between 700 and 1,600 m elevation in HAVO. Though frequent in wet forests in the park (Pratt et al. 1992), dense thickets appeared limited to recently disturbed habitats and were seldom encountered in deep shade. As a result, thimbleberry has been a low priority for management.

Thimbleberry has a number of invasive congeners in Hawai‘i, with which the plant shares biological characteristics (Wagner et al. 1999). The invasion does not appear as aggressive as in the Society Islands, and is too widespread for effective containment in the park. However, because of the highly invasive nature of this genus (Daehler 1998) and its documented impacts in other Pacific oceanic islands, this species should be monitored over time and an appropriate management strategy formulated if any changes in its invasiveness are detected.

Samanea saman (Jacq.) Merr. (Monkeypod)

Monkeypod (*Samanea saman*) is a tree with a broad, spreading crown, native to Central and South America (Wagner et al. 1999) belonging to the family Fabaceae. In Hawai‘i, trees are planted for shade and naturalized in disturbed areas on at least Kaua‘i, Maui, O‘ahu and Hawai‘i (Wagner et al. 1999; Wagner et al. 2003). In HAVO, Higashino et al. (1988) reported monkeypod from the coastal lowlands. In 2007, nine mature monkeypod trees were controlled near the Keauhou Trail at 90 m elevation. Trees were growing among alien vegetation including grasses and Formosa koa trees. Plants were sterile and no evidence of recently established new individuals was noted. Two additional monkeypod trees were noted further upslope along the Keauhou Trail; these individuals were smaller and have not yet been controlled.

Monkeypod was not found elsewhere in HAVO. Monkeypod is not considered invasive in Hawai‘i, and the plant’s mode of ingress into the park remains unknown, although human vectoring along trails is possible given the plant’s location. Though monkeypod is a low priority for control, this species is naturalized and belongs to a family overrepresented in Hawai‘i with natural area invaders (Daehler 1998). Accordingly additional monitoring at this site and elsewhere in HAVO is recommended along with removal of individuals that may be found as a preventative measure.

Sambucus mexicana K. Presl ex DC (Mexican elderberry)

Mexican elderberry is an ornamental shrub native to North America, sparingly naturalized in Hawai’i, and recently transferred from the family Caprifoliaceae to the Adoxaceae (Wagner et al. 1999). In HAVO, Mexican elderberry was noted in cultivation by Fosberg as early as the 1940’s (1966) and later observed by Higashino et al. (1988). During 2003 surveys, one Mexican elderberry was found growing among alien vegetation behind park headquarters. No evidence of new recruitment was observed in the area surrounding this plant, and no additional plants were noted in HAVO.

Mexican elderberry has never been controlled in HAVO, and although this plant does not yet appear to be spreading, removal leading to eradication is feasible and warranted due to small population size and evidence of naturalization elsewhere in Hawai‘i.

Scaevola cf*. aemula* R. Brown (Fairy fan flower)

Scaevola is a genus of ~100 herbs, shrubs and small trees endemic to Australia and the Indo-Pacific basin (Staples and Herbst 2005). One indigenous and eight endemic species are known from Hawai‘i (Wagner et al. 1999). One alien species, fairy fanflower (*S. aemula*) is common in cultivation in Hawai‘i (Staples and Herbst 2005).

This species was first discovered in HAVO in 2001 when a small matting *Scaevola* shrub with blue-purple flowers, apparently fairy fanflower, was found in a recently (2000) burned ‘ōhi‘a woodland. The area where the plant was discovered was resurveyed in late 2004, but no plants were found.

A cultivated plant, this species is not reported naturalized in Hawai‘i, and may not set seed in the Islands (Staples and Herbst 2005). Fairy fanflower’s mode of ingress into HAVO remains unknown; vegetative material may have accidentally or deliberately been introduced to the area by park staff or visitors. This scenario seems unlikely however, because the site is reasonably removed from roads and a nearby picnic area. Accordingly, establishment of fairy fan flower from seed transported by more natural vectors (e.g., wind, birds) cannot be ruled out, and searches should be made for populations surrounding HAVO and elsewhere in Hawai‘i to determine if plants are naturalized, particularly in the Volcano Golf Course subdivision. Similarly, continued monitoring of the site is warranted to search for additional undetected individuals, and these should be eradicated if found.

Schefflera arboricola (Hayata) Merrill (Dwarf umbrella tree)

Dwarf umbrella tree (*Schefflera arboricola*) is a shrub native to Taiwan, cultivated but not naturalized in Hawai‘i (Staples and Herbst 2005). In HAVO, dwarf umbrella tree was not noted on previous plant checklists (Fosberg 1966; Higashino et al. 1988). In 2003, one plant was mapped in the park residential area near the Volcano House dormitory.

Staples and Herbst (2005) note that dwarf umbrella tree has an aggressive root system, and can overwhelm a garden. These authors suggest cautious management with this plant, as it may become invasive. In 2006, a large, fruiting dwarf umbrella tree ~4 m tall was removed from the recently acquired Kahuku Unit; the tree was cut with a chainsaw and a solution of 50 % Garlon 3A applied to the cut stump. Removal of the individual from the residential area of HAVO is also recommended, to prevent invasion and more costly control in the future.

Schefflera actinophylla (Endl.) Harms (Octopus tree)

Octopus tree (*Schefflera actinophylla*) is native to Australia and New Guinea, capable of epiphytic growth, and found in Hawai‘i at lower elevations on all of the principal islands (Wagner et al. 1999). Dense octopus tree stands can develop in wet forest (Motooka et al. 2003), leading Staples and Herbst (2005) to consider octopus tree a

very serious weed of Hawaiian ecosystems. In HAVO, Fosberg (1966) reported an octopus tree in Kīpuka Puaulu in 1940, and Higashino et al. (1988) noted octopus tree in the sub-montane and montane seasonal ecological zones, though precise location data is unavailable.

Recent surveys identified two octopus trees in HAVO. In 2002, one octopus tree was found on the edge of a recent lava flow, near the Kalapana Trail at ~300 m elevation. No additional plants were noted in the vicinity, and this area has since been covered by lava. In 2005, a second octopus tree was found and controlled in mesic forest in the East Rift SEA (Luhi block 7) during systematic sweeps to control invasive weeds. Octopus tree is bird-dispersed, and these plants may represent colonies from the adjacent Kahauale‘a forest reserve or the Wao Kele ‘O Puna forest, where naturalized octopus trees have been observed during helicopter overflights. Alternatively, mature undetected trees may exist nearby, although plants were not encountered elsewhere in the East Rift SEA by Pratt et al. (1992) or the present surveys, and no additional trees were found in the remainder of HAVO. The plant reported by Fosberg in Kīpuka Puaulu appears to be no longer extant.

Continued parkwide control to eradicate individuals of this aggressive invader is recommended. Additional aerial and ground surveys of the Kīlauea East Rift are warranted to search for additional plants and to better map the distribution in the park and on adjacent lands.

The synonym *Brassaia actinophylla* Endl. has previously been applied to octopus tree.

***Schinus terebinthifolius* Raddi (Christmasberry)**

Christmasberry (*Schinus terebinthifolius*) is a tree native to Brazil. First collected in Hawai‘i in 1911, christmasberry is considered one of Hawai‘i’s worst weeds (Smith 1985), where it infests mesic-dry areas on Midway Atoll and the main Hawaiian Islands except Ni‘ihau and Kaho‘olawe.

Christmasberry is widespread in HAVO and was not intensively mapped. Plants were typically found near sea level along the park’s eastern and western lowlands, and in kīpukas up to ~900 m elevation, particularly along the southwest flank of Kīlauea. Christmasberry was found at a maximum elevation of 1,280 m elevation in a kīpuka dominated by koa on deep soils with an understory of alani (*Melicope* sp.) and ’a’ali’i (*Dodonaea viscosa*) with alien grasses. This plant was removed, and no additional plants were encountered in the surrounding areas. No additional christmasberry was found in plant surveys on Mauna Loa.

Elsewhere on Hawai‘i, Ka‘ū is notable as a site of christmasberry infestation (Motooka et al. 2003). In Ka‘ū plants have been mapped at a maximum 1,500 m elevation within the Kahuku unit of HAVO (Benitez et al. 2008).

In HAVO, christmasberry is controlled in the Keamoku SEA and in the Kīpuka Pepeiao burn restoration site. Continued control in these areas and other SEAs where infestations are small and manageable will prevent the buildup of larger populations and is recommended to protect native plant communities. Eradication of outlying plants such as the individual found on Mauna Loa is recommended to prevent christmasberry establishment in new areas. The preferred control method is a basal bark application of 15% Garlon 4 in diesel fuel oil.

Schizachyrium condensatum (Kunth) Nees (Bush beardgrass)

Bush beardgrass (*Schizachyrium condensatum*) is a C_4 grass, native to tropical and subtropical America (Wagner et al. 1999), found primarily in HAVO, but also recently documented in roadside locations and natural areas near the Ko'olau mountains on O‘ahu. The distribution of bush beardgrass was not mapped parkwide, but plants were found widespread in the original park section primarily in dry ‘ōhi‘a woodlands and mesic areas.

Since the late 1960’s bush beardgrass has invaded large areas of the sub-montane seasonal zone in HAVO, and along with other alien grasses (e.g., broomsedge – *Andropogon virginicus*) can form a continuous fine fuel layer (D’Antonio 1992). This invasion is at least partly responsible for a doubling of the fire frequency and a 50-fold increase in fire size between pre-invasion times and the 20 years following invasion (D'Antonio and Vitousek 1992). Plants are too widespread for control, and removal from selected project areas is recommended. Bush beardgrass is controlled using foliar application of 1% Roundup in water.

Sechium edule (Jacq,) Sw. (Pepinella)

Pepinella (*Sechium edule*) is a climbing herb likely native to Central America (Wagner et al. 1999), and sparingly naturalized in Hawai‘i. In HAVO, pepinella was not noted by Fosberg (1966). Higashino et al. (1988) reported this species from wet forest and roadsides, but Tunison et al. (1992) did not map this species’ distribution.

Between 1988 and 1989, three plants were discovered and uprooted in the ‘Ōla‘a wet forest unit of HAVO. Plants were not observed on subsequent control visits, and no pepinella was found during subsequent surveys. This species is presumed extirpated, but control leading to eradication should be re-intiated if new individuals are found.

Senecio madagascariensis Poir. (Madagascar fireweed)

Madagascar fireweed (*Senecio madagascariensis*) is an herb native to Madagascar and southern Africa. A phylogeographical analysis of Hawaiian Madagascar fireweed populations suggested these are most closely related to populations from the KwaZulu-Natal Region of South Africa (LeRoux et al. 2006). In Hawai‘i, plants are recently naturalized on Kaua‘i, Maui and Hawai‘i (Wagner et al. 1999). On the island of Hawai‘i, dense Madagascar fireweed infestations occur in the vicinity of Kamuela, along Saddle

Road and in the Kaʻū district in disturbed areas and pastures (Motooka et al. 2003). In addition to the potential for rapid spread though wind dispersed seeds, this species is disruptive because plants rapidly colonize open areas. Furthermore, plants contain secondary compounds including pyrrolizidine alkaloids toxic to livestock (Motooka et al. 2003) which may potentially also affect native wildlife.

Madagascar fireweed is an incipient invader within the original sections of HAVO. In 2001, individuals were first observed along Hwy. 11, between mile markers 31 and 33 (Pratt et al. *In review*). From 2001-2003, 29 plants were treated during three site visits using foliar solutions of 5% Roundup in water, and plants have not been observed since. Along other roadsides in HAVO, a fertile plant was encountered on an unpaved road along the Kapāpala Ranch boundary (1,450 m elevation) in 2002, and a fertile plant was found along Crater Rim Drive (1,200 m elevation) between HVO and KMC in 2003. Two additional fertile plants were found in the park Resources Management parking lot in 2010, and a small infestation was identified at Three Trees kīpuka on Mauna Loa strip at approximately 2,000 m elevation. The populations at Kapāpala and Crater Rim Drive were controlled by uprooting, and although plants have not been seen at these sites since their initial discovery, their occurrence suggests either continued ingress or the presence of undetected populations elsewhere in the park. Accordingly, a thorough search of the surrounding areas is recommended. Madagascar fireweed was not observed elsewhere in the survey area.

Since 2001, Madagascar fireweed has been controlled where found in the original sections of HAVO. Due to the aggressive nature of Madagascar fireweed in Hawaiʻi, continued control leading to eradication is recommended. Additional surveys are recommended along roadsides and areas of high visitor and animal traffic (e.g. trails, horse hitches) and in the vicinity of previous occurrences.

***Setaria palmifolia* (J. König) Stapf (Palmgrass)**

Palmgrass (*Setaria palmifolia*) is a broadleaved invasive grass native to Asia. In Hawaiʻi, palmgrass is naturalized in mesic valleys, wet forest, and streams on Oʻahu, Lānaʻi, Maui, and Hawaiʻi (Wagner et al. 1999) and more recently on Kauai and Molokaʻi. Palmgrass is a serious pest of Hawaiian ecosystems capable of shading out native understory vegetation (Smith 1985). In HAVO, Fosberg (1966) reported plants infrequent in wet forests along trails and disturbed areas. Relatively small palmgrass infestations have been controlled in SEA units Thurston and Keanakākoʻi since 1990.

Palmgrass was found widespread in HAVO, apparently becoming more widespread in wet forest since Fosberg's (1966) report. In 1998, it was found in 40% (491/1227) of transect stations in the ʻŌlaʻa wet forest unit, principally in units unmanaged for weeds and feral ungulates. In eastern ʻŌlaʻa, plants can form a continuous ground cover in native forest over areas exceeding 1 ha (Benitez pers. obsn.). Smaller and less dense infestations were found in wet forest and disturbed areas of the Kīlauea summit including Thurston SEA. Palmgrass was not observed in wet forest in Kīlauea's East Rift by Pratt et al. (1992) or during the present surveys. Palmgrass is too widespread for

control in ʻŌlaʻa units, and no control is recommended in these areas. Smaller infestations in Thurston and other SEA units or project sites should be controlled if resources permit, while research is undertaken to develop more effective control methods which can be applied to larger areas. Plants are controlled using foliar application of 1% Roundup in water.

Solanum linnaeanum Hepper and P. Jaeger (Apple of Sodom)

Apple of Sodom (*Solanum linnaeanum*), is a thorny shrub that grows up to 1 m tall and is native to Africa (Wagner et al. 1999). In Hawaiʻi, apple of Sodom is a weed of dry forests and pastures (Motooka et al. 2003). It was not found in the older section of HAVO by Fosberg (1966), but Higashino et al. (1988) reported this species as a new addition to the park flora. In 1995, a collection was made from a roadside location along Highway 11 near the 34 mile marker (L. Pratt, pers. com), and in 2003 several mature plants were mapped during a survey outside of the park along the HAVO/Kapāpala boundary fence at approximately 1,150 m elevation but plants were not found in the park. Because of the invasive potential of this species and previous reports of this plant, further surveys to map the distribution in areas adjacent to the park and to search for individuals in HAVO are recommended, and plants should be eradicated if found. Presumably, the collection made in 1995 was uprooted, but otherwise Apple of Sodom has never been controlled in the park. Motooka et al. (2003) recommend foliar applications of dicamba, a synthetic auxin type herbicide not currently used in HAVO.

Solanum pseudocapsicum L. (Jerusalem cherry)

Jerusalem cherry (*Solanum pseudocapsicum*) is a shrub native to South America (Wagner et al. 1999), and naturalized in Hawaiʻi on Oʻahu, Molokaʻi, Maui and Hawaiʻi. In HAVO, Fosberg (1966) found Jerusalem cherry frequent in forested areas of Mauna Loa Strip around 1,400 m elevation.

Recent surveys found Jerusalem cherry in 44% of transect plots (n=162) between 1,180 and 1,800 m elevation on the Mauna Loa Strip. These included areas previously identified by Fosberg (1966) and new infestations in mesic and dry koa/ʻōhiʻa, where plants occasionally formed very dense thickets. Plants were most abundant in a 532 ha area of dry to mesic koa/ʻōhiʻa forest (<1,430 m elevation) that included Kīpuka Kī SEA (92.3 ha). Here, Jerusalem cherry was typically mapped at 1-5% cover with numerous large patches (up to 500 m²) of nearly 100% cover Jerusalem cherry. Jerusalem cherry was less abundant east of Kīpuka Kī. For example, Kīpuka Puaulu SEA and surrounding koa/ʻōhiʻa forest were mapped with <1% Jerusalem cherry cover. Between 1,580 and 1,800 m elevation, Jerusalem cherry populations were infrequent, and usually consisted of only a few individuals, although localized areas with denser infestations have been reported (L. Pratt, pers. com.). Jerusalem cherry was not found along transect lines on Mauna Loa in mesic or dry ʻōhiʻa woodlands, open alien or native grasslands or ʻaʻā flows, and plants appeared relegated to forested areas on more developed soils. A disjunct infestation was mapped in a small, unnamed koa/ʻōhiʻa kīpuka makai of Hwy. 11 at 1,100 m elevation.

In HAVO, Jerusalem cherry has been controlled in portions of Kīpuka Puaulu and Kīpuka Kī since 1985 and 1990 respectively. Continued control of Jerusalem cherry is recommended in these units, to prevent the buildup of large disruptive populations in areas were considerable work has been devoted to preserve and restore unique plant communities. Should resources permit, control efforts should be expanded to unmanaged portions of the SEA's and adjacent areas. Outside of SEA's, Jerusalem cherry appears too widespread and abundant for parkwide eradication. The widespread distribution and disruptive nature of populations in native plant communities in HAVO and elsewhere in the Islands make Jerusalem cherry a candidate species for biological control research. Jerusalem cherry is controlled using a foliar application of 2% Garlon 4 in water.

Soliva sessilis Ruiz and Pav. (Soliva)

Soliva (*Soliva sessilis*) is an asteraceous herb native to South America recently naturalized in Hawai'i (Wagner et al. 1999). In HAVO, soliva was not noted by Fosberg (1966), but Higashino et al. (1988) reported roadside populations of this weed. Soliva has been controlled in HAVO since 1985.

Three small populations of soliva (each occupying an area of <5 m^2) were found in HAVO during recent mapping. Soliva populations were mapped in Kīpuka Puaulu, the Mauna Loa rock quarry and the Jaggar Museum (HVO). These populations have been retreated at 2-6 months to remove newly established individuals by either pulling or treating with a foliar solution of 1% Roundup in water.

Relatively little is known about the invasive potential of soliva, but a continuation of control efforts is recommended to eradicate this species as a precautionary measure in light of the recent naturalization of this species.

Spermacoce sp. L. (Button weed)

An undetermined herb in the family Rubiaceae was collected in May 2010 by vegetation management staff along Highway 11 near Piimauna drive. This plant appears to be a new park record , and although material for a specific determination has not been collected, it likely belongs to the genus *Spermacoce* or related *Mitracarpus* (Wagner et al. 1999). Additional mapping is recommended in areas surrounding this population, and if the species is not found to be widespread, then eradication is recommended as a precautionary measure.

Sphaeropteris cooperi (Hook. ex F. Muell.) R. M. Tyron (Australian tree fern)

Australian tree fern (*Sphaeropteris cooperi*) is a fast growing arborescent fern native to eastern Australia, popular as an ornamental in Hawai'i (Staples and Herbst 2005). Apparently first naturalized on O'ahu around 1950, Australian tree fern has become naturalized in a variety of habitats on Kaua'i, O'ahu, Maui and Hawai'i (Palmer 2003). In

Maui, Australian tree fern has become a serious pest and is intensively managed to protect native plant communities in Kipahulu Valley (Palmer 2003) and in the Nature Conservancy's Wainiha preserve on Kaua'i.

Australian tree fern was first discovered in HAVO when two mature plants were found and removed from native wet forest at Thurston SEA in 2000. From 2001 to 2008, 125 individuals were found and treated along trailsides, in project areas and within SEA units. Relatively high numbers of plants were found and controlled in the Byrons Ledge project site (17.4 ha - 39 plants), Thurston SEA 19 (40.3 ha - 78 plants) and plants were also frequently encountered elsewhere near the Kīlauea summit and in 'Ōla'a. Plants were typically found in groupings of 1-10 individuals. Dense stands have not been observed.

Australian tree fern is a serious threat in Hawai'i, with the potential to severely alter the structure and function of invaded wet forest systems (Medeiros et al. 1992). Spores are produced abundantly and are easily dispersed by winds, perhaps as much as 12 km. Australian tree ferns may grow up to three times faster than native tree ferns, and their trunk does not support epiphytic flora as do native tree fern species. Furthermore, Medeiros et al. (1992) found relatively low biodiversity and biomass beneath dense Australian tree fern stands.

Parkwide control of Australian tree fern leading to eradication is recommended due to the plant's aggressive nature and limited distribution. Control should continue in all weed managed SEAs, and additional surveys should be undertaken in surrounding wet forest to more precisely map the distribution of this weed. Prior to 2005, trees were controlled by manually uprooting or cutting the plant near the base. Although this method was effective at controlling plants, concern for contamination of crews and equipment by falling spores led staff to explore chemical treatment, and the efficacy of foliar applications of Garlon 3A and Roundup are currently being evaluated. Elsewhere in Hawai'i, The Nature Conservancy reports successful control of Australian tree fern using helicopter based applications of herbicide.

Despite the plant's negative environmental impacts, Australian tree fern remains a popular landscape plant in Hawai'i. Cultivated individuals are found in residential lots in Volcano Village and the Volcano Golf Course subdivision, and these plants may represent a source for individuals found in HAVO. Accordingly, an effective parkwide control program should emphasize outreach to discourage planting, and incentives (e.g., native plants) to replace cultivated alien tree ferns.

Australian tree fern was formerly known as *Cyathea cooperi* (Hook. ex F. Muell.) Dom. Botanists and horticulturalists in Hawai'i have previously misidentified Australian tree fern as *Cyathea australis* (R. Br.) Copel. (Neal 1965).

***Spiraea cantoniensis* Lour. (Chinese spiraea)**

Chinese spiraea (*Spiraea cantoniensis*) is a rosaceous shrub native to Japan and China. In Hawai‘i, Chinese spiraea is occasionally cultivated but not reported naturalized (Staples and Herbst 2005). In the park, Fosberg (1966) noted Chinese spiraea in the residential area, and Japanese spiraea (*S. japonica* L. f.) was reported from the same locality. Higashino et al. (1988) noted both Chinese and Japanese spiraea presumably near park headquarters, the residential area and ‘Āinahou.

In 1983, 11 Chinese spiraeas were controlled at upper ‘Āinahou and near Kīlauea Iki. The three plants at ‘Āinahou were found 10 m south of the old nursery. Four mature plants and one seedling were controlled in a vegetated island between the Kīlauea Iki parking lot and Chain of Craters Road. Three additional mature plants were treated nearby (10 m west of the Escape Road and 15 m north of Crater Rim Drive). A fourth population in dense wet forest (30 m west of Escape Road and 15 m north of Crater Rim Drive) was mapped, and although no control work records were located, these plants may have been controlled with other populations as no plants were located in later surveys.

In 2003, one Chinese spiraea was found during surveys in HAVO at the park headquarters. The plant was fertile, but no evidence of new recruitment surrounding the plant was noted. No additional spiraeas were observed in park administrative areas or elsewhere in HAVO.

Removal of the Chinese spiraea at park headquarters leading to eradication is recommended as a precautionary measure. The population is extremely small and manageable, and while Chinese spiraea has not been regarded invasive in Hawai‘i, plants appear capable of natural recruitment in native plant communities. Spiraea’s potential for range expansion remains unknown, however, a disproportionate number of invasive taxa in natural areas belong to the family Rosaceae (Daehler 1998).

Chinese spiraea was initially controlled with a 5% foliar solution of Roundup in water, and later 5% Garlon 3A in water. These treatments did not produce a complete kill, and a basal bark application of 5% Garlon 4 in diesel fuel oil was used to kill the wounded plants.

***Syzygium cumini* L. (Java plum)**

Java plum is a tree perhaps native to Indo-Malaysia, widely cultivated in the region and elsewhere in the tropics (Wagner et al. 1999; Staples and Herbst 2005). In Hawai‘i, Java plum is occasionally cultivated and naturalized in mesic valleys and disturbed areas on all main islands except Ni‘ihau and Kaho‘olawe. In HAVO, Fosberg (1966) noted Java plum from Kīlauea’s East Rift, near Pānau Nui. A 9 ha grove inside lama forest in the Pānau Nui area was mapped in 1998 (NPS unpublished data).

In 2002, the population of Java plum described by Fosberg (1966) was mapped along the Kalapana Trail in the Pānau Nui area. Mature trees, saplings and seedlings were found in forest and woodland vegetation. Plants extended along 2.6 km of trail. A

number of other formerly cultivated trees (e.g., mango - *Magnifera indica*, guava - *Psidium guajava*) were naturalized in the area.

Wildfires and lava flows in 2002-2004 covered most of Java plum's former range in HAVO, and the main infestation has not been resurveyed since. Scattered individuals observed in coastal lowlands below the Hōlei pali prior to the wildfires may still persist. Naturalized or planted Java plum was not found elsewhere in HAVO, including surveys of trails, fences and natural areas throughout Kīlauea's East Rift. No additional Java plum was found in surveys of park residential and administrative areas.

A resurvey of the coastal lowlands and the historical populations is recommended to map Java plum's current range extent, and to develop a control strategy if necessary. Java plum is a weedy tree capable of forming a dense cover that excludes all other species (Smith 1985, Staples and Herbst 2005). This and a number of other species belonging to the family Myrtaceae are highly invasive in Hawai'i (Smith 1985; Daehler 1998).

Syzygium jambos L. (Rose apple)

Rose apple is a tree native to Malaysia and perhaps southeastern Asia (Wagner et al. 1999). Rose apple has been cultivated in Hawai'i since 1825, and is now naturalized in mesic valleys and disturbed areas on all the main islands except Ni'ihau and Kaho'olawe. In HAVO, Fosberg (1966) noted one rose apple in forest near Kīlauea Crater. This may have been the same population reported by Tunison et al. (1992), leading to the removal of two trees below the Volcano House in the Kīlauea Crater in 1985. An additional rose apple was controlled at Steam Vents in 1986 (HAVO Vegetation Management Files 1986). Higashino et al. (1988) reported plants in the submontane seasonal and wet forest zones, and a 7 ha grove of rose apple in lama forest was mapped above the Kalapana trail (NPS unpublished data).

During recent surveys, no rose apple was found in the former population sites including residential and administrative areas of Kīlauea summit. The grove mapped above the Kalapana trail was covered by lava in 2003. Continued monitoring is recommended for this species, and should new individuals be encountered, control leading to eradication is recommended given this species' invasive potential.

Rose apple is abundant in wet areas at lower elevations outside of HAVO. A recently introduced pathogen, the guava rust (*Puccinia psidii* Winter) has become widespread in Hawai'i. This rust, which has a wide host range within the family Myrtaceae, has caused extensive mortality of rose apple trees.

Tecoma stans (L.) Juss. ex Kunth (Yellow elder)

Yellow elder is a tree native to South America, sparingly naturalized in Hawai'i. Yellow elder was not previously reported in parkwide plant checklists (Fosberg 1966;

Higashino et al. 1988). Recent synonyms for yellow elder include *Bignonia stans* L. and *Stenolobium stans* (L.) Seem.

In 2002, a single mature tree was found along the edge of the Mother's Day lava flow in eastern HAVO. The tree was in a remote area at 400 m elevation, and although the plant's mode of ingress remains unknown, the remote location suggests natural dispersal. This area has since been covered by lava. No additional yellow elder plants were found in the area surrounding this tree, or elsewhere in HAVO.

Yellow elder is a new alien species in HAVO. This sighting underscores the need for more frequent monitoring of remote locations throughout the park to locate invasive species beginning to establish. Although yellow elder has not become a serious invader in Hawai'i, naturalized populations have been observed in disturbed sites in the Kā'u district, and the confamilial species African tulip tree (*Spathodea capanulata*) is an extremely serious invader in Hawai'i (Smith 1985). Should additional individuals be discovered, eradication is recommended if populations appear manageable.

Thunbergia alata Bojer ex Sims (Black-eyed Susan vine)

Black-eyed Susan vine (*Thunbergia alata*) is native to tropical Africa (Wagner et al. 1999), and sparingly naturalized in Hawai'i, including Volcano. In HAVO, black-eyed Susan vine was not noted by Fosberg (1966), but Higashino et al. (1988) reported plants naturalized in the montane seasonal zone. An unrelated vine with a similar common name, the Black-eyed Susan (*Abrus precatorius*) is known from drier lowland areas in the park.

During recent surveys, black-eyed Susan vines were found in a nearby residential lot in the Volcano Golf Course subdivision among cultivated alien vegetation and spreading into the park in native forest with alien grasses, where vines are routinely controlled.

Continued control of Black-eyed Susan vine leading to eradication is recommended to prevent the spread of this weed into native plant communities. If feasible, control should be expanded to target plants on the bordering residential lot. Black-eyed Susan vine is common in disturbed areas throughout the Volcano Golf Course subdivision (Benitez pers. obsn.), and additional populations may eventually also encroach. Because of this, annual surveys of these boundary areas and communication with adjacent landowners are recommended to prevent establishment of this weedy vine, as well as other weeds cultivated on nearby lands (e.g., English ivy, plumbago, glory bush). Vines are controlled using a foliar application of 1 % Garlon 4 in water.

Tibouchina herbacea (DC) Cogn. (Cane tibouchina)

Cane tibouchina (*Tibouchina herbacea*) is an herb or sub-shrub native to southern Brazil, Paraguay, Uruguay (Wagner et al. 1999) Bolivia (Wurdack 1962) and likely

Argentina (NYBG 2007, MOBOT 2010). Declared a noxious weed in Hawai‘i (USDA-NRCS 2010a), cane tibouchina is widespread on Maui and Hawai‘i in disturbed mesic and wet forests, and more recently smaller infestations have been discovered on O‘ahu, Moloka‘i, and Lāna‘i in similar habitat (Wagner et al. 1999, Purell 2006). Cane tibouchina is a relatively recent arrival in Hawai‘i, first collected in 1977. The provenance of Hawaiian cane tibouchina is unknown, and a precise morphological match has not been found in the native range, where cane tibouchina forms a widespread polymorphic complex (Pedrosa-Macedo et al. 2000, Benitez 2010, Goldenberg pers. com.).

Between 1993 and 2008, cane tibouchina was observed in HAVO's wet forests in ‘Ōla‘a, Thurston and Kīlauea's East Rift. In ‘Ōla‘a, cane tibouchina was infrequent, apparently at an early stage of invasion. In 1992-1993, plants were found in 2 transect stations in the New unit and one in the Koa unit. During 1998 transect surveys, only three occurrences were found among 1,227 transect stations, all in interior units (Ag, New, ‘Ōla‘a) unmanaged for weeds at the time. In 2001, plants were found in Koa unit for the first time; initially 170 plants were treated that year, and from 2002-2007 an additional 125 individuals plus patches totaling 122 m² were removed from the 245 ha unit. Foliar applications of 10 % Garlon 3A in water effectively control this species.

In Kīlauea's East Rift cane tibouchina was more frequent. In 2004, plants were found in 9.3% of the 171 transects stations sampled, typically at less than 5% cover. These occurrences were predominately in disturbed areas burned by wildfires in 2002-2003, and dramatically exceeded earlier reports by Pratt et al. (1999), who found cane tibouchina occurring as scattered individuals or small clumps at low frequencies (1.2%) along transects. Cane tibouchina increased from less than 1% frequency in 1988 to 5% frequency in 1992 (in 50-m increments) on a subset of transects of the East Rift SEA (Pratt et al. 1999).

Relative to the East Rift, plants were less frequent at the summit of Kīlauea. A plant was discovered along a pipeline in the residential area in 2002; and 21 plants were discovered during systematic sweeps to control alien plants in Thurston SEA in 2006. No additional cane tibouchina was found elsewhere along roads, trails and fencelines outside of areas previously discussed. Outside of the park, cane tibouchina has been observed in residential areas including Mauna Loa and Royal Hawaiian Estates in Volcano, and along Highway 11 from the park boundary northward to approximately 500 m elevation (Benitez pers. obsn.).

Cane tibouchina is an aggressive, highly dispersible weed, and while most often found in disturbed areas, plants have the potential to invade forests and displace native species (Almasi 2000). Such dynamics may contribute to the spread of this species throughout the East Rift and elsewhere in the park, and continued control in SEA's and along nearby corridors seems warranted to prevent movement of this species. A potential biocontrol agent, the Brazilian flea beetle *Syphraea uberabensis* (Coleoptera: Chrysomelidae), is under evaluation and in quarantine at HAVO (Souder 2008).

***Tibouchina urvilleana* (DC) Cogn. (Glorybush)**

Glorybush (*Tibouchina urvilleana*) is a small tree native to southern Brazil (Wagner et al. 1999) and declared a noxious weed by the State of Hawai‘i (USDA-NRCS 2010a). Several common names are known locally for glorybush, these include lasiandra, princess flower and tibouchina. In Hawai‘i, glorybush is commonly cultivated for its attractive large showy purple flowers, and has become naturalized on Kaua‘i, O‘ahu, Maui and Hawai‘i. In HAVO, Fosberg et al. (1966), noted glorybush around the Kīlauea region at the Hilo entrance, the residential area, the Volcano House, and the Nāhuku (Thurston) Lava Tube. Tunison et al. (1992) reported glorybush widespread around park headquarters, Volcano House and residential areas. In these areas, plants grew at low densities, with additional populations scattered across the Kīlauea summit. Since 1976, glorybush has been selectively controlled in SEAs and in several small, accessible populations near the Kīlauea summit.

In 2003, glorybush was found in 26 populations totaling 2,000 m² throughout the Kīlauea summit. Individual populations covered areas between 10 and 350 m^2, near park headquarters, the rainshed and the residential area. Plants were growing in landscaped and disturbed habitats and in native dominated wet forest where they often formed monotypic stands that excluded other vegetation. Additional populations, previously noted by Tunison et al. (1992) were observed on the pali behind the Volcano House; on a steep rock face above the Sulphur Banks Trail; and near a crack system between the maintenance yard and the park entrance station.

Tunison et al. (1992) mapped additional populations of glorybush not encountered during recent surveys. These include populations at KMC, Pu‘u Puai, Nāhuku (Thurston) Lava Tube and along the Escape Road.

In HAVO, intermittent control of glorybush began in 1976, and continuous control has occurred since 1987. Kuron was initially used to treat plants, but was replaced by Tordon 22K in 1986. From 1987-present, a solution of 1-2% (foliar) or 15-50% (cut stump) Garlon 4 in water has been used to control glorybush.

Glorybush is an aggressive invader of wet areas in Hawai‘i (Smith 1985, Motooka et al. 2003). Plants form dense impenetrable stands that may prevent native plant establishment in wet forest at HAVO and in the adjacent Volcano Village. Plants reproduce vigorously by vegetative means (Staples and Herbst 2005). Establishment from seed has been observed rarely in Volcano (Tunison pers. com.). Continued control leading to eradication from Kīlauea summit wet forest is recommended, with initial work focused within and adjacent to SEAs. Techniques for accessing plants on steep cliffs using ropes have been developed by Vegetation Management staff and HAVO EPMT but are labor intensive.

***Trema orientalis* (L.) Blume (Gunpowder tree)**

Gunpowder tree (*Trema orientalis*) is native to the Paleotropics, Japan, Australia, Melanesia, Micronesia and Polynesia (Wagner et al. 1999). Formerly in the family

Ulmaceae, this genus is now assigned to the Cannabaceae (Wagner et al. 1999). Fosberg (1966) did not find gunpowder tree in HAVO, however his surveys did not include ʻĀinahou Ranch which was privately owned at that time. Higashino et al. (1988) noted it along roadsides, and Tunison et al. (1992) mapped 11 populations along roadsides.

Gunpowder tree has been controlled since 1983. Between 1983 and 1988, four plants were treated in the residential area near the Waldron's Ledge overlook; and four additional plants were controlled along Chain of Craters road near the ʻĀinahou Ranch road and Puhimau Crater.

During 2000-2005 surveys, less than 50 seedlings and saplings were found and removed from the Mauna Loa rock quarry, along Highway 11, and Crater Rim drive. These individuals were likely established by seeds deposited from motor vehicles and human traffic. Outside the park, plants are abundant along roadsides and disturbed areas in the adjacent Puna and South Hilo districts of Hawaiʻi, and mesic forests from 30-800 m elevation on all the main islands except Niʻihau and Kahoʻolawe, (Wagner et al. 1999).

Gunpowder tree is an aggressive invader with the potential to form dense stands in Hawaiʻi (Benitez pers. obsn.). Plants are abundant in areas adjacent to HAVO, and roadsides appear to be the principal corridors for the spread of propagules into the park. Consequently, these roadsides and the natural areas surrounding them should be continually monitored to eradicate new individuals.

Tropaeolum majus L. (Common nasturtium)

Common nasturtium (*Tropaeolum majus*) is a vine with peltate leaves and showy yellow-red flowers, native to uplands of the Andes mountains in South America (Wagner et al. 1999). In Hawaiʻi, plants have been naturalized since the 1800's (Staples and Herbst 2005). Common nasturtium thrives in upland climates; and plants are found in mesic disturbed areas between 850 and 1,350 m elevation on Kauaʻi, Molokaʻi, Maui, and Hawaiʻi.

In HAVO, the principal infestation is distributed across 45 ha of mesic koa and ʻōhiʻa forest in the vicinity of Kīpuka Puaulu (1,200-1,300 m elevation). Systematic surveys in 2001-2004 mapped 88 populations, each covering between 1 and 80 m² (2,032 m² total). An additional 24 populations previously controlled by park staff could not be relocated.

Beyond the vicinity of Kīpuka Puaulu were three small satellite populations 500 m to the northeast, near the HAVO/Keauhou boundary, and populations have also been observed in Kīpuka Kī, the KMC Ball field, Haunani Road, ʻŌlaʻa, Tree Molds, and the Volcano Golf Course. These populations are controlled to remove plants that establish intermittently.

Common nasturtium has been controlled in HAVO since 1979. Tunison et al. (1992) described a more widespread and abundant distribution of common nasturtium than what was most recently mapped. He described populations covering up to 19,000 m² area and numerous satellite populations. Control work appears to have limited the spread and abundance of nasturtium in core areas and reduced the number of outlying populations. Consequently, continuation of control leading to eradication and expanded monitoring in the vicinity of existing and formerly documented populations is recommended to eradicate this species from the park. Since 1984, a foliar solution of 1% Garlon 4 in water has been used to treat plants, with a 2-4 month return interval to treat new individuals. Younger plants can be uprooted.

Ulex europaeus L. (Gorse)

Gorse (*Ulex europaeus*) is a thorny shrub native to western Europe, naturalized in pastures and roadsides on Maui and Hawai‘i, and designated a noxious weed in Hawai‘i. Previously unknown from the Kīlauea and Mauna loa sectors of the park, a single plant was found along Highway 11 near Pi’imauna Drive in 2010. The plant was flowering with immature seed pods, and was uprooted after it was reported by a local resident. Roadsides near the plant were searched and no additional gorse was found. This plant may have been an accidental introduction via contaminated road fill or transported by a motor vehicle. Continued monitoring of this site at six-month intervals is recommended to detect additional individuals which may establish, and if plants are found there or elsewhere than control leading to eradication is recommended for this species, as it is an aggressive invader with a limited distribution.

Verbascum thapsus L. (Common mullein)

Common mullein (*Verbascum thapsus*) is a wooly biennial herb native to Eurasia, naturalized in mostly subalpine and alpine sites on the island of Hawai‘i. Common mullein is widespread at higher elevations (>1,500 m) in HAVO. Recent mapping (Loh et al. 2000) found mullein distributed over 1,002 ha of open lava fields between 1,500 and 2,100 m elevation. Densities were low (<1 individual/ha) on open ‘a‘ā flows; moderate (10-100 individuals/ha) on ‘a‘ā flows that edged kīpukas; and high (1,400 individuals/ha) in areas that straddled vegetated kīpukas and extremely weathered ‘a‘ā flows that contained pockets of soil.

Beginning in 2001, a pilot program to contain and reduce the range of mullein in the park was implemented. An evaluation of the effectiveness of the control work to date is recommended for this species. Common mullein is controlled using a foliar application of 1 % Roundup in water.

Yucca filamentosa L. (Yucca)

Yucca (*Yucca filamentosa*) is a small rosette forming shrub native to southeastern North America, not reported naturalized in Hawai‘i, though this and other related species are cultivated in the Islands (Wagner et al. 1999, Staples and Herbst 2005).

In HAVO, ten yucca plants were found at 1,200 m elevation near the intersection of Hwy. 11 and the Volcano Golf Course Road and inside a managed SEA unit (Puaulu Block 6) in 2005. Plants included mature individuals and seedlings, suggesting natural recruitment with the potential for plants to become more widespread. No additional yucca was noted elsewhere in HAVO.

Yucca was previously known from five populations that occurred near the Kīlauea summit (Sulphur Banks trail, park headquarters, the hula platform, the Mauna Loa Strip Road quarry and Kīlauea Iki). From 1982-1992, 99 individuals were treated at these sites, using a foliar solution of 5% Garlon 4 in water. No individuals have been treated since at these sites, and none were found during 2005 surveys.

Pollination of yucca is dependent mostly on specialized symbiotic moths which are absent in Hawai‘i (Staples and Herbst 2005), and this likely limits yucca spread, although other less specialized moths occasionally pollinate it. In light of apparent reproduction and potential for further spread, continued control leading to eradication and monitoring of former populations seems warranted to protect native plant communities in the park. Monitoring should also examine changes in invasiveness and spread in response to pollination and seed set.

DISCUSSION

The greatest number of alien, localized plant species was found in the Kīlauea summit area. This area receives the highest concentrations of people and vehicles, and encompasses the visitor center, administrative and residential areas, Volcano House, Kīlauea Military Camp (KMC), and many miles of roads and trails. Forty nine localized species were mapped in this area, including ten species not previously noted by Higashino et al. (1988), and an additional four new species were identified in a separate study by Pratt *et al*. (*In review*). Localized plants found in the Kīlauea summit area were either deliberately or accidentally introduced.

A disproportionate number of new invasive species were found near (<50 m) roadsides, trails, or visitor lookouts, these were also concentrated in the Kīlauea summit. These findings provide evidence of a greater potential for new introductions in such high traffic areas, and aid in the prioritization of monitoring throughout the park (Table 4). Other high traffic areas at risk for new species introductions include popular lowland pullouts and parking areas (e.g., Kealakomo, end of Chain of Craters road). These areas also warrant frequent monitoring, although they appear to represent a lower priority relative to the more intensively visited upland environments.

High traffic and importation of materials for road construction activities appear to pose an additional risk of introduction for disruptive species, particularly along Highway 11 and at the Mauna Loa rock quarry. Such vectoring appears to be the most likely

pathway for the introduction of disruptive species including parasol leaf tree, gorse, melochia, gunpowder tree and fireweed.

Twenty-seven species detailed in this report appear deliberately planted, including three species new to the park. The list of deliberate introductions includes species with presumably low invasive potential (e.g., aechmea, spider lily) as well as species considered highly disruptive to Hawaiian ecosystems (e.g., kāhili ginger first recorded in cultivation in 1943). It should be noted that the tally of planted species is likely conservative, since many species presented in this study were introduced to `Āinahou while under private ownership prior to 1972, or subsequently following NPS acquisition. Since the date of introduction for many of these is uncertain, they are not included in this analysis.

Nevertheless, owing to a history of planting and former ranching, the `Āinahou vicinity is notable for high numbers of invasive taxa, with 20 localized species mapped and many other disruptive widespread species either established (e.g., faya tree, olive) or in the early stages of invasion (e.g., Himalayan raspberry). An inventory of the cultivated flora of `Āinahou was completed in 2004 for a cultural landscape inventory of the area (NPS 2004), however this work is incomplete and includes at least 14 mis-identified species (L. Pratt, unpublished data). In light of the history of planting and the high invasive potential of many species here, a more thorough botanical survey of `Āinahou is urgently needed.

The present study permits an analysis of control efforts which supports the effectiveness of eradication as a strategy for controlling incipient infestations. Relative to the 41 species mapped and identified for management by Tunison et al. (1992), 30 species managed to eradicate or contain populations have apparently become less abundant, and no significant new populations were identified. Using the same criteria, eight species apparently became more abundant despite management. Three species could not be evaluated; these were blue gum, managed as part of the Nāmakani Paio cultural landscape, wisteria, a planted ornamental not apparently spreading, and christmasberry, a widespread species not intensively mapped. Thirteen species previously noted (Higashino et al. 1988, Tunison et al. 1992) and managed to eradicate individuals parkwide could not be relocated, these include aggressive invaders such as Cape ivy and ironwood, and species of unknown invasive potential, such as guavasteen. Control work appears largely responsible for these reductions, although lava flows from Kīlauea have further reduced sisal, ironwood, and rose apple populations, and biological control apparently has checked the spread of prickly pear.

The taxonomic scope of the park's alien plant control program has expanded considerably over the past 30 years, and this study identifies additional species which warrant inclusion. Weed control (eradication, containment, or exclusion from SEAs) has increased from 10 species in 1980 to the current 113 species (82 parkwide eradication, 5 containment, 26 exclusion from SEA or project sites). An additional 13 species which have never been controlled appear to warrant eradication efforts based on their distribution or potential invasiveness (Table 5), and the remaining 8 species presented

do not warrant control but should be monitored for changes in invasiveness or distribution. The high numbers of localized species relative to more widespread species also validates the effectiveness of the SEA model, where widespread species are targeted only in selected areas. Under this model, resources are available to search and control species at earlier stages of invasion, where the likelihood of eradication is greater.

The expanded taxonomic scope and technical nature of alien plant control operations also supports continuation of the park's Exotic Plant Management Team (EPMT). This team, initially deployed in 2005, has specialized plant identification and control skills which are of strategic value to the early detection and rapid response of infestations. For example, the EPMT detected and led control operations of Padang cassia seedlings, and led rappel control operations of Koster's curse on the steep slopes of Byron's ledge; these notoriously disruptive species would likely otherwise have remained undetected. Such specialized support is also important for the management of more widespread species; EPMT assisted in the development of more effective ground and aerial control techniques of banana poka vines, and led control operations to eradicate guinea grass and contain silk oak populations.

For widespread disruptive species biological control is considered an important management tool to control invasions (Malecki et al. 1993, Tunison 2002, DeWalt 2006). Based on their mapped distribution and documented deleterious effects on native ecosystems (Smith 1985), park management of christmasberry, Jerusalem cherry, knotweed, strawberry guava, tibouchina and alien *Rubus* species may benefit from further biological control research.

MANAGEMENT RECOMMENDATIONS

The park's alien plant control program has expanded significantly in scope and complexity over the past 30 years. Since the early 1980's, the annual number of worker days spent in the field searching for and removing weeds has increased from <200 to >500 by the early 1990's and is upward of 1,200 worker days today. Since the 1988 checklist (Higashino et al. 1988), 30 new alien plant species have been recorded in the park, and new introductions as well as range expansion of established species are expected to continue in the future. In addition, the acquisition of the Kahuku unit expanded park lands by 50% (Benitez et al. 2008). These changes will provide additional invasive species challenges, and the recommendations presented here will assist managers in making the most effective use of limited resources.

Early detection and eradication of invasive plant populations are considered the most cost effective and efficient management strategies (Rejmanek and Pitcairn 2002, Simberloff 2003, Lodge et al. 2006) and aggressive control leading to eradication should continue to be sought for all newly established species in the park. Such precautionary actions are needed since invasive potential is difficult to predict and species not previously considered naturalized or invasive in Hawai'i (e.g., coast banksia,

guavasteen, hebe, yucca) have been observed recruiting and forming disruptive populations in the park.

The disproportionate numbers of localized, alien species discovered along roadsides, trails and lookouts make these areas priorities for monitoring and control, consistent with findings from other National Parks and reserves (Tyser and Worley 1992, Lonsdale and Lane 1994). These findings provide compelling evidence for the need for increased monitoring of high risk areas of the park (Table 4).

The occurrence of high numbers of localized alien species along roads, trails, and lookouts also underscores the importance of stricter sanitation parkwide. Sanitation measures to limit the spread of species along trailsides by park users should include interpretative signage and establishment of dedicated boot and gear cleaning stations at all major trailheads. Protocols for inspecting and sanitizing gear and clothing should be implemented by park personnel and non-park workers such as contractors, concessioners, special use permittees (e.g. Kīlauea Military Camp), researchers and special operations personnel including firefighters, to prevent the ingress of species from areas outside of the park, and to prevent further dispersal of established localized populations. Park machinery, including mowers, tractors and off road vehicles are also potential vectors for invasive species, and should be routinely inspected and cleaned, and all construction projects should be communicated to park botanists so that these areas may be monitored.

At least 27 species detailed in this report were deliberately planted (e.g., dwarf octopus tree, hebe, century plant), primarily in the Kīlauea summit area and `Āinahou ranch. Kāhili ginger (*Hedychium gardnerianum*), formerly cultivated in the park as early as 1943 (Fosberg 1966) is illustrative of the threat posed by intentionally introduced species; it escaped cultivation and is now distributed over 3,000 ha, often in thickets that prevent native wet forest regeneration, and is among the most intensively managed species. More recent plantings identified in this study are evidence that the practice of deliberate introductions persists, and underscore the need for stricter compliance with NPS policy including Section 4.4.4.1 – Management or Maintenance of Exotic Species (National Park Service 2006), which clearly bars the introduction of alien species. A secondary but also very serious concern surrounding introduction of plants is that these may harbor harmful organisms including coqui frogs (*Eleutherodactylus coqui*), invasive snails, or fungal pathogens such as *Puccinia psidii* which threaten Hawaiian ecosystems.

At least 5 additional species appear to have escaped cultivation in Volcano Village and established in the park, suggesting the need for greater outreach with this community, and a more active role by park managers to encourage suitable native or non-invasive ornamental species for landscaping. Development of a Memorandum of Understanding (MOU) with bordering residential communities is one possible avenue to discourage use of invasive species in lands adjacent to the park. Inclusion of park concessioners in this MOU would help address issues of deliberately introduced species previously mentioned. This avenue would work best in situations where an

organized community association exists, without such a body, an MOU would likely be an ineffectual tool to limit the use of invasive landscape plants in bordering residential areas and other strategies should be sought.

Thirteen species which had previously been found and controlled in HAVO could not be relocated. The absence of these species suggests eradication efforts have been effective. However, this designation should be considered tentative because survey techniques are imperfect (Regan et al. 2006). For example, lupine had not been observed in HAVO from 1994-2002 and was considered extirpated, yet plants were found in the former population and 8 km from this area in 2002. Similarly, a mature blackwattle tree was found on the edge of a managed population in 2003, this individual had been undetected for several years near the forest edge. Such occurrences underscore the importance of continued monitoring, albeit at a scale that balances the cost of additional searches versus the risk that the species remains or reappears elsewhere in the park (Regan et al. 2006).

Rejmánek and Pitcairn's (2002) analysis of plant eradication efforts by the California Department of Food and Agriculture concluded that 3 consecutive years without detection was an adequate measure of eradication for small infestations (< 1 ha), and we recommend a more conservative minimum of 5 years without detection prior to declaring eradication of localized populations. Continued surveys should consider specific characteristics of the plant (e.g., seed longevity, maturation time, invasive potential). For example several species (e.g., Formosa koa, blackwattle, lupine, castorbean) have seeds which are notoriously long lived (>10 years) and may require indefinite monitoring, while herbaceous species require more frequent monitoring given their rapid time to maturation.

Additional mapping is recommended for species such as Australian tree fern, Japanese anemone, melochia, octopus tree, clidemia and rose, which were found in forested interiors or remote locations where detection is more challenging. Since these areas were not as intensively searched as roadsides and trails, the mapped distribution of these invaders may underestimate their distribution, ecological range, and rate of spread, complicating formulation of an effective control strategy. Until further mapping is complete, removal of all individuals encountered is recommended parkwide excluding Japanese anemone, unless workloads become prohibitive. At the minimum, the previously mentioned species should be controlled to exclude them from park SEAs. Control data from these units, which are systematically swept to remove invasives, could serve to direct future surveys. Because of the severe threat to native plant communities, a more thorough mapping of the distribution of kāhili ginger is also recommended, as well as an analysis of control data to evaluate the efficacy of control operations and native species recovery following removal of this species.

While existing filling systems, spreadsheets and databases have enabled the capture and summary of control and monitoring data presented here, new technologies could optimize workflows and enhance detection and reporting of invaders. For example, control data and survey data recorded in the field on paper data sheets could then be

input into a GIS rather than a tabular database, thereby reducing workloads and permitting better visualization of geographic invasive plant patterns in relation to control efforts. A greater reliance on a GIS would also permit a more strategic management of invasive plants, including better planning and route optimization for field crews managing diverse and distant populations. Finally, development of a website or internet portal should be pursued within the NPS framework to create a centralized page to share information about alien plant management in the park, including control techniques and recommended alternative non-invasive landscape plants. This portal should include a web map service which permits staff and visitors to track individual species and report new sightings.

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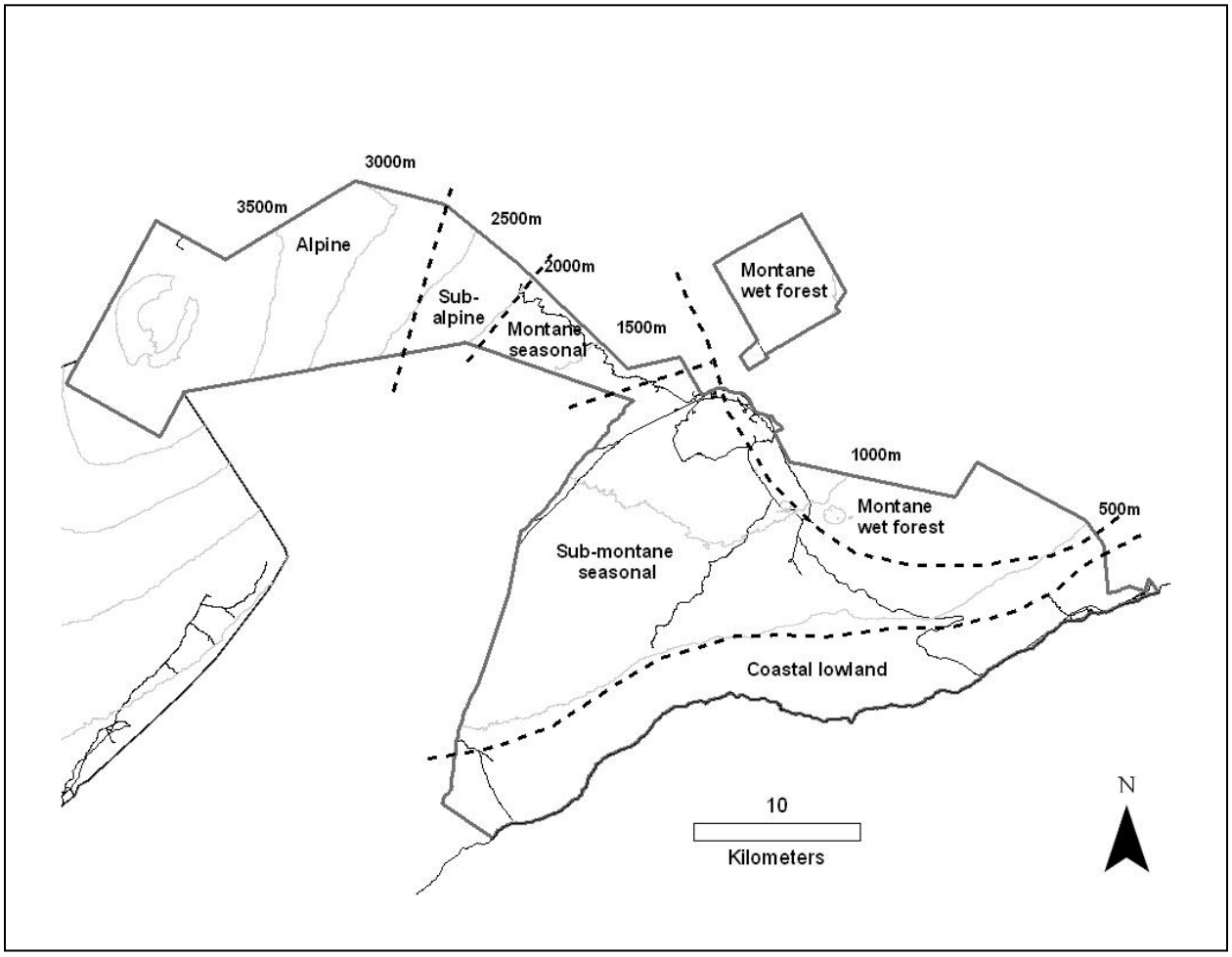


Figure 1. HAVO Mauna Loa and Kīlauea unit ecological zones. Adapted from Mueller-Dombois (1976) and Tunison et al. (1992).

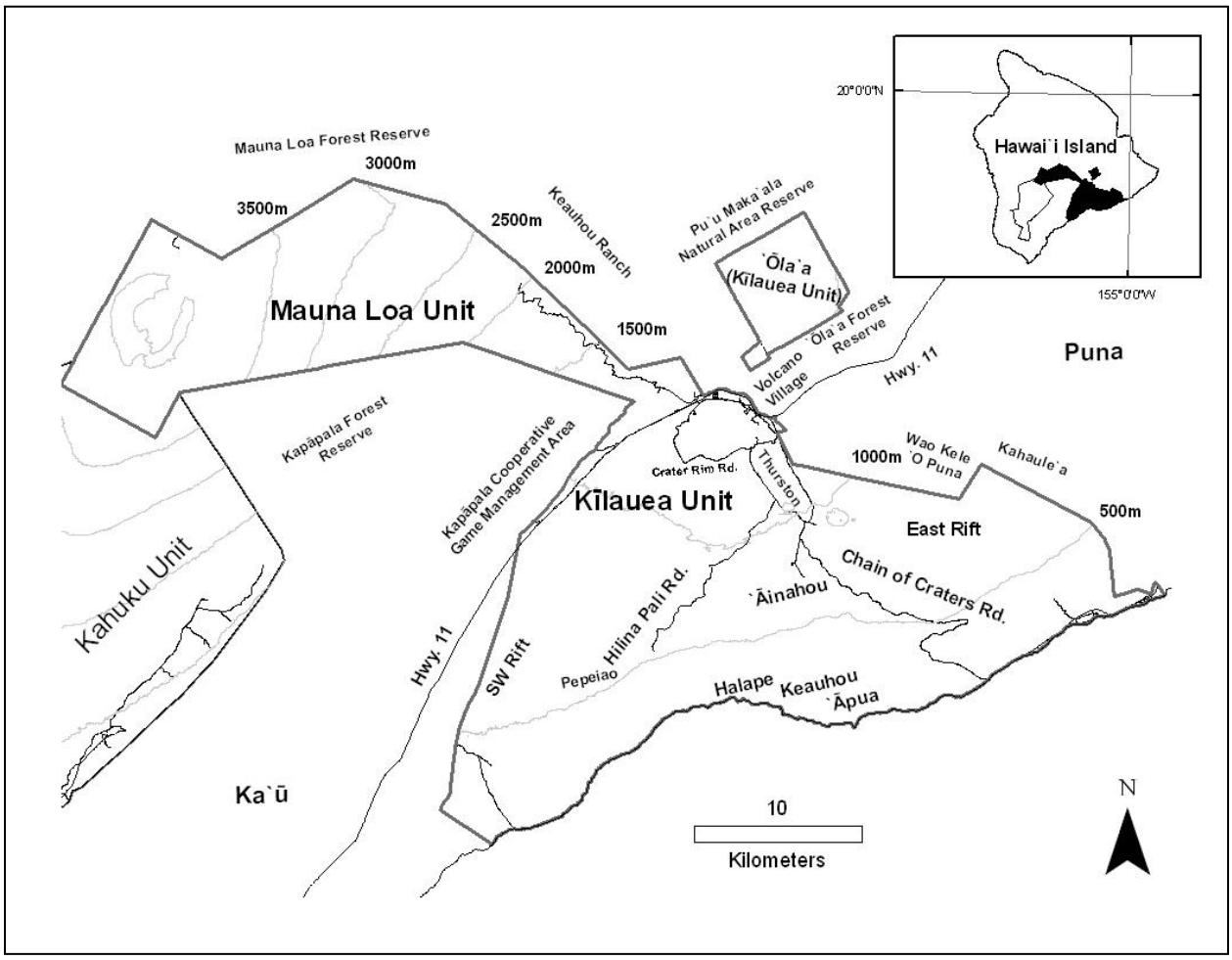


Figure 2. Mauna Loa and Kīlauea unit survey areas, Hawai`i Volcanoes National Park, including adjacent lands.

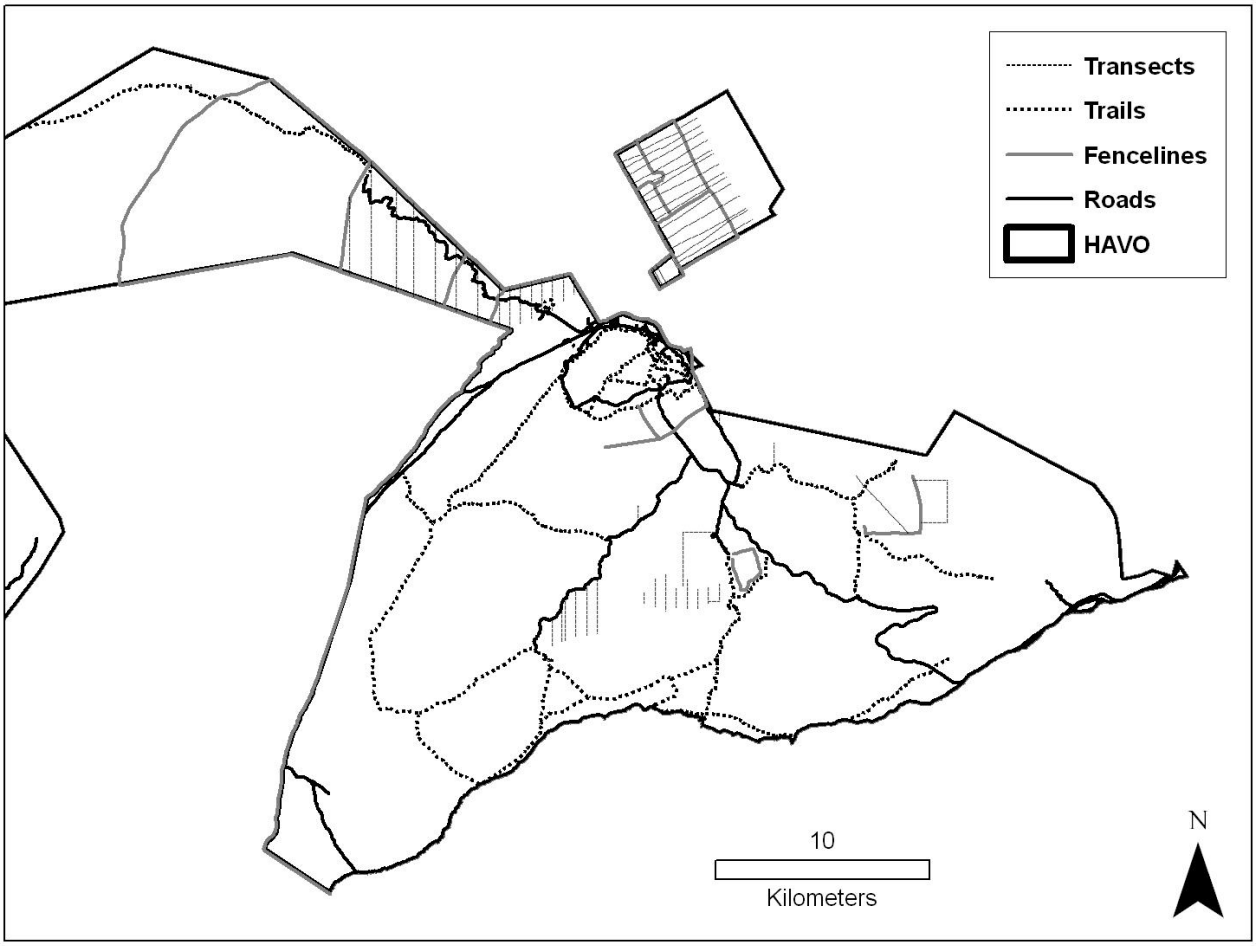


Figure 3. HAVO Kīlauea and Mauna Loa survey areas along transects, roads, trails and fencelines.

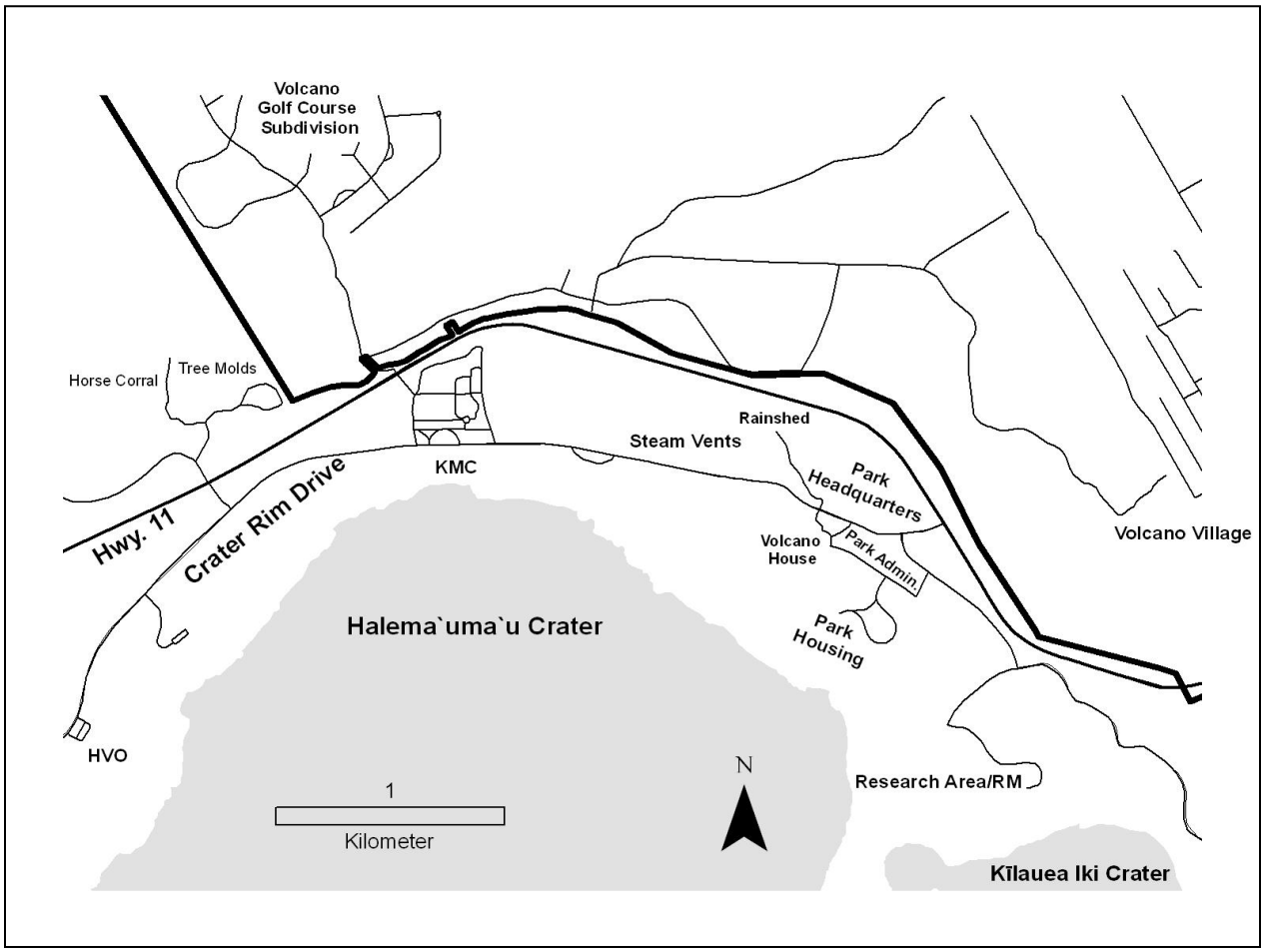


Figure 4. HAVO Kīlauea unit summit area.

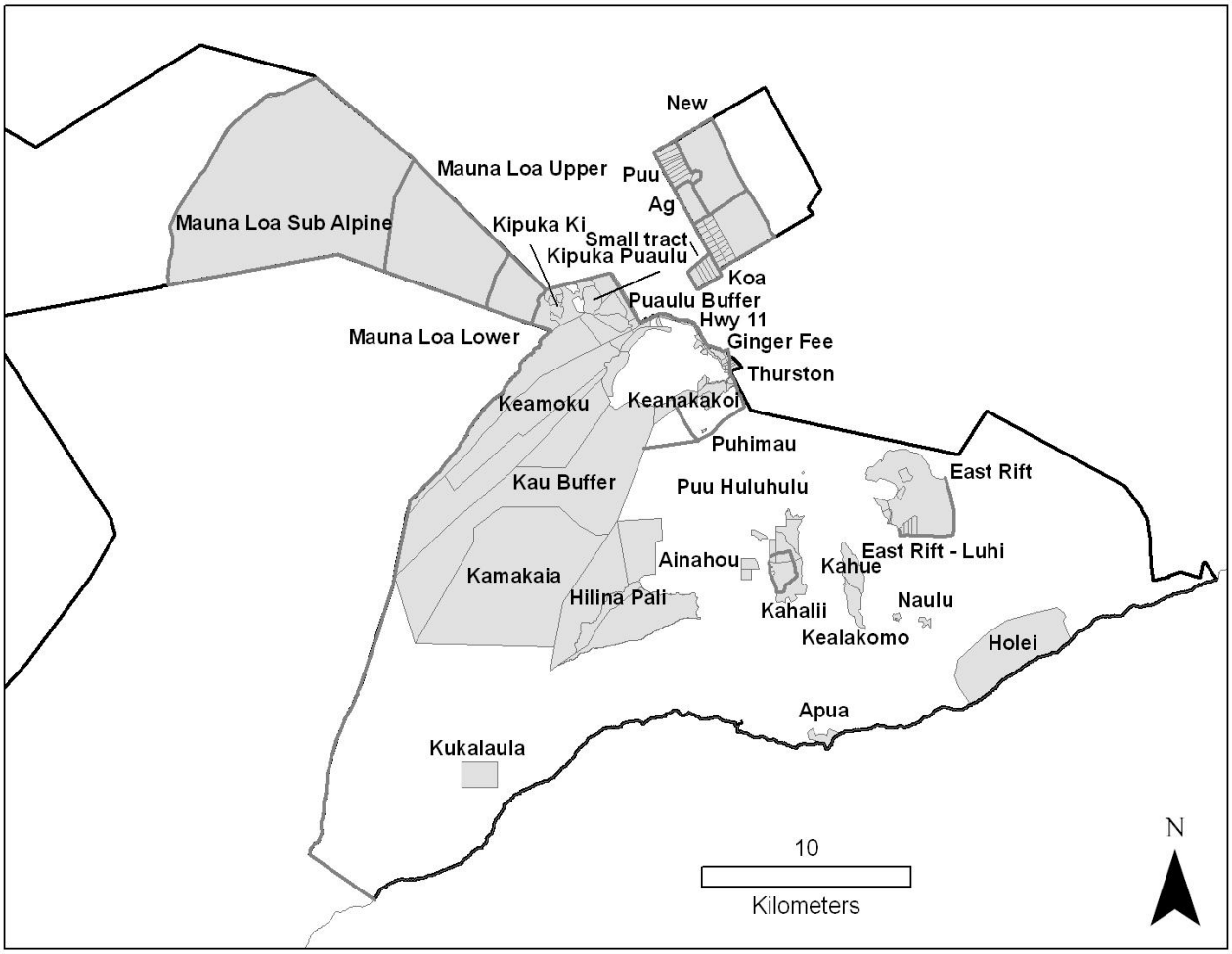


Figure 5. HAVO Special Ecological Area (SEA) system.

Table 1. Common and scientific names of species mapped in HAVO from 2000 to 2010, including distribution and current control strategy.

Scientific name	Common name	Habit	Distribution	Strategy
Abrus precatorius	Black-eyed Susan	Vine	Localized	Eradicate
Acacia confusa	Formosa koa	Tree	Localized	Eradicate
Acacia mearnsii	Blackwattle	Tree	Localized	Eradicate
Acacia melanoxylon	Blackwood acacia	Tree	Localized	Eradicate
Acca sellowiana	Guavasteen	Shrub	Localized	Eradicate
Aechmea sp.	Aechmea	Herb	Localized	Eradicate
Agave americana	Century plant	Herb	Localized	Eradicate
Agave sisalana	Sisal	Herb	Localized	Eradicate
Andropogon virginicus	Broomsedge	Grass	Widespread	Projects
Anemone hupehensis	Japanese anemone	Herb	Widespread	Monitor
Ardisia crenata	Hilo holly	Shrub	Localized	Eradicate
Arundo donax	Giant reed	Grass	Localized	Eradicate
Asclepias physocarpa	Ballon plant	Herb	Widespread	Monitor
Banksia cf. *integrifolia*	Coast banksia	Tree	Localized	Eradicate
Benicasa hispida	Chinese melon	Vine	Localized	Eradicate
Buddleia asiatica	Butterfly bush	Shrub	Widespread	Monitor
Buddleia davidii	Summer lilac	Shrub	Localized	Eradicate
Casuarina equisetifolia	Ironwood	Tree	Localized	Eradicate
Cestrum nocturnum	Night cestrum	Shrub	Localized	Eradicate
Chlorophytum cosmosum	Spider plant	Herb	Localized	Eradicate
Cinnamomum burmanii	Padang cassia	Tree	Localized	Eradicate
Clidemia hirta	Koster's curse	Shrub	Localized	Eradicate
Commelina diffusa	Honohono grass	Herb	Widespread	Projects
Coreopsis lanceolata	Tickseed	Herb	Localized	Monitor
Cotoneaster pannosa	Cotoneaster	Shrub	Localized	Eradicate
Delairea odorata	Cape ivy	Vine	Localized	Eradicate
Desmodium cajanifolium	Tree desmodium	Shrub	Localized	Eradicate
Dicksonia fibrosa	New Zealand tree fern	Tree	Localized	Eradicate
Digitaria insularis	Sourgrass	Grass	Localized	Eradicate
Ehrharta stipoides	Meadow ricegrass	Grass	Widespread	Projects
Eleagnus umbellata	Elaeagnus	Tree	Localized	Eradicate
Erigeron karvinskianus	Daisy fleabane	Herb	Localized	Eradicate
Eriobotria japonica	Loquat	Tree	Localized	Eradicate
Eucalyptus globulus	Blue gum	Tree	Localized	Contain
Eucalyptus robusta	Swamp mahogany	Tree	Localized	Contain
Falcataria moluccana	Albizia	Tree	Localized	Eradicate
Ficus carica	Common fig	Shrub	Localized	Eradicate
Ficus macrophylla	Moreton bay fig	Tree	Localized	Eradicate

Scientific name	Common name	Habit	Distribution	Strategy
Ficus pumilla	Creeping fig	Vine	Localized	Eradicate
Fraxinus spp	Tropical ash	Tree	Localized	Eradicate
Fuchsia hybrida	Fuchsia	Shrub	Localized	Eradicate
Fuchsia magellanica	Hardy fuchsia	Shrub	Localized	SEA
Fucshia paniculata	Fuchsia	Shrub	Localized	Eradicate
Grevillea banksii	Kāhili flower	Tree	Localized	Eradicate
Grevillea robust	Silk oak	Tree	Widespread	Contain
Hebe speciosa	Hebe	Shrub	Localized	Eradicate
Hedera helix	English ivy	Vine	Localized	Eradicate
Hedychium gardnerianum	Kāhili ginger	Herb	Widespread	SEA
Heterocentron subtriplinerveum	Pearl Flower	Shrub	Localized	Eradicate
Heterotheca grandiflora	Telegraph weed	Herb	Localized	Eradicate
Hyparrhenia rufa	Thatching grass	Grass	Widespread	Contain
Ipomea triloba	Little bell	Vine	Localized	Eradicate
Jasminum humile	Jasmine	Shrub	Localized	Eradicate
Justicia betonica	Shrimp tail plant	Shrub	Localized	Eradicate
Kalanchoe pinnata	Air plant	Herb	Localized	Eradicate
Kalanchoe tubiflora	Chandelier plant	Herb	Localized	Eradicate
Lantana camara	Lantana	Shrub	Widespread	SEA, Projects
Lathyrus odoratus	Sweet pea	Vine	Localized	Eradicate
Leucaena leucocephala	Koa haole	Tree	Widespread	Projects
Ligustrum ovalifolium	Chinese privet	Shrub	Localized	Eradicate
Ligustrum sinense	California privet	Shrub	Localized	Eradicate
Lonicera japonica	Japanese honeysuckle	Vine	Localized	Eradicate
Lophosperma erubescens	Roving sailor	Vine	Localized	Eradicate
Luculia gratissima	Luculia	Tree	Localized	Eradicate
Lupinus hybridus	Lupine	Herb	Localized	Eradicate
Macaranga tanarius	Bingabing	Tree	Localized	Eradicate
Marrubrium vulgare	Common horehound	Herb	Localized	Eradicate
Melaleuca quinquenervia	Paperbark	Tree	Localized	Eradicate
Melinis minutiflora	Molasses grass	Grass	Widespread	Projects
Melochia umbellata	Melochia	Tree	Localized	Eradicate
Morella faya	Faya tree	Tree	Widespread	SEA, Projects
Muehlenbeckia complexa	Wire vine	Vine	Localized	Eradicate
Nephrolepsis multiflora	Swordfern	Herb	Widespread	Projects
Olea europaea	Olive	Tree	Widespread	SEA, Projects
Opuntia ficus-indica	Prickly pear	Shrub	Localized	Monitor
Paederia foetida	Maile pilau	Vine	Localized	Eradicate
Panicum maximum	Guinea grass	Grass	Widespread	Eradicate
Passiflora edulis	Purple granadilla	Vine	Widespread	Monitor
Passiflora tarminiana	Banana poka	Vine	Widespread	SEA, Contain
Pennisetum clandestinum	Kikuyu grass	Grass	Widespread	Projects

Scientific name	Common name	Habit	Distribution	Strategy
Pennisetum purpureum	Elephant grass	Grass	Localized	Eradicate
Pennisetum setaceum	Fountain grass	Grass	Widespread	Eradicate
Persea americana	Avocado	Tree	Localized	SEA
Persicaria capitata	Knotweed	Herb	Widespread	Projects
Philodendron sp.	Philodendron	Vine	Localized	Eradicate
Phoenix dactylifera	Date palm	Tree	Localized	Eradicate
Phoenix robelenii	Dwarf date palm	Tree	Localized	Eradicate
Phormium tenax	New Zealand flax	Herb	Localized	Eradicate
Phyllostachis nigra	Bamboo	Grass	Localized	Eradicate
Pinus caribaea	Slash pine	Tree	Localized	Eradicate
Pittosporum undulatum	Orange pittosporum	Tree	Localized	Eradicate
Plumbago auriculata	Plumbago	Shrub	Localized	Eradicate
Prosopsis pallida	Kiawe	Tree	Localized	Eradicate
Prunus sp.	Prunus	Tree	Localized	SEA
Psidium cattleianum	Strawberry guava	Tree	Widespread	SEA, Projects
Psidium guajava	Common guava	Tree	Widespread	SEA
Pterolepis glomerata	Pterolepis	Shrub	Localized	Eradicate
Pueraria lobata	Kudzu	Vine	Localized	Eradicate
Pyracantha koidzumii	Firethorn	Shrub	Localized	Eradicate
Ricinis communis	Castor bean	Tree	Localized	Eradicate
Rosa multiflora	Multiflora rose	Shrub	Localized	Eradicate
Rosa laevigata	Cherokee rose	Shrub	Localized	Eradicate
Rosa sp.	Wild rose	Shrub	Localized	Eradicate
Rubus argutus	Florida prickly blackberry	Shrub	Widespread	SEA
Rubus ellipticus	Yellow raspberry	Shrub	Widespread	SEA
Rubus glaucus	Andean raspberry	Shrub	Widespread	SEA
Rubus rosifolius	Thimbleberry	Shrub	Widespread	Monitor
Samanea saman	Monkeypod	Tree	Localized	Eradicate
Sambucus mexicanus	Mexican elderberry	Shrub	Localized	Eradicate
Scaevola cf. *aemula*	Fairy fanflower	Shrub	Localized	Eradicate
Schefflera actinophylla	Octopus tree	Tree	Localized	Eradicate
Schefflera arboricola	Dwarf octopus tree	Tree	Localized	Eradicate
Schinus terebinthifolius	Christmasberry	Tree	Widespread	SEA, Projects
Schizachyrium condensatum	Bush beard grass	Grass	Widespread	Projects
Sechium edule	Pipinella	Vine	Localized	Eradicate
Senecio madagascarensis	Fireweed	Herb	Localized	Eradicate
Setaria palmaefolia	Palm grass	Grass	Widespread	Projects
Solanum linneaum	Apple of Sodom	Shrub	Localized	Eradicate
Solanum pseudocapsicum	Jerusalem cherry	Shrub	Widespread	SEA
Soliva sessilis	Soliva	Herb	Localized	Eradicate
Spermacoce sp.	Buttonweed	Herb	Localized	Eradicate
Sphaeropteris cooperi	Australian tree fern	Tree	Localized	Eradicate

Scientific name	Common name	Habit	Distribution	Strategy
Spiraea cantonensis	Spirea	Shrub	Localized	Eradicate
Syzygium cumini	Java plum	Tree	Localized	Monitor
Syzygium jambos	Rose apple	Tree	Localized	Eradicate
Tecoma stans	Yellow elder	Tree	Localized	Eradicate
Thunbergia alata	Black-eyed Susan vine	Vine	Localized	Eradicate
Tibouchina herbacea	Cane tibouchina	Herb	Widespread	SEA
Tibouchina urvilleana	Glorybush	Tree	Localized	Eradicate
Trema orientalis	Gunpowder tree	Tree	Localized	Eradicate
Tropaeolum majus	Common nasturtium	Vine	Localized	Eradicate
Ulex europaeus	Gorse	Shrub	Localized	Eradicate
Verbascum thapsus	Mullein	Herb	Widespread	Contain
Yucca filamentosa	Yucca	Shrub	Localized	Eradicate

Table 2. Newly documented species in the survey area.

Scientific name	Common name	Location
Aechmea sp.	Aechmea	Hilina Pali shelter
Banksia cf. *integrifolia*	Coast banksia	Broomsedge burn
Chlorophytum comosum	Spider plant	Park administrative area
Cinnamomum burmannii	Padang cassia	Resources management
Clidemia hirta	Clidemia	Byrons ledge
Digitaria insularis	Sourgrass	Coastal lowlands
Grevillea banksii	Bottlebrush	Southwest rift
Ipomea triloba	Little bell	Steam vents
Macaranga tanarius	Bingabing	Mauna loa rock quarry
Marrubium vulgare	Horehound	Park administrative area
Scaevola cf. *aemula*	Fairy fanflower	Broomsedge burn
Schefflera arboricola	Dwarf octopus tree	Park administrative area
Spermacoce spp.	Buttonweed	Hwy. 11, mm 30
Sphaeropteris cooperi	Australian tree fern	Wet forest
Tecoma stans	Yellow elder	Kalapana trail
Ulex europaeus	Gorse	Hwy. 11, mm 30

Table 3. Newly documented roadside species by Pratt et al. (*In Review*) during roadside weed surveys.

Family	Scientific name	Location
Poaceae	*Axonopus compressus*	Mile 7, Crater Rim Drive
Euphorbiaceae	*Chamaesyce hyssopifolia*	Hwy. 11, Kau
Fabaceae	*Crotalaria lanceolata*	Hwy. 11 below Nāmakani
Poaceae	*Digitaria* cf*. abyssinica*	Crater rim near T junction to Res./RM
Boraginaceae	*Heliotropium amplexicaule*	Hwy. 11 below Nāmakani
Lamiaceae	*Leonotis nepetifolia*	Hwy. 11
Brassicaceae	*Lepidium africanum*	Hwy. 11
Fabaceae	*Neonotonia wightii*	Miles 33- 40, Chain of Craters Road
Poaceae	*Paspalum notatum*	Hwy. 11, Crater Rim Drive
Poaceae	*Paspalum paniculatum*	Hwy. 11, Crater Rim Drive
Poaceae	*Schedonorus arundinaceus*	Crater Rim Drive near KMC
Asteraceae	*Senecio madagascariensis*	Hwy 11, miles 31 and 32
Poaceae	*Setaria sphacelata*	Hwy. 11
Asteraceae	*Sphagneticola triflora*	Mile 8, Crater Rim Road
Poaceae	*Sporobolus indicus*	Chain of Craters Road

Table 4. Recommended survey intervals and workloads for key at risk areas.

Area	Survey interval	Estimated workloads
`Āinahou	1-2 years	5 workerdays
Backcountry trails	2-4 years	20 workerdays
Chain of Craters Road	2 years	5 workerdays
Crater Rim Drive	1 year	1 workerday
End of Chain of Craters Road	1 year	1 workerday
Frontcountry trails	1 year	20 workerdays
Highway 11	1 year	5 workerdays
KMC	1 year	1 workerday
Park administrative, headquarters and residential areas	1 year	5 workerdays
Steam Vents	1 year	1 workerday
Nāhuku (Thurston) Lava Tube	1 year	1 workerday
Transects	5 years	40 workerdays

Table 5. New species to control.

Family	Common name	Scientific name	Habit
Poaceae	Giant reed	*Arundo donax*	Grass
Buddleiaceae	Summer lilac	*Buddleia davidii*	Shrub
Lilliaceae	Spider plant	*Chlorophytum cosmosum*	Herb
Asteraceae	Daisy fleabane	*Erigeron karvinskianus*	Herb
Scrophulariaceae	Hebe	*Hebe speciosa*	Shrub
Caprifoliaceae	Japanese honeysuckle	*Lonicera japonica*	Vine
Lamiaceae	Common horehound	*Marrubrium vulgare*	Herb
Arecaceae	Dwarf date palm	*Phoenix robelenii*	Tree
Rosaceae	Cherokee rose	*Rosa laevigata*	Shrub
Caprifoliaceae	Mexican elderberry	*Sambucus mexicanus*	Shrub
Araliaceae	Dwarf octopus tree	*Schefflera arboricola*	Tree
Solanaceae	Apple of Sodom	*Solanum linneaum*	Shrub
Rubiaceae	Buttonweed	*Spermacoce* spp.	Herb

Appendix A. Sample field data sheet for localized invasive plant control.

LOCALIZED DATA SHEET

Activity
T=Treatment
R=Retreatment
M=Monitor

Herbicide Method:
BB=basal bark
C=cut or cutstump
F=foliar
FR=frill

Herb ID
G3A - garlon3a
G4 - garlon 4
G4D - garlon 4 with diesel
Esc - escort
RU - roundup
ARS - arsenal

Dye/Surfactant
TM=Turfmark

Weather code:
0 = MOSTLY SUNNY >50%
1=MOSTLY CLOUDY >50%
2= MISTY
3=DRIZZLE
4= RAIN

SPECIES_____

Location/ GPS or block	Date/ Inspector	Activity	# of Indiv Uprooted	# of Indiv or area(m) Herb Trted	HERBICIDE METHOD(s)	Herb ID	Herb Mix Concentration % or g/L	Dye or Surfactant	Dye/Surfactant Concentration (% or ml/liter)	Amt of mix used	unit ml or L	Mature	% Resprout	Juvenile	Veg	Worker Hours Crew	EPMT	other	Weather

Appendix B. Sample field data sheet for Special Ecological Area (SEA) invasive plant control.

SEA UNIT_____

Herbicide Method:
BB=basal bark
C=cut or cutstump
F=foliar
FR=frill

Herb ID
G3A - garlon3a
G4 - garlon 4
G4D - garlon 4 with diesel
Esc - escort
RU - roundup
G3A/Esc - garlon3a/escort mix
ARS - arsenal

Dye/Surfactant
TM=Turfmark

Seedling = <0.2m or 1 ft hgt

Weather code:
0 = MOSTLY SUNNY >50%
1=MOSTLY CLOUDY >50%
2= MISTY
3=DRIZZLE
4= RAIN

BLOCK_____
CONTROL DATE_____ DATA ENTRY DATE_____ INSPECTOR_____ WEATHER_____

(circle one): Treatment or retreatment

Species	# of Individuals Uprooted	# of Individuals or area treated (m) Herb Trted	HERBICIDE METHOD(s)	Herb ID	Herbicide mix Concentration (% or gram/liter)	Dye or Surfactant	Dye/surfactant Concentration (% or ml/liter)	Amt of mix used	unit ml or liter	check box Mature	Resprout	Seedling	Worker Days Veg	Crew	EPMT	other	Remarks
						unit total						unit total					

BLOCK_____
CONTROL DATE_____ DATA ENTRY DATE_____ INSPECTOR_____ WEATHER_____

(circle one): Treatment or retreatment

Species	# of Individuals Uprooted	# of Individuals or area treated (m) Herb Trted	HERBICIDE METHOD(s)	Herb ID	Herbicide mix Concentration (% or gram/liter)	Dye or Surfactant	Dye/surfactant Concentration (% or ml/liter)	Amt of mix used	unit ml or liter	check box Mature	Resprout	Seedling	Worker Days Veg	Crew	EPMT	other	Remarks
						unit total						unit total					

Appendix C. Map book of selected invasive plant species of concern in the Kilauea and Mauna Loa Strip areas of Hawai‘i Volcanoes National Park, 2000-2010.

Available from http://manoa.hawaii.edu/hpicesu/techrep.htm or by request to author.

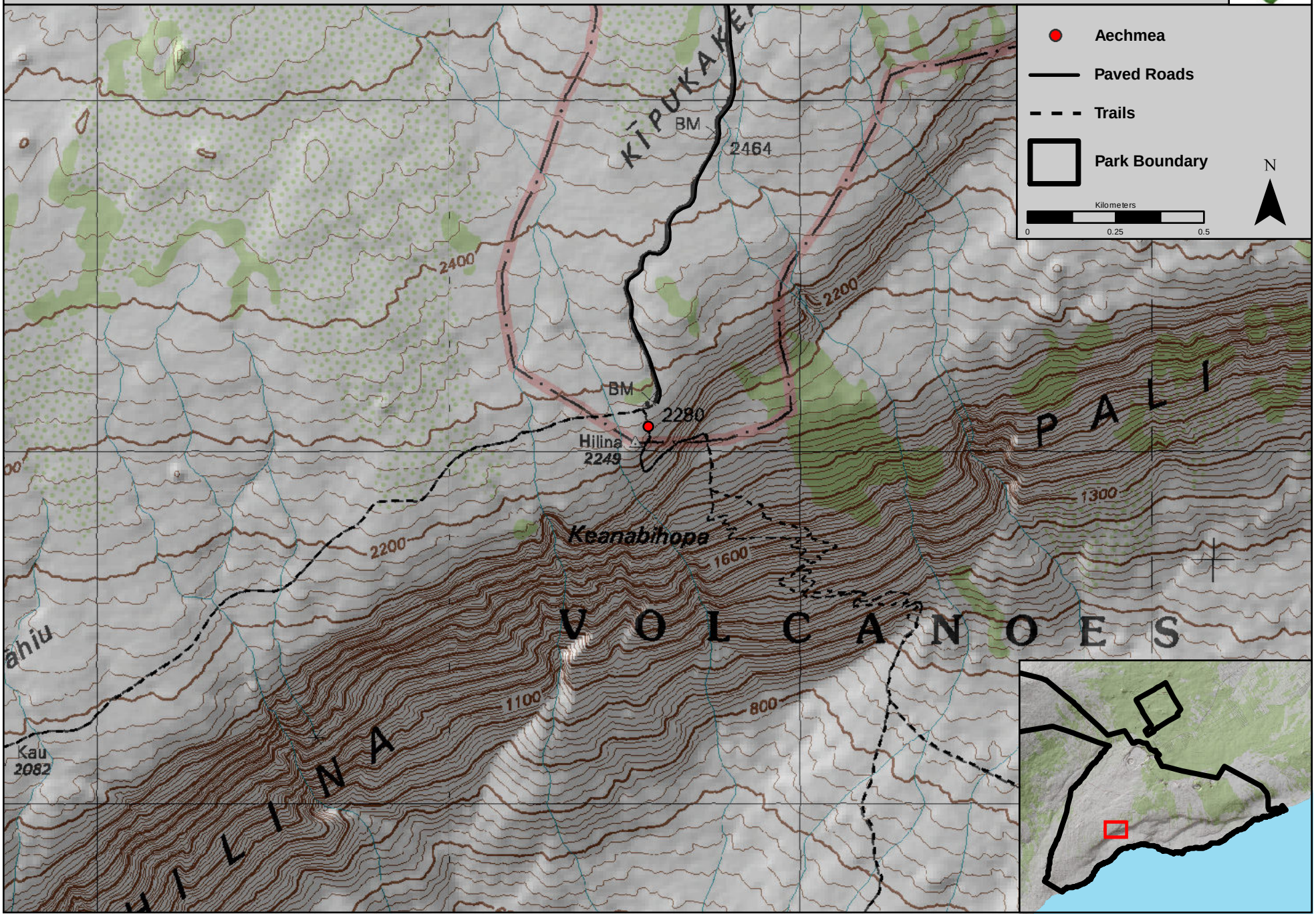
THE DISTRIBUTION OF INVASIVE PLANT SPECIES OF CONCERN IN THE KĪLAUEA AND MAUNA LOA STRIP AREAS OF HAWAIʻI VOLCANOES NATIONAL PARK, 2000-2010

APPENDIX C : MAP BOOK OF SELECTED INVASIVE PLANT SPECIES OF CONCERN IN THE KILAUEA AND MAUNA LOA STRIP AREAS OF HAWAI'I VOLCANOES NATIONAL PARK, 2000-2010

David M. Benitez[1, 2], Rhonda Loh[1], Tim Tunison[1], Nicholas G. Zimmer[1], Jon Makaike[1], Robert Mattos[1], and Matt Casali[1]

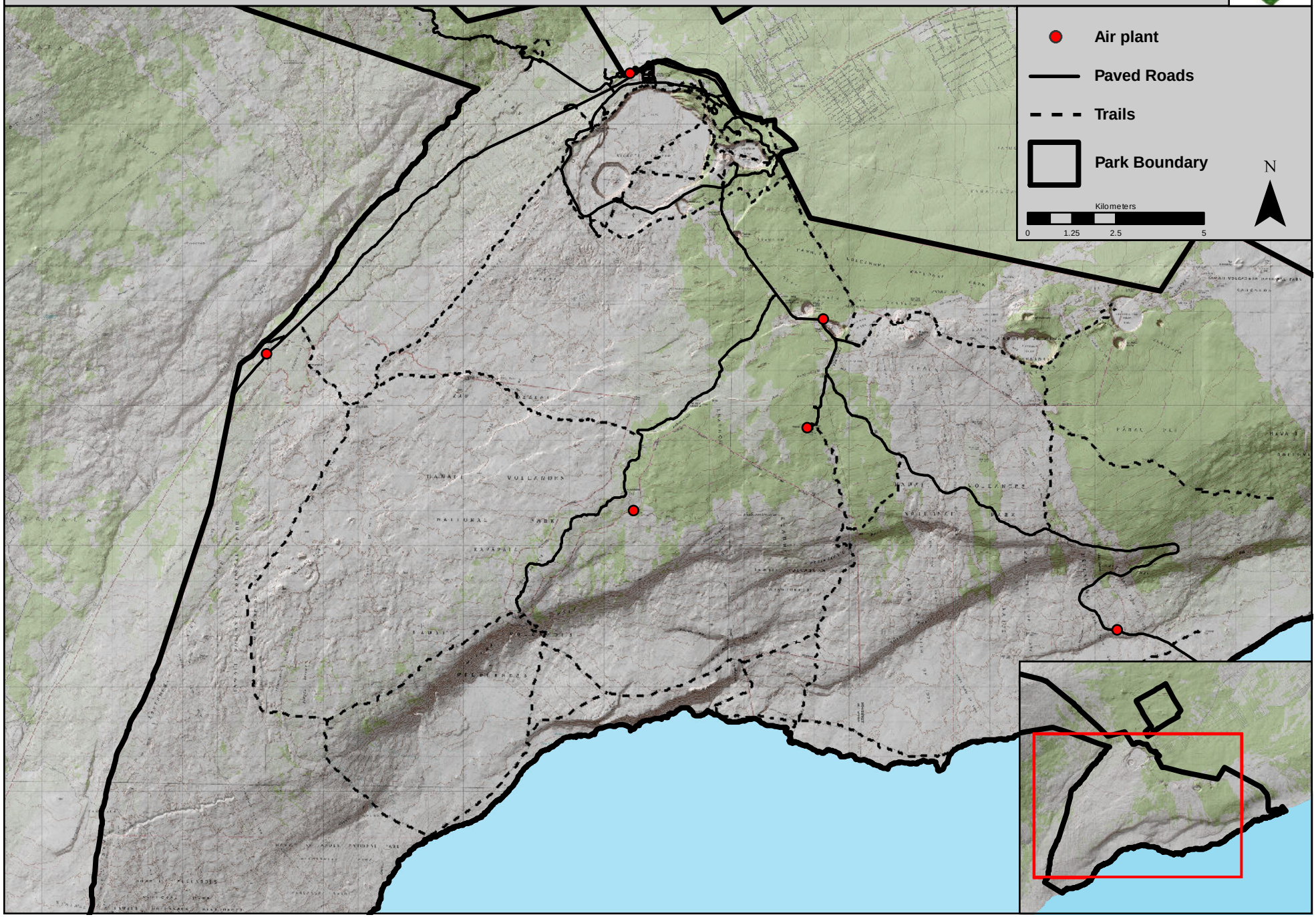
[1]National Park Service, Hawai'i Volcanoes National Park, Resources Management Division, PO Box 52, Hawai'i National Park, HI 96718
[2]Exotic Plant Management Team, National Park Service, Hawai'i Volcanoes National Park, PO Box 52, Hawai'i National Park, HI 96718

Aechmea (*Aechmea* sp.)



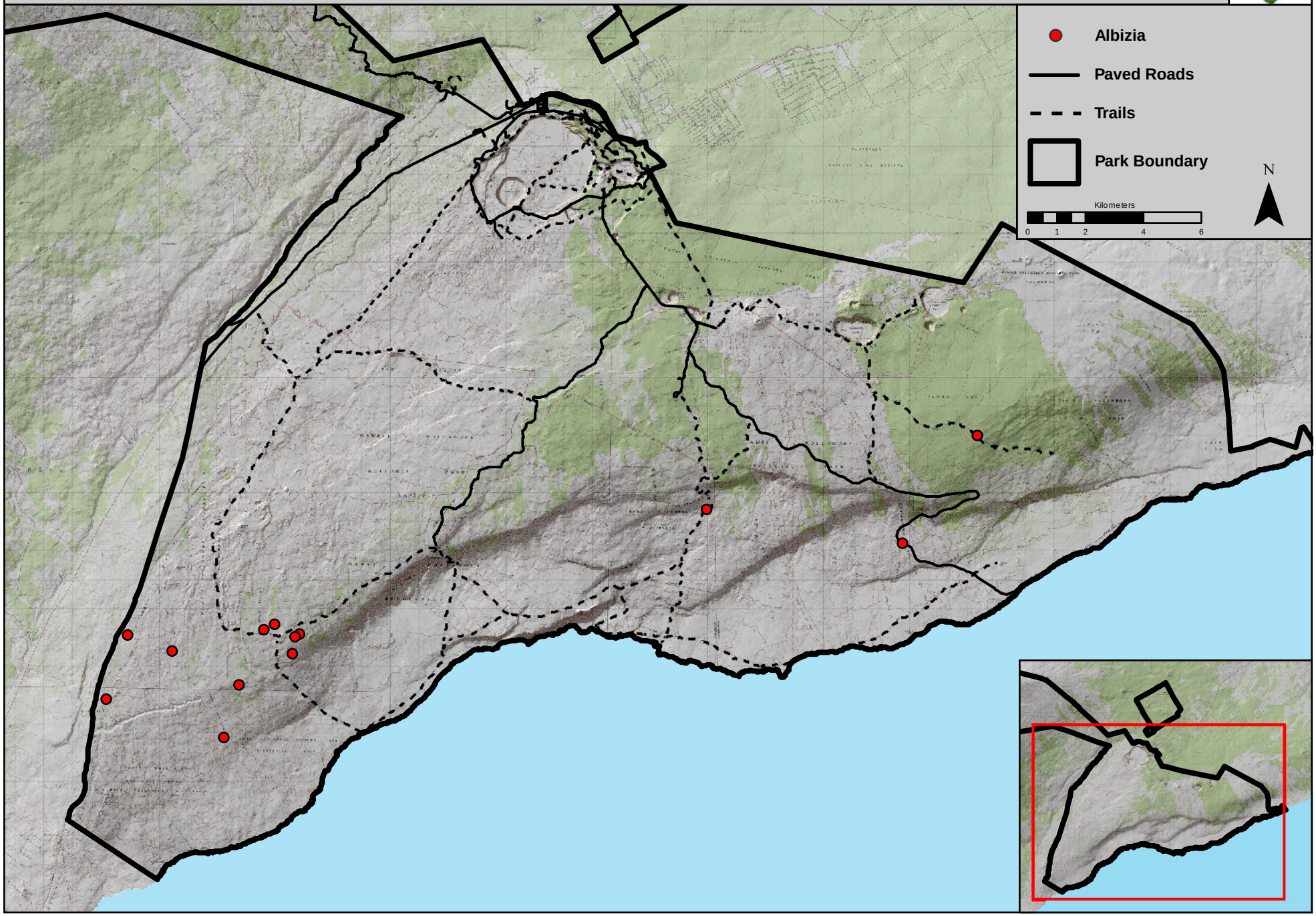
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Air plant (*Kalanchoë pinnata*)



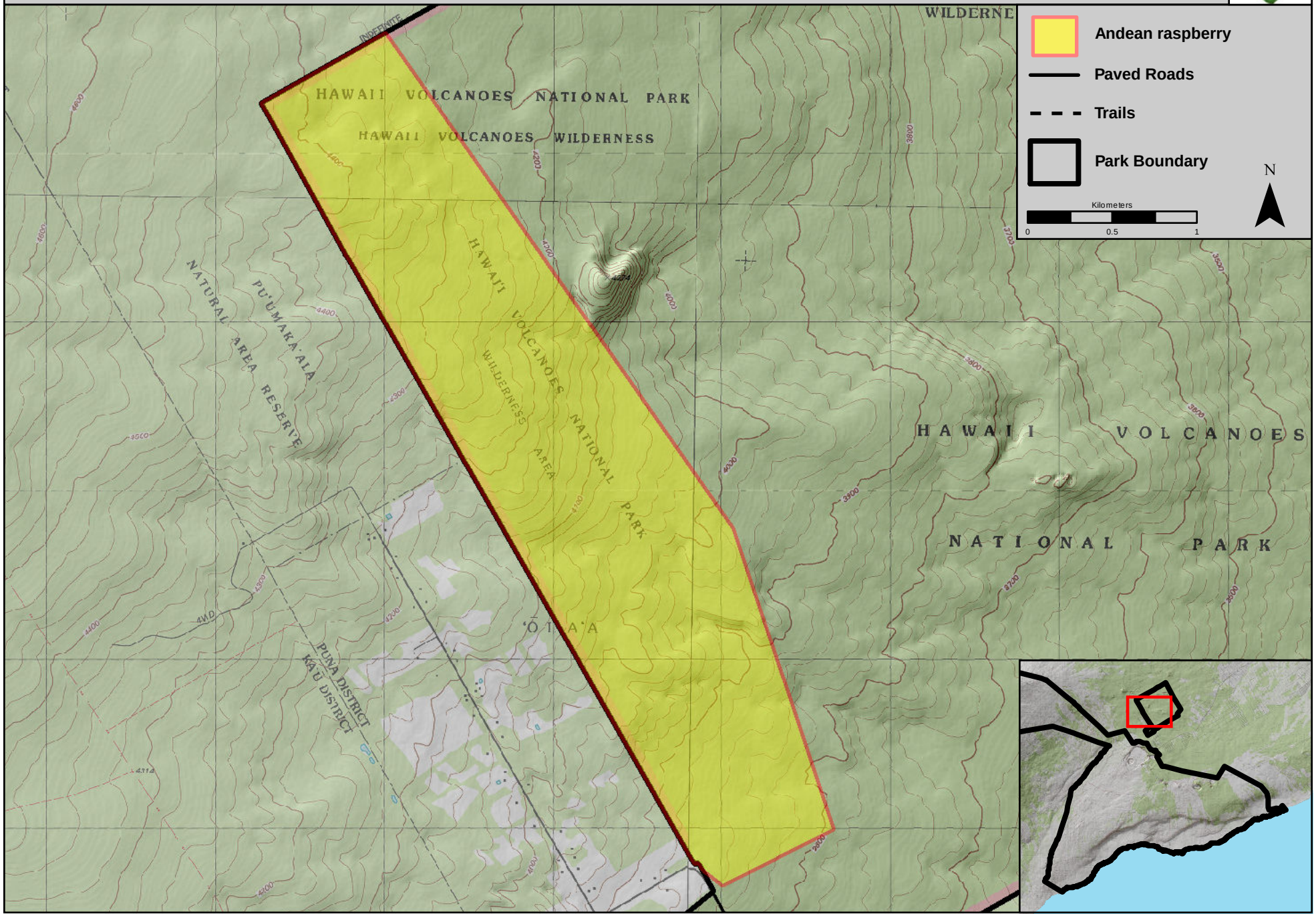
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Albizia (*Falcataria moluccana*)



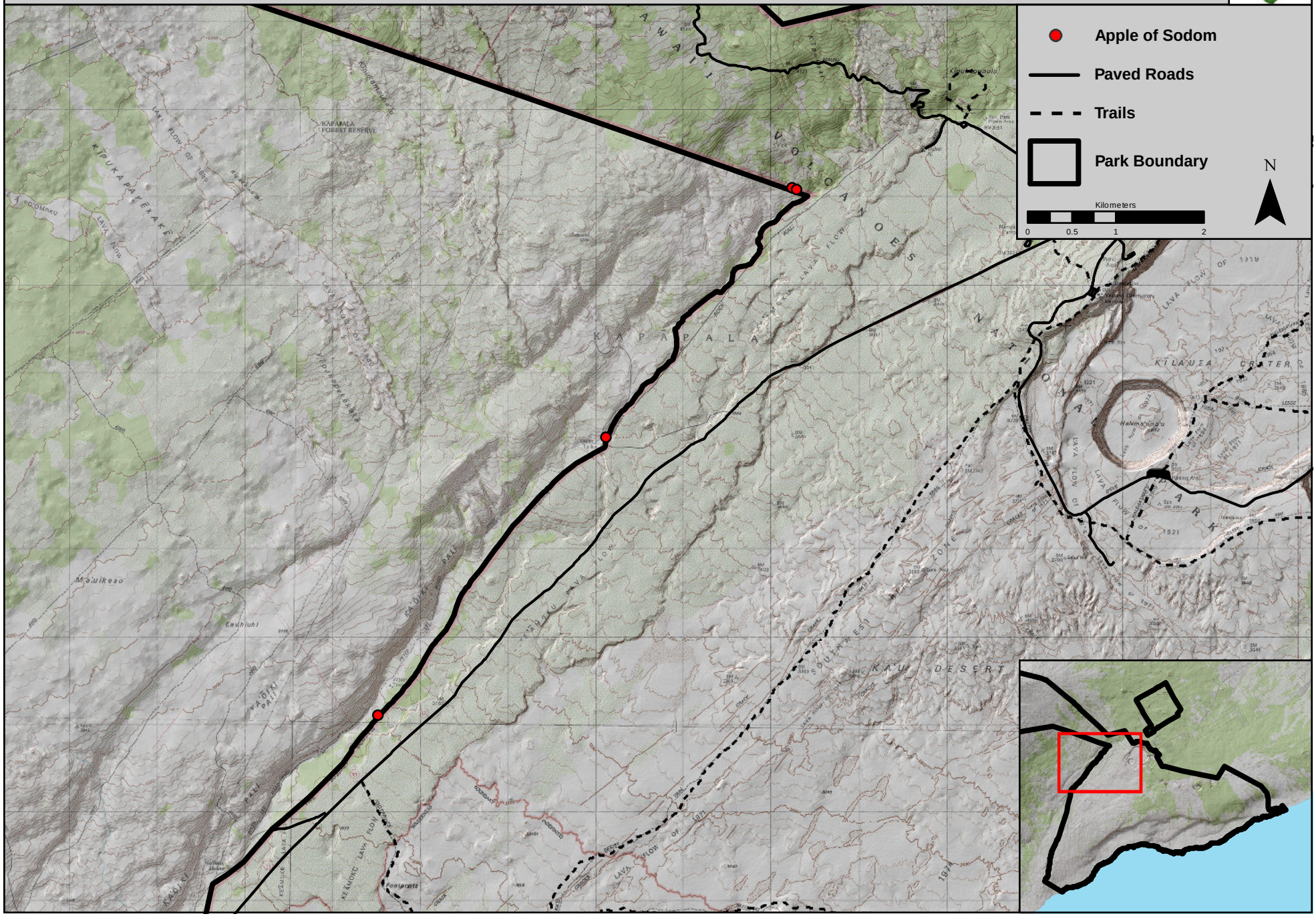
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Andean raspberry (*Rubus glaucus*)



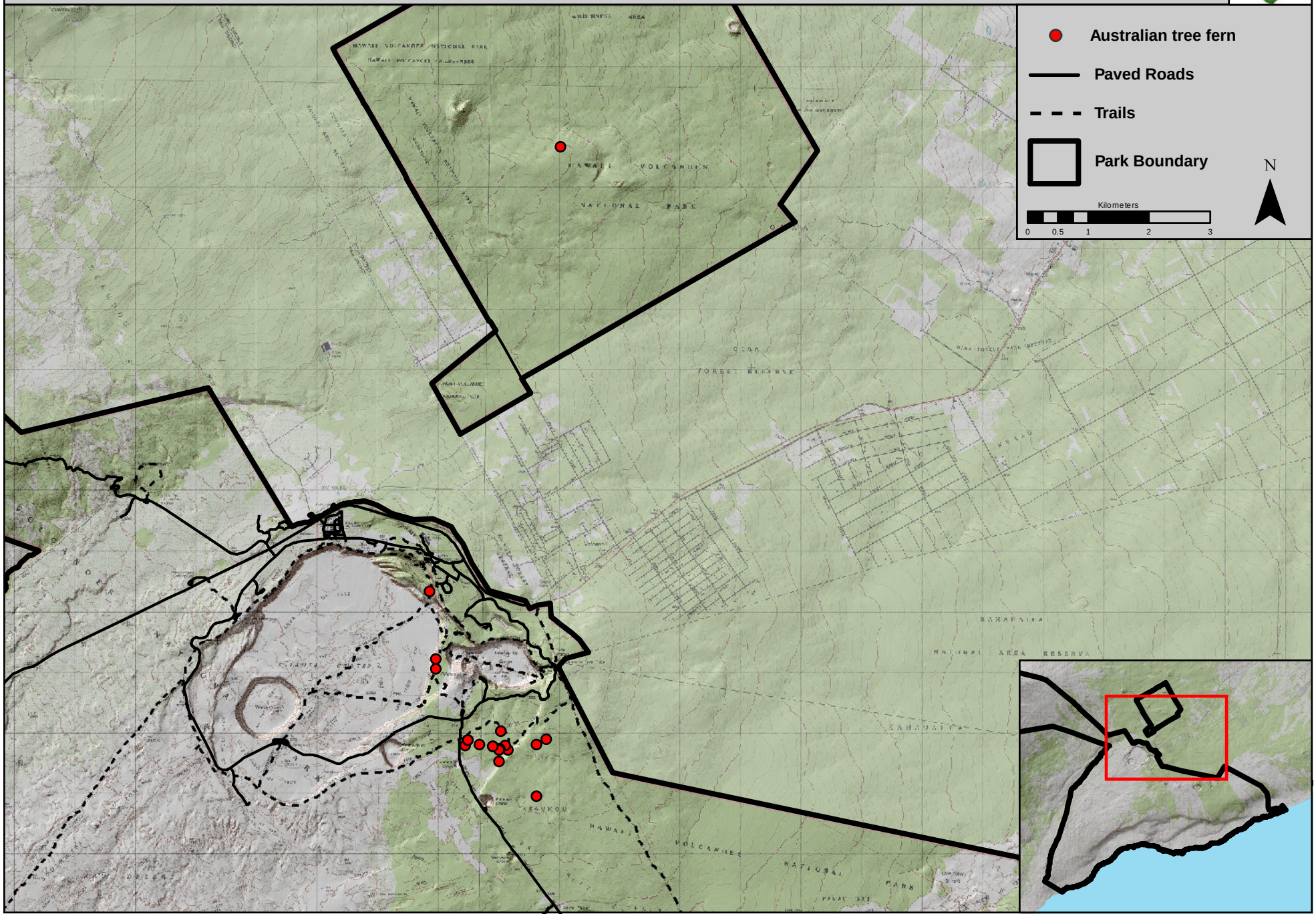
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/20/2011

Apple of Sodom (*Solanum linneaum*)



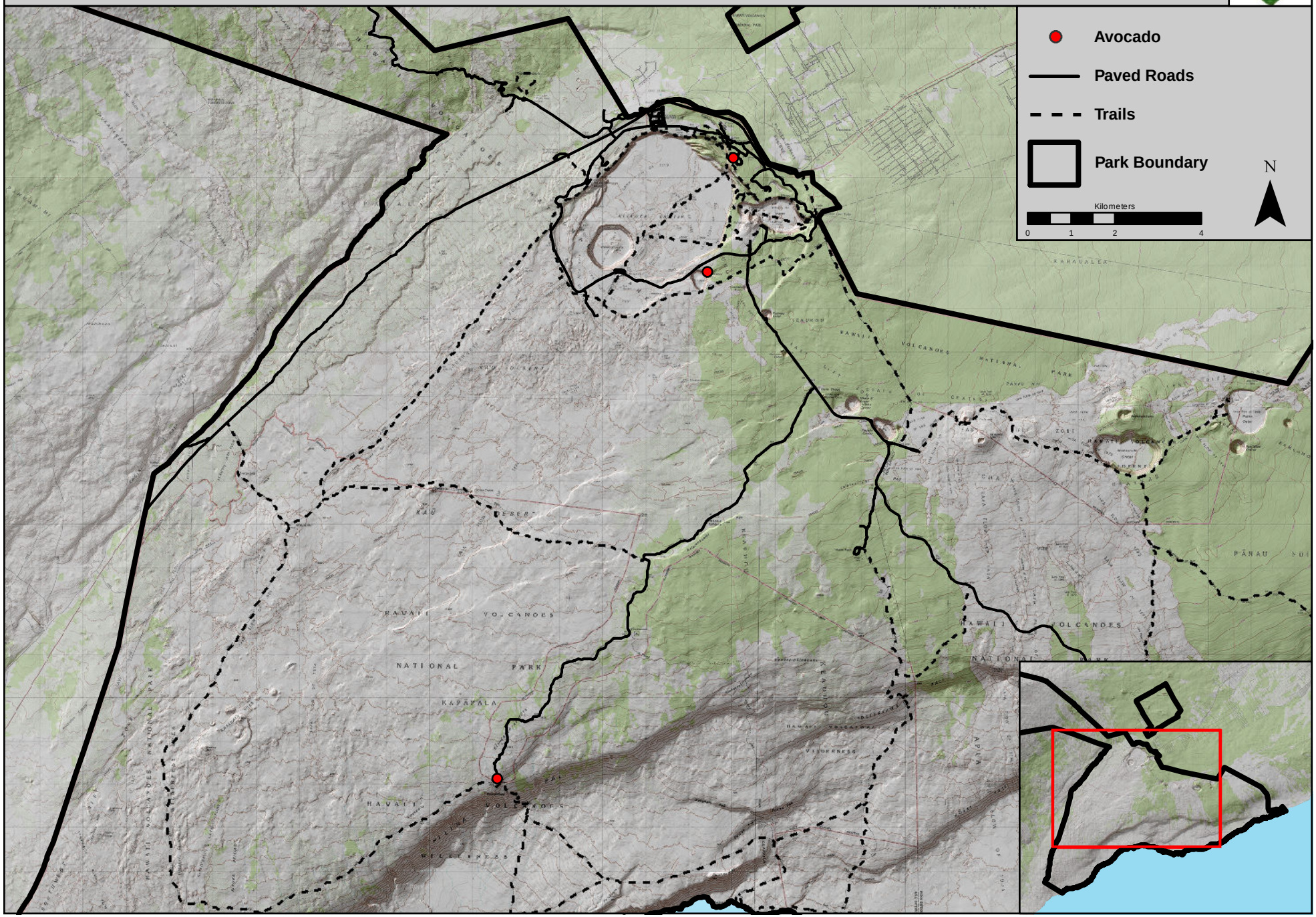
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Australian tree fern (*Sphaeropteris cooperi*)



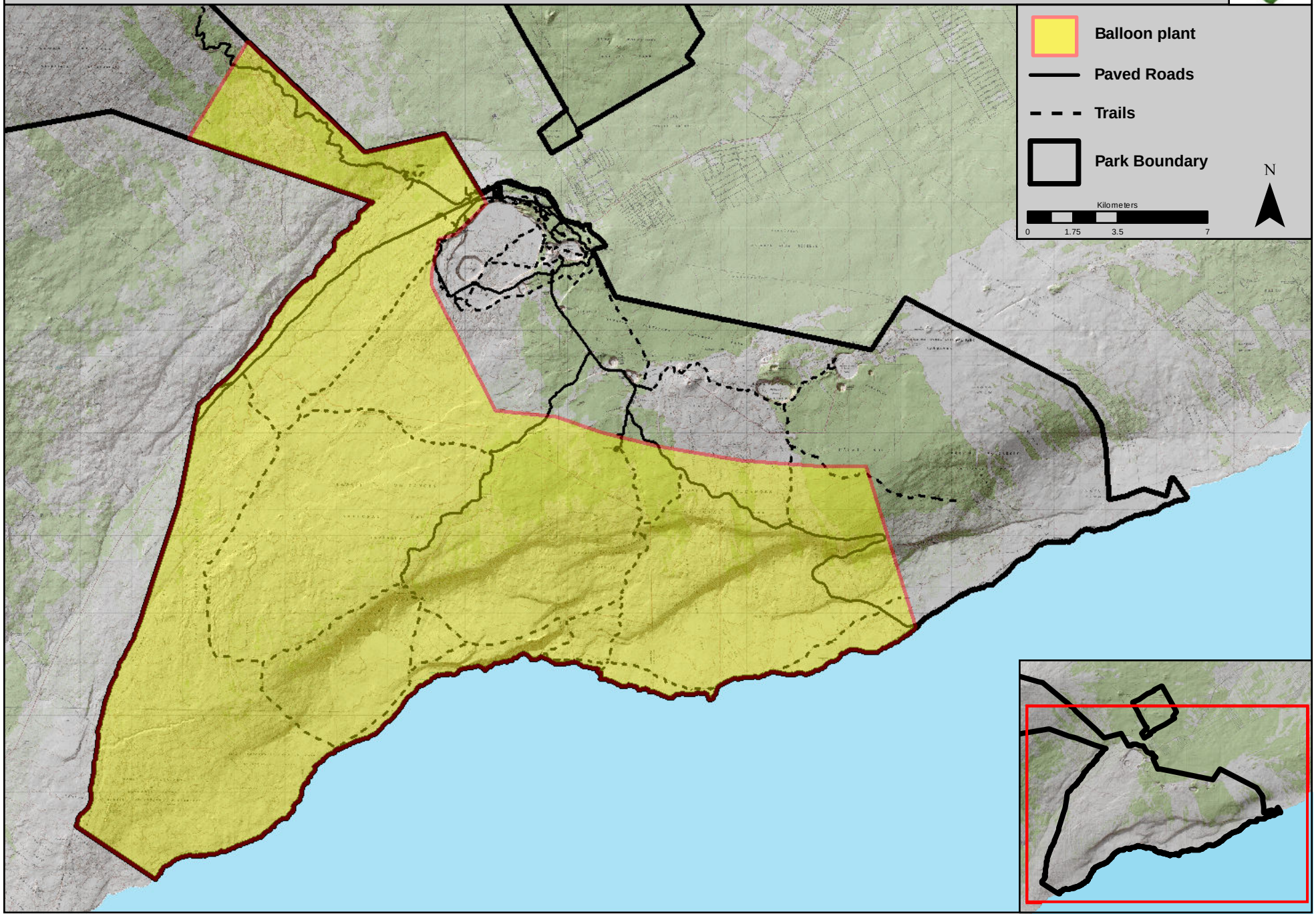
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Avocado (*Persea americana*)



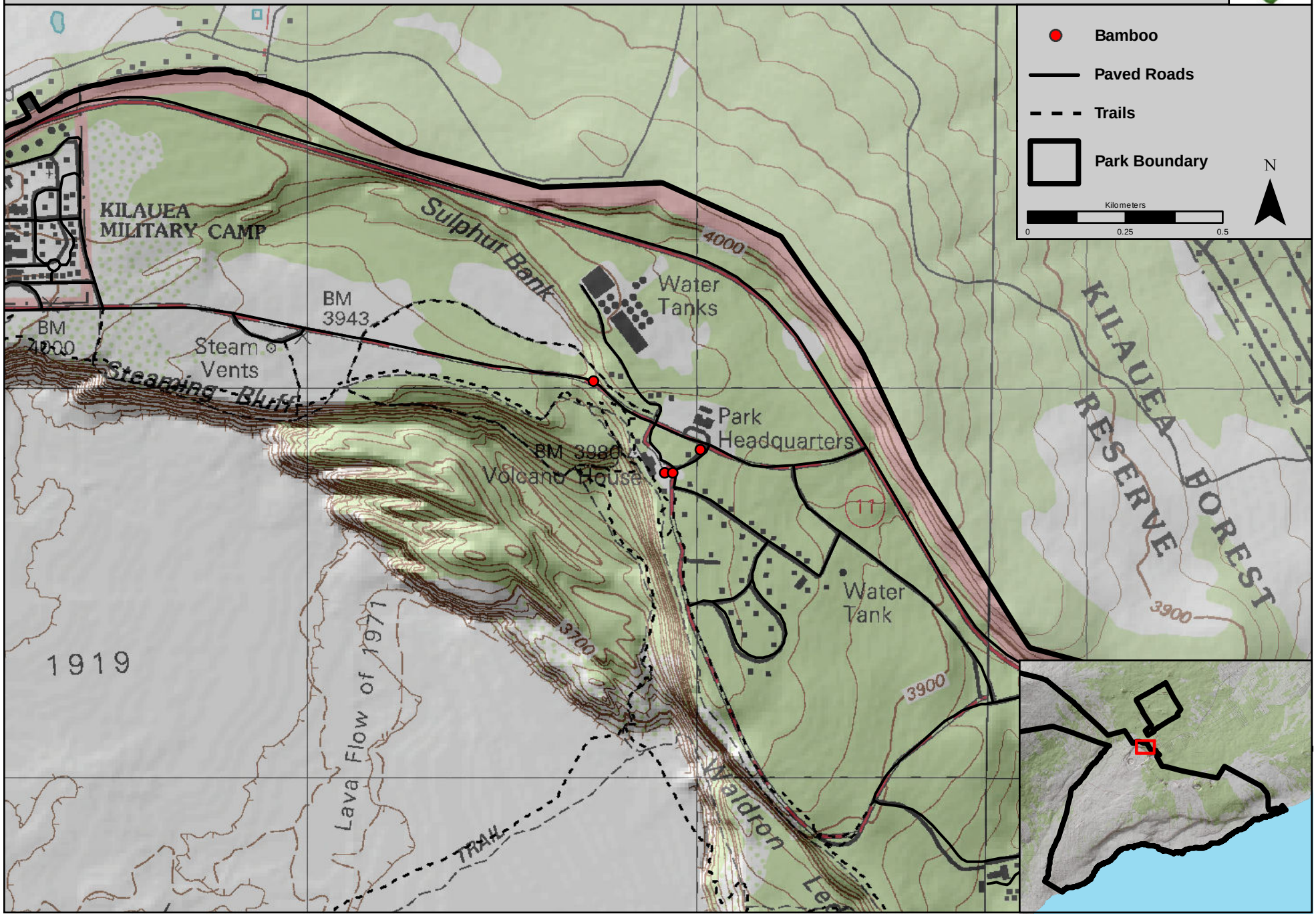
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Balloon plant (*Asclepias physocarpa*)



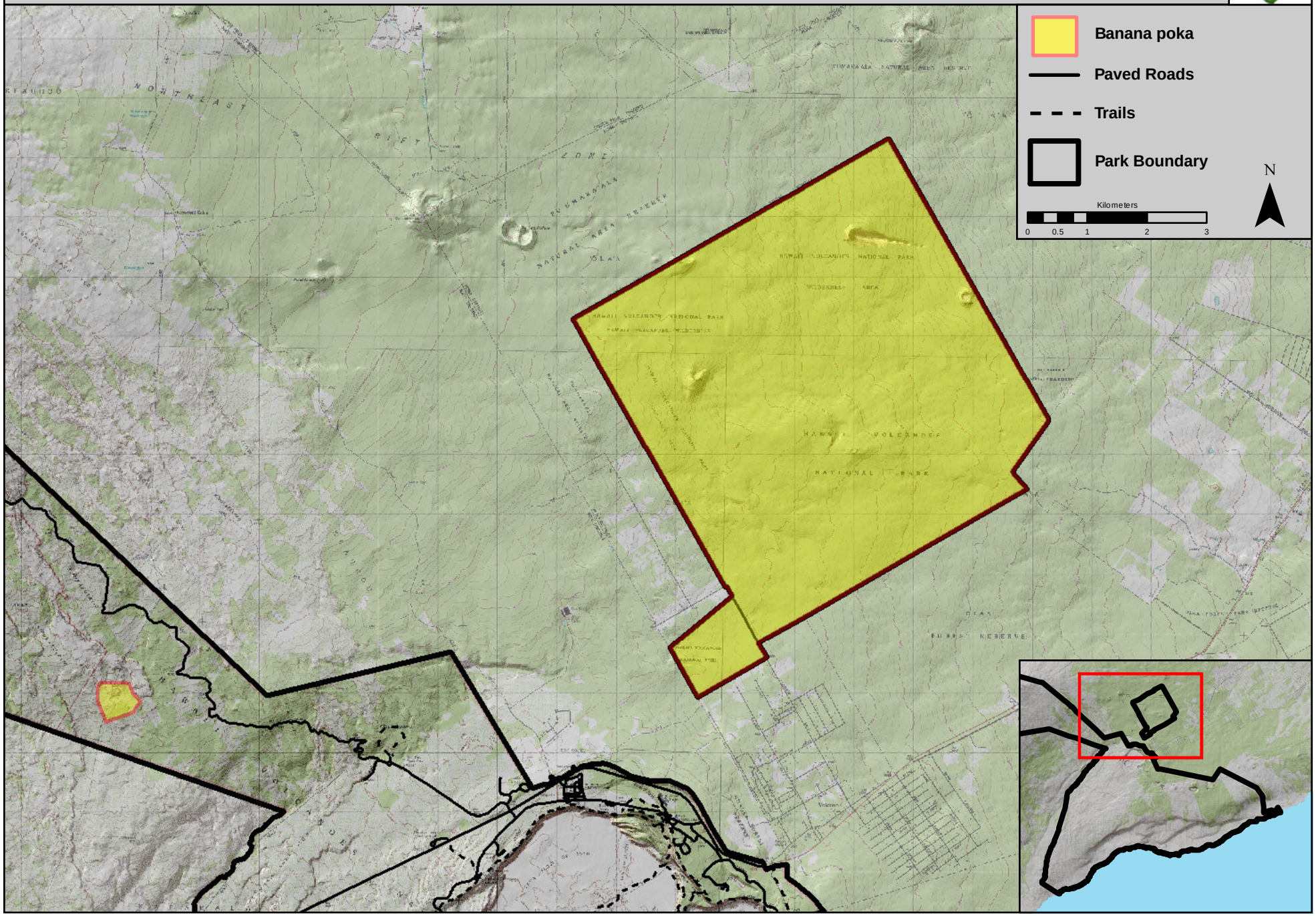
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/23/2011

Bamboo (*Phyllostachis cf. nigra*)



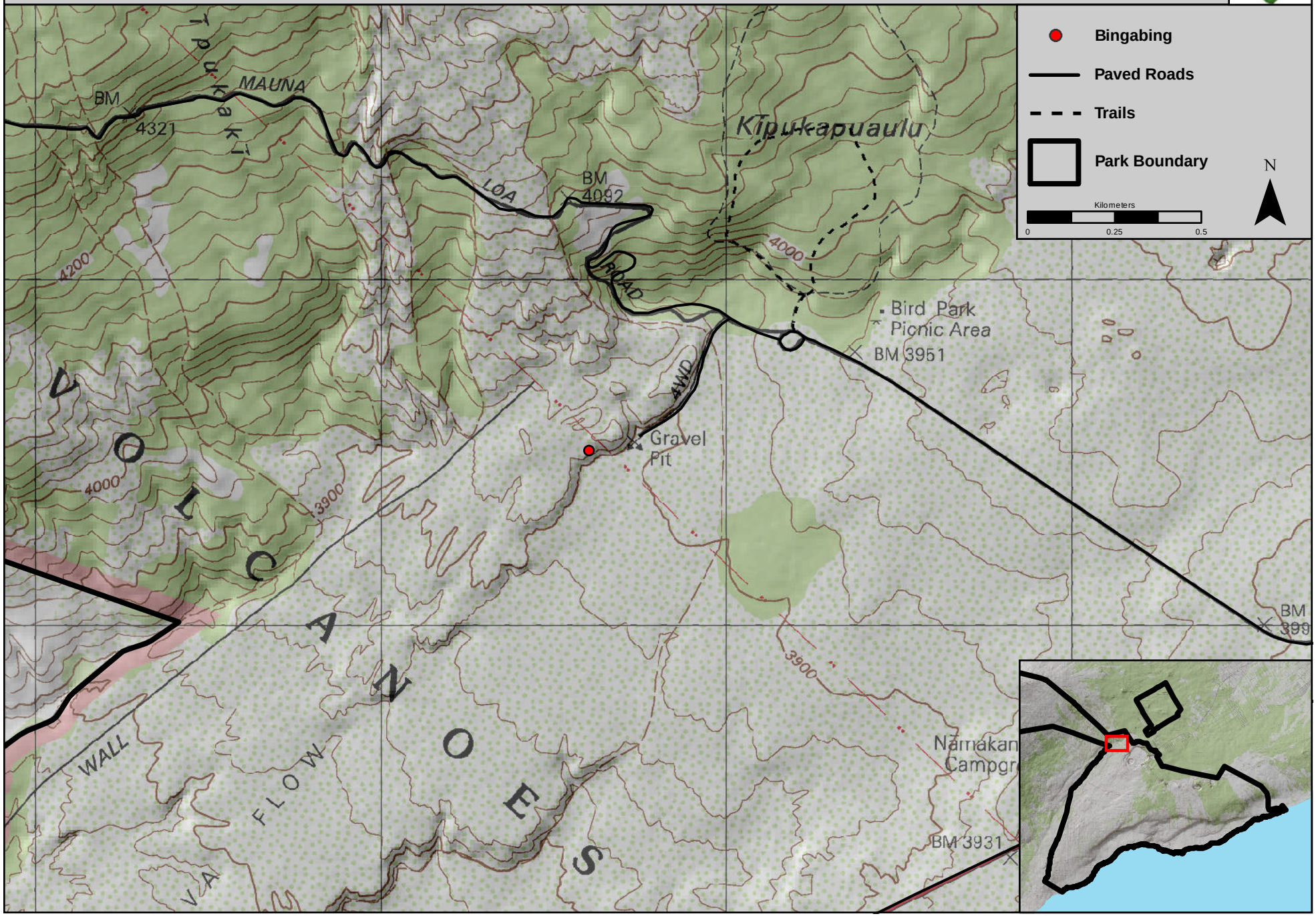
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/10/2011

Banana poka (*Passiflora tarminiana*)



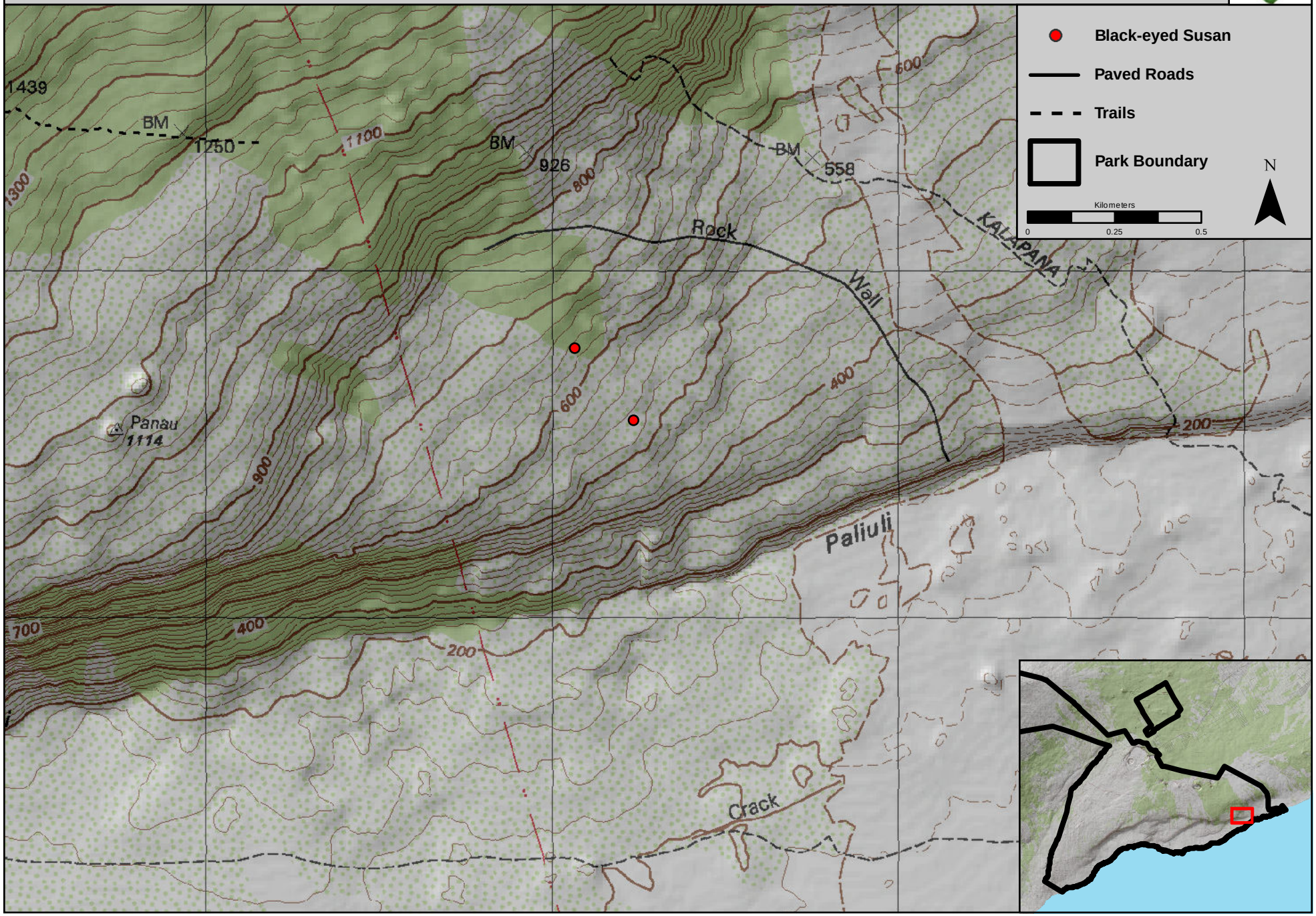
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/23/2011

Bingabing (*Macaranga tanarius*)



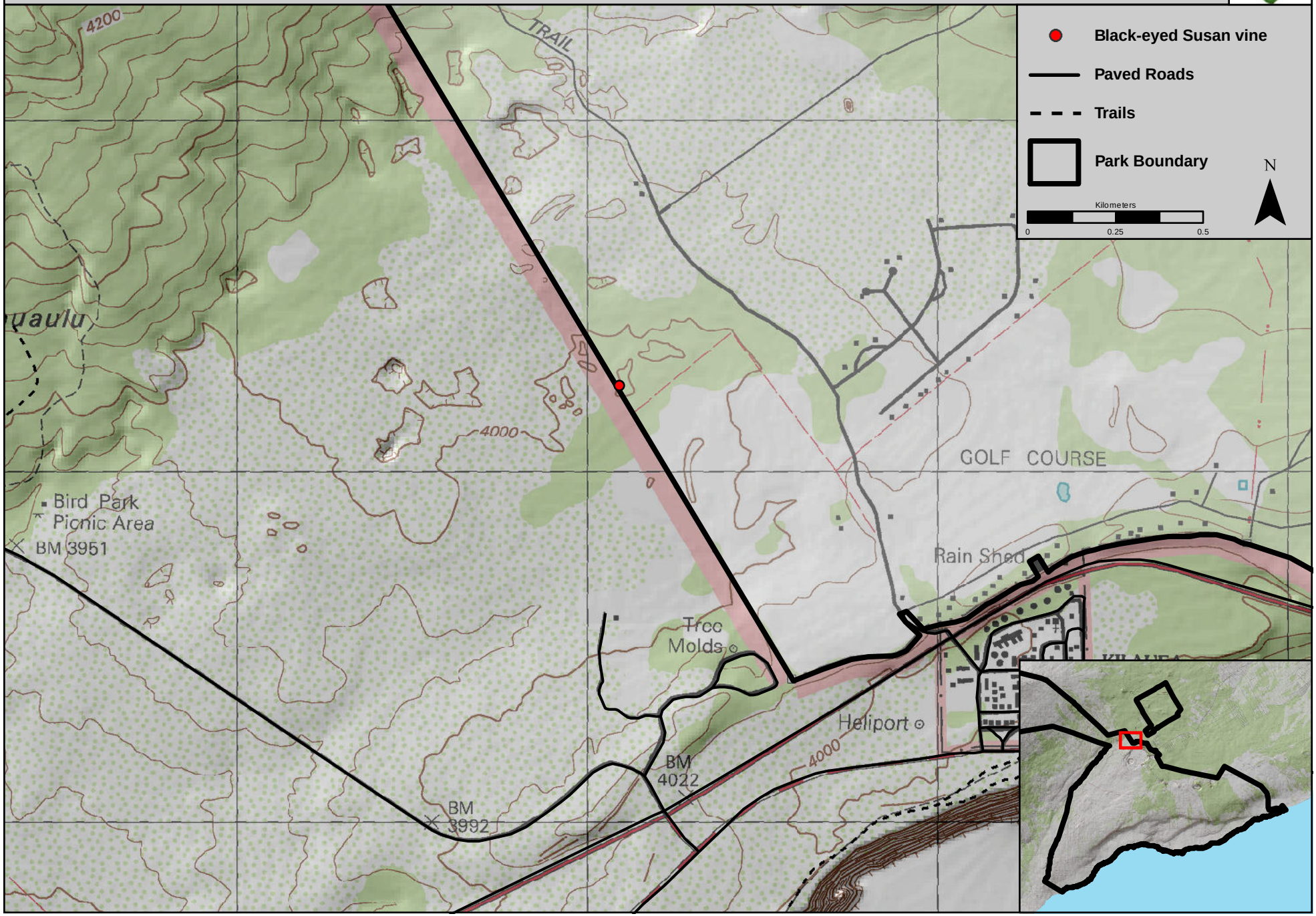
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Black-eyed Susan (*Abrus precatorius*)



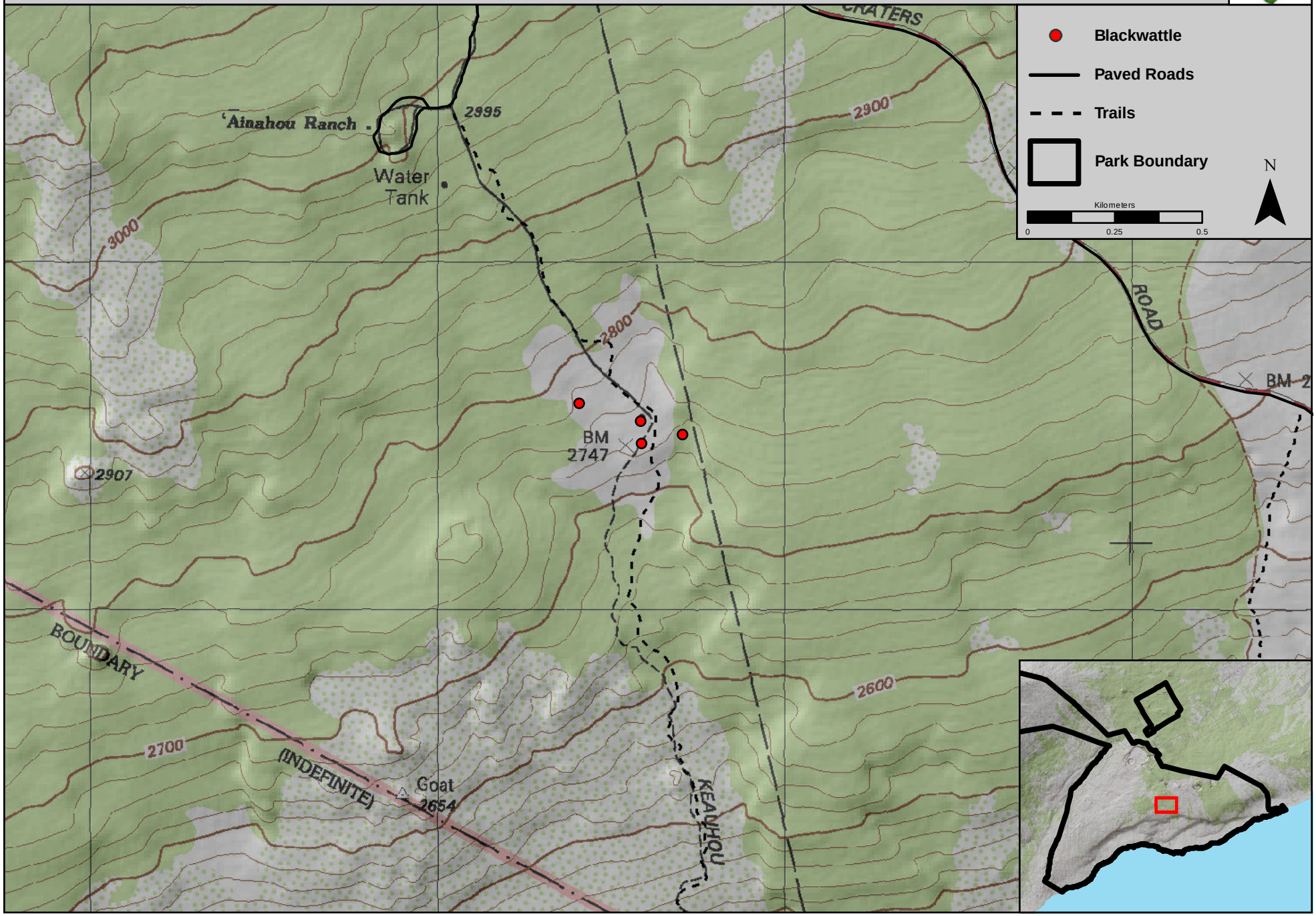
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Black-eyed Susan vine (*Thunbergia alata*)



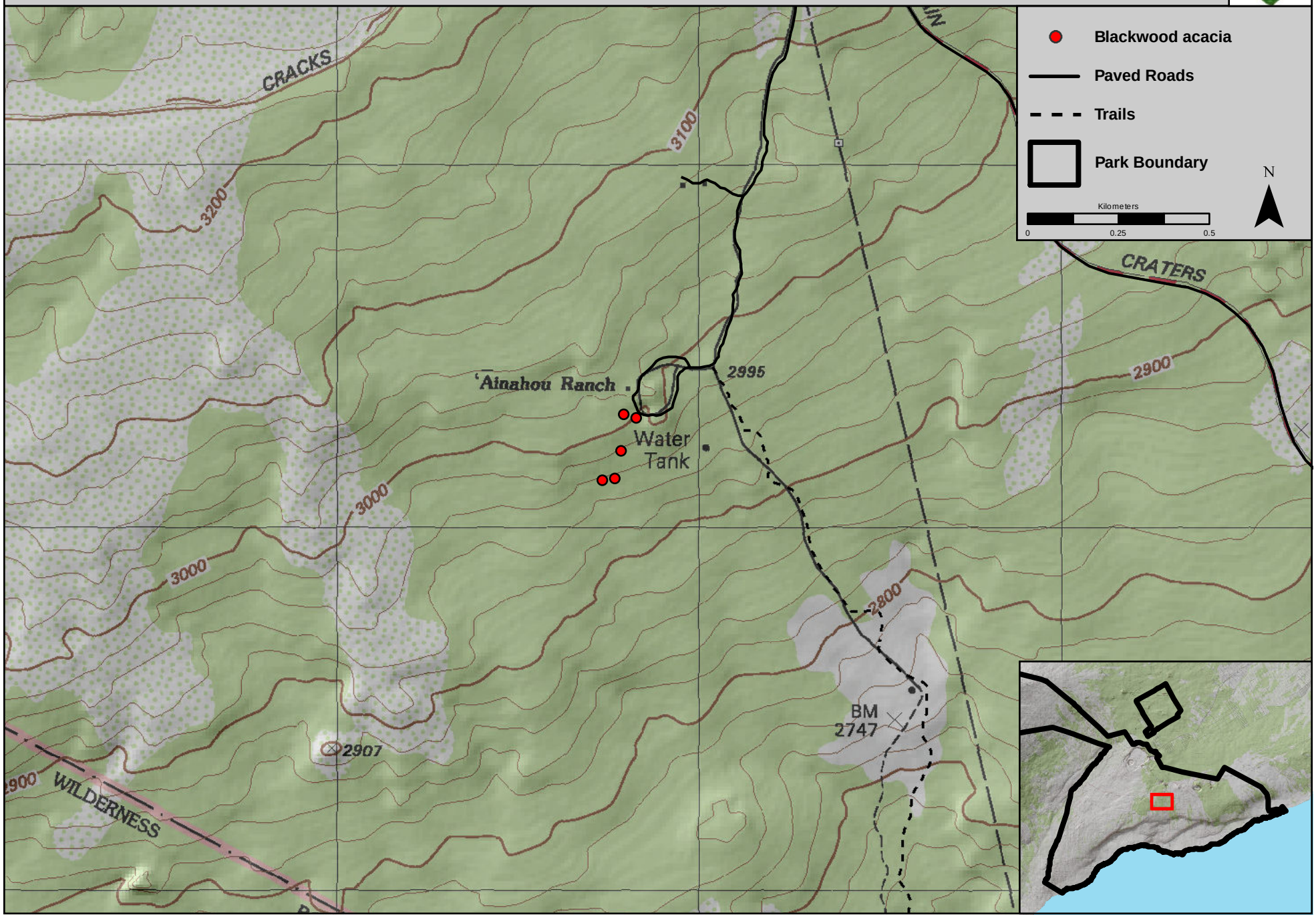
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Blackwattle (*Acacia mearnsii*)



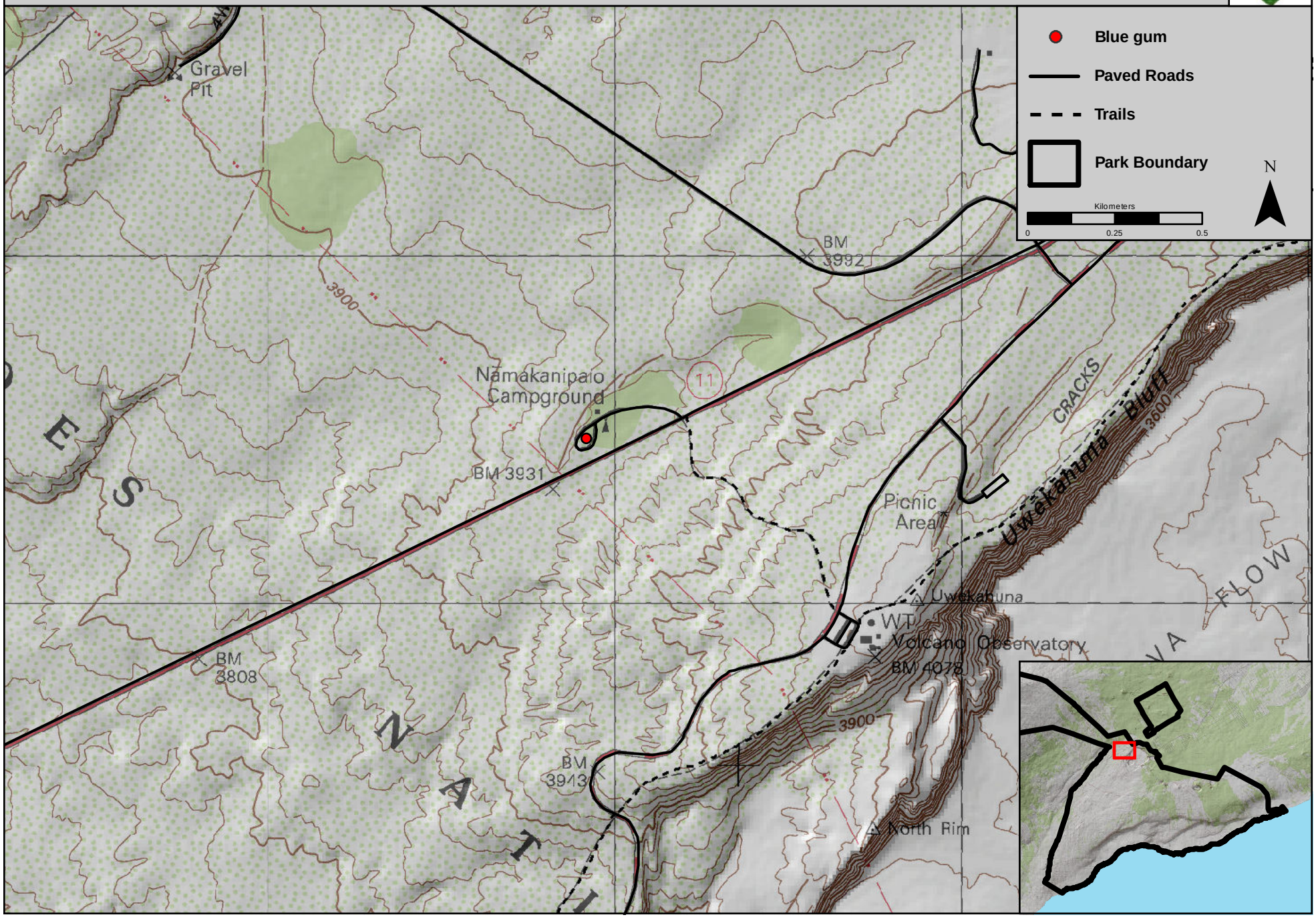
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Blackwood acacia (*Acacia melanoxylon*)



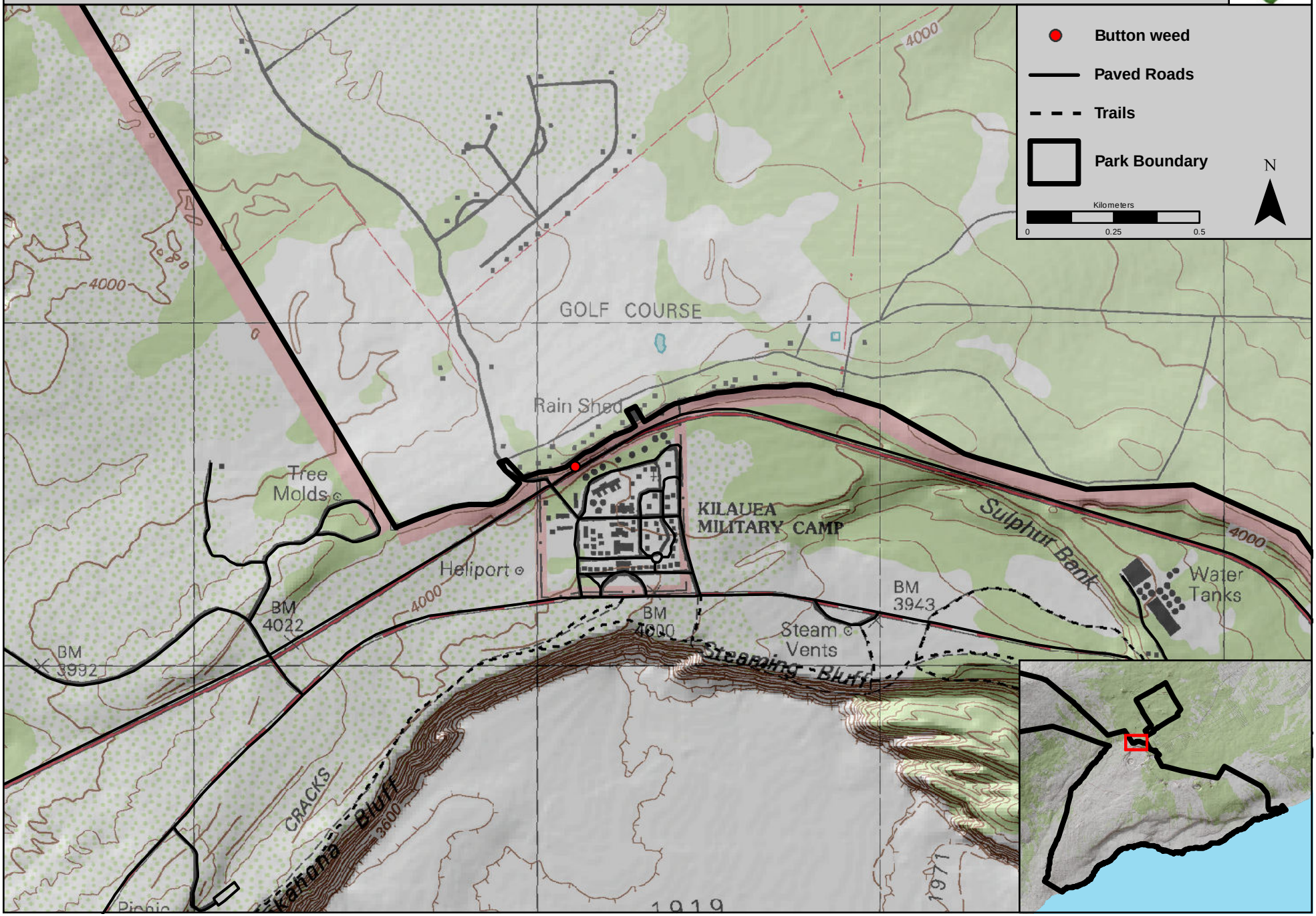
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Blue gum (*Eucalyptus globulus*)



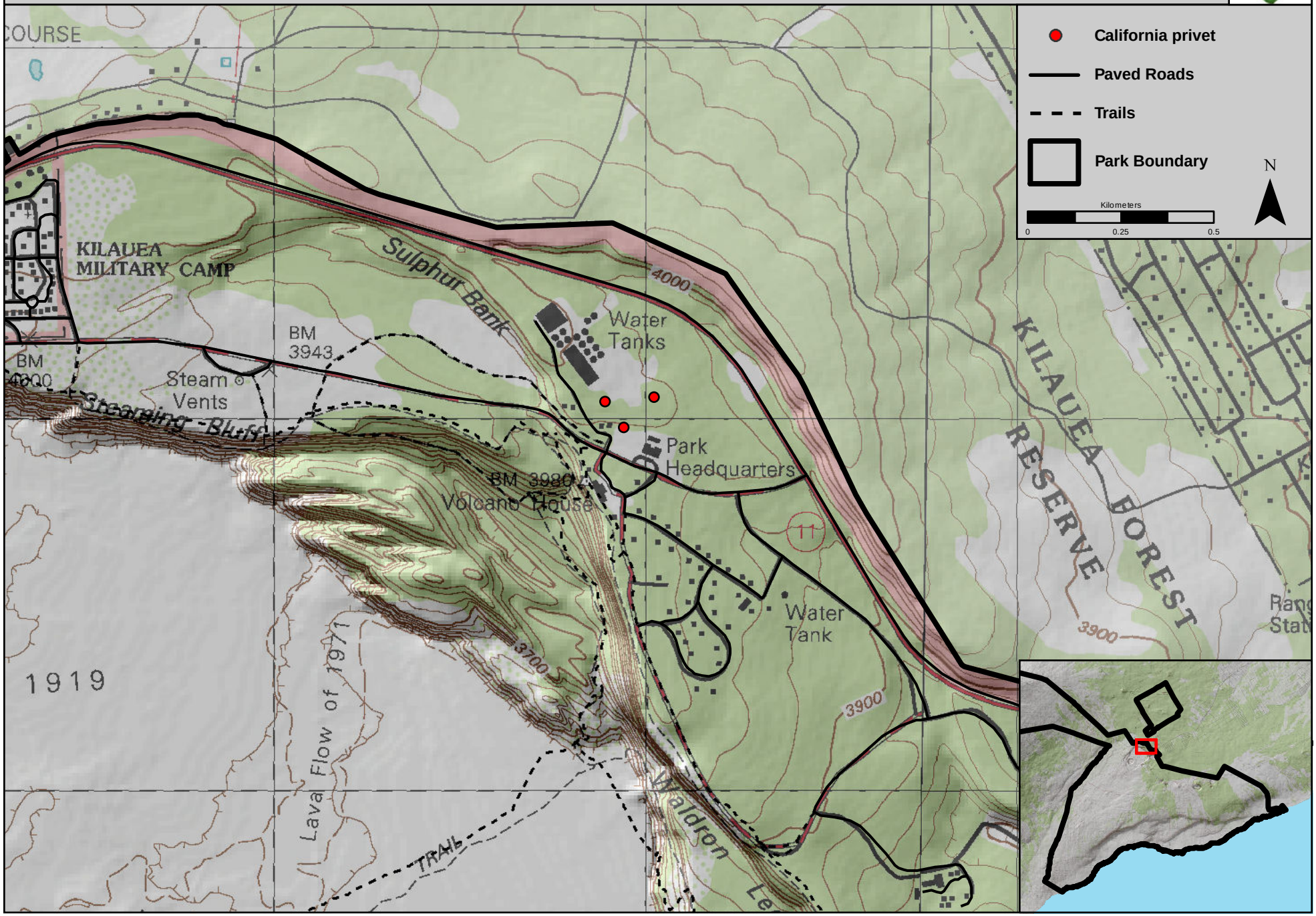
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Button weed (*Spermacoce* sp.)



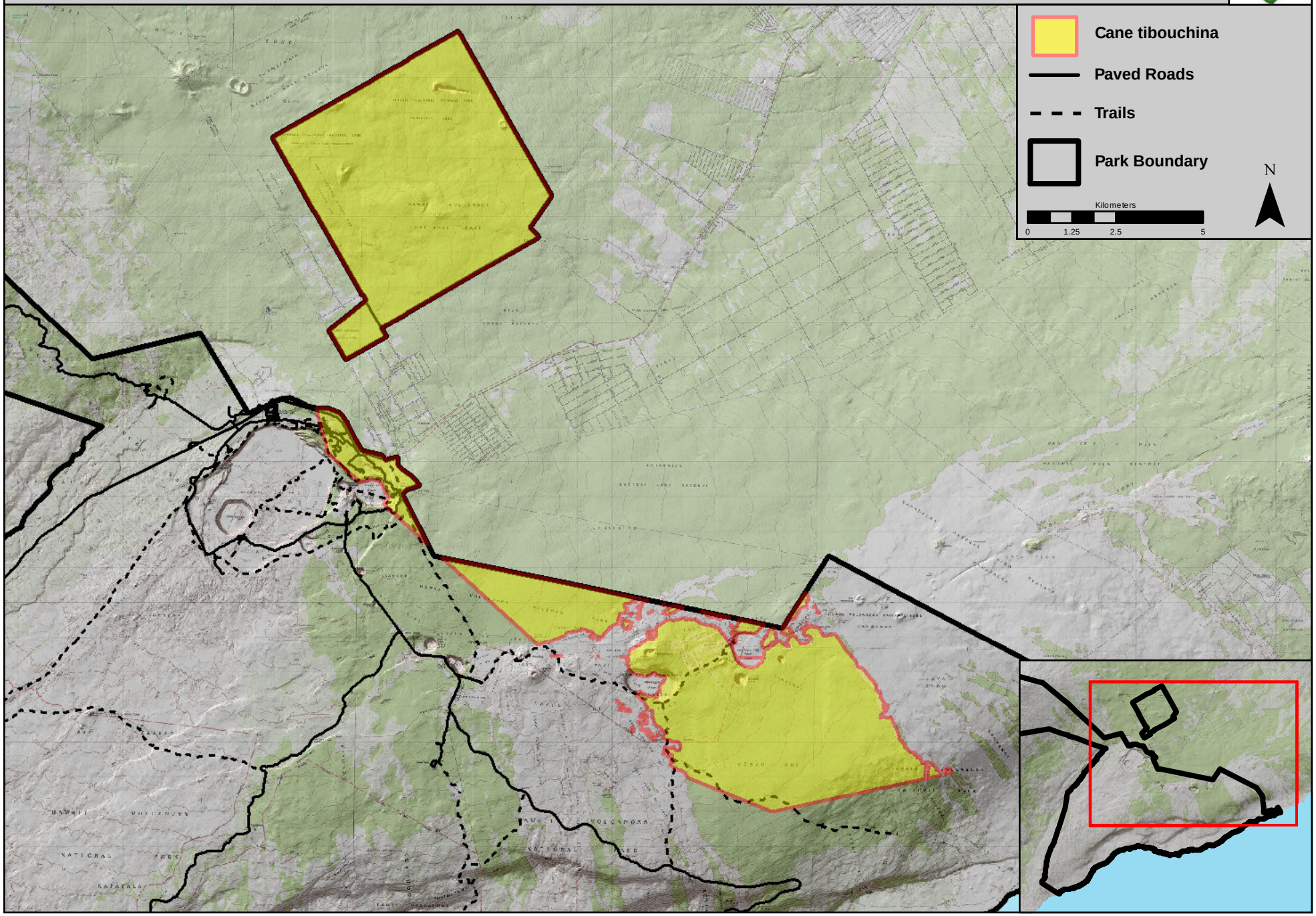
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

California privet (*Ligustrum sinense*)



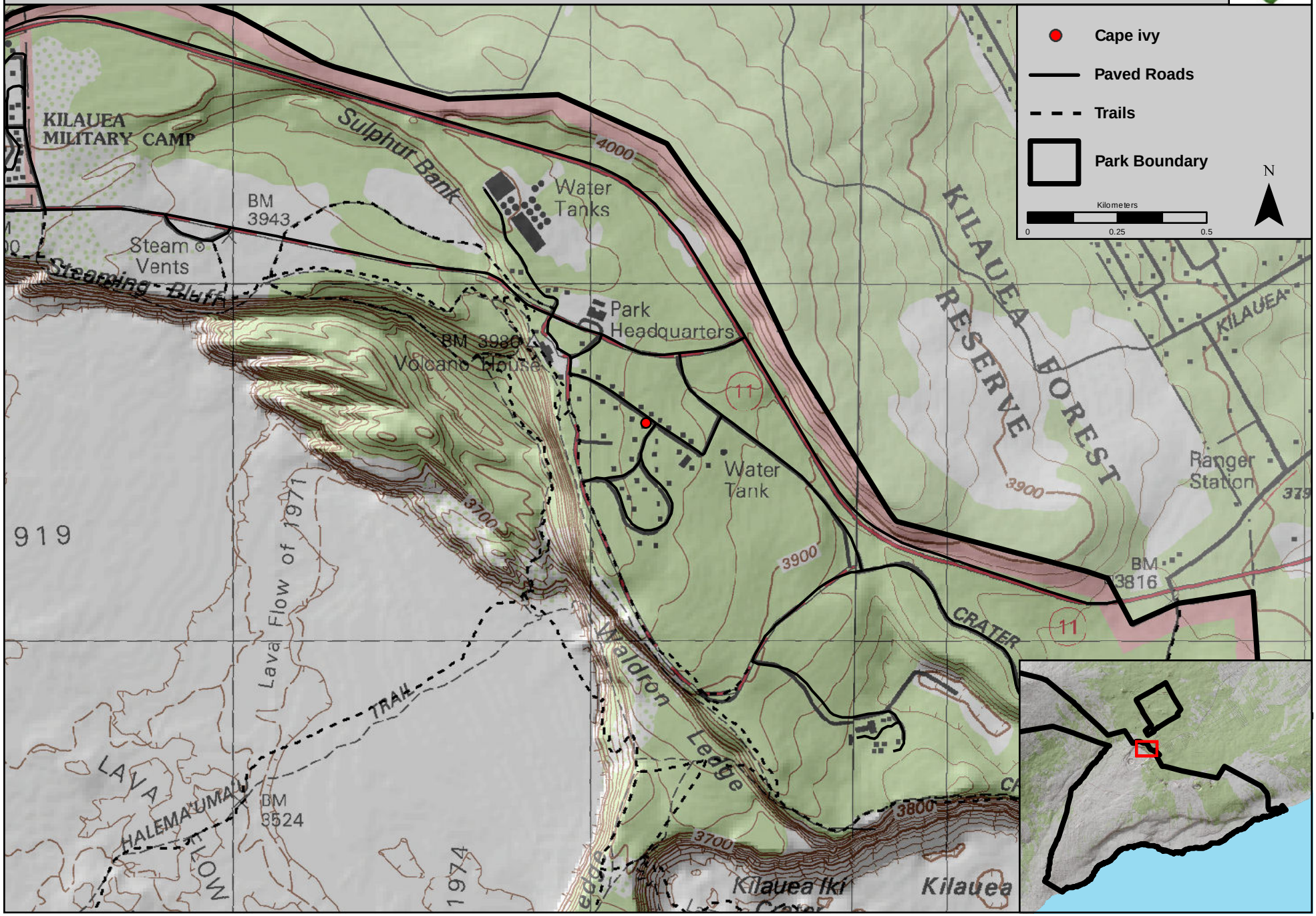
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Cane tibouchina (*Tibouchina herbacea*)



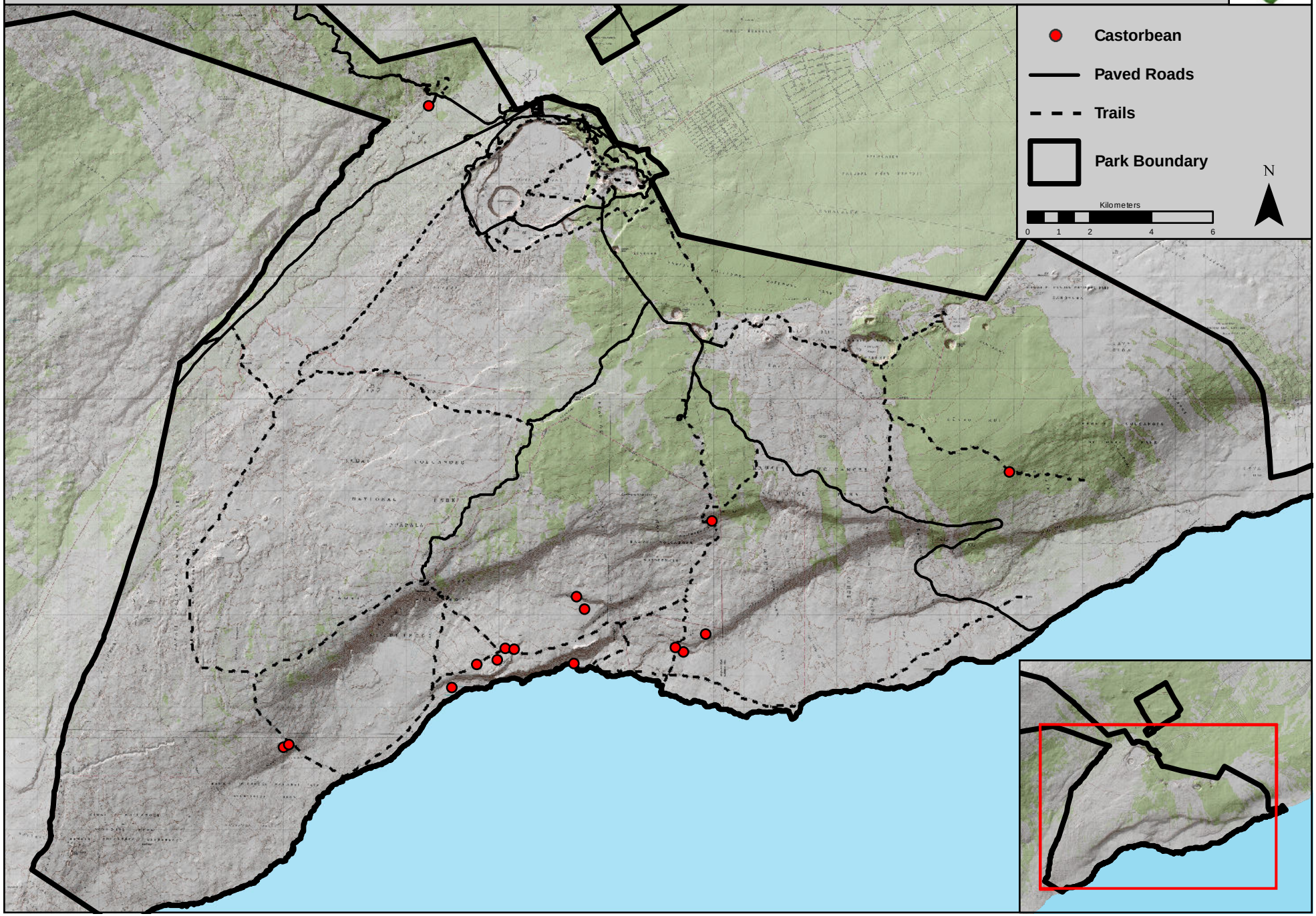
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/22/2011

Cape ivy (*Delairea odorata*)



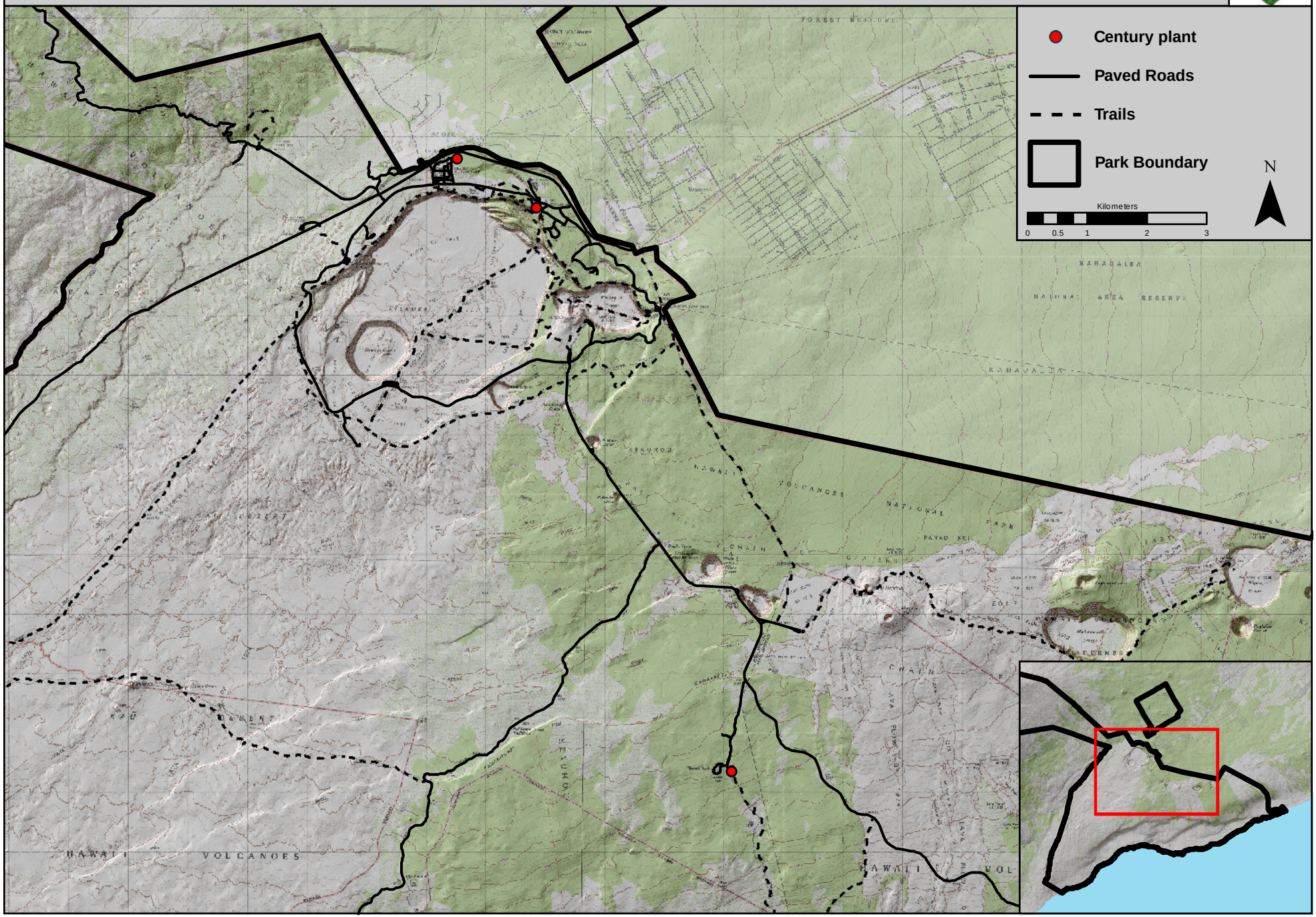
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Castorbean (*Ricinus communis*)



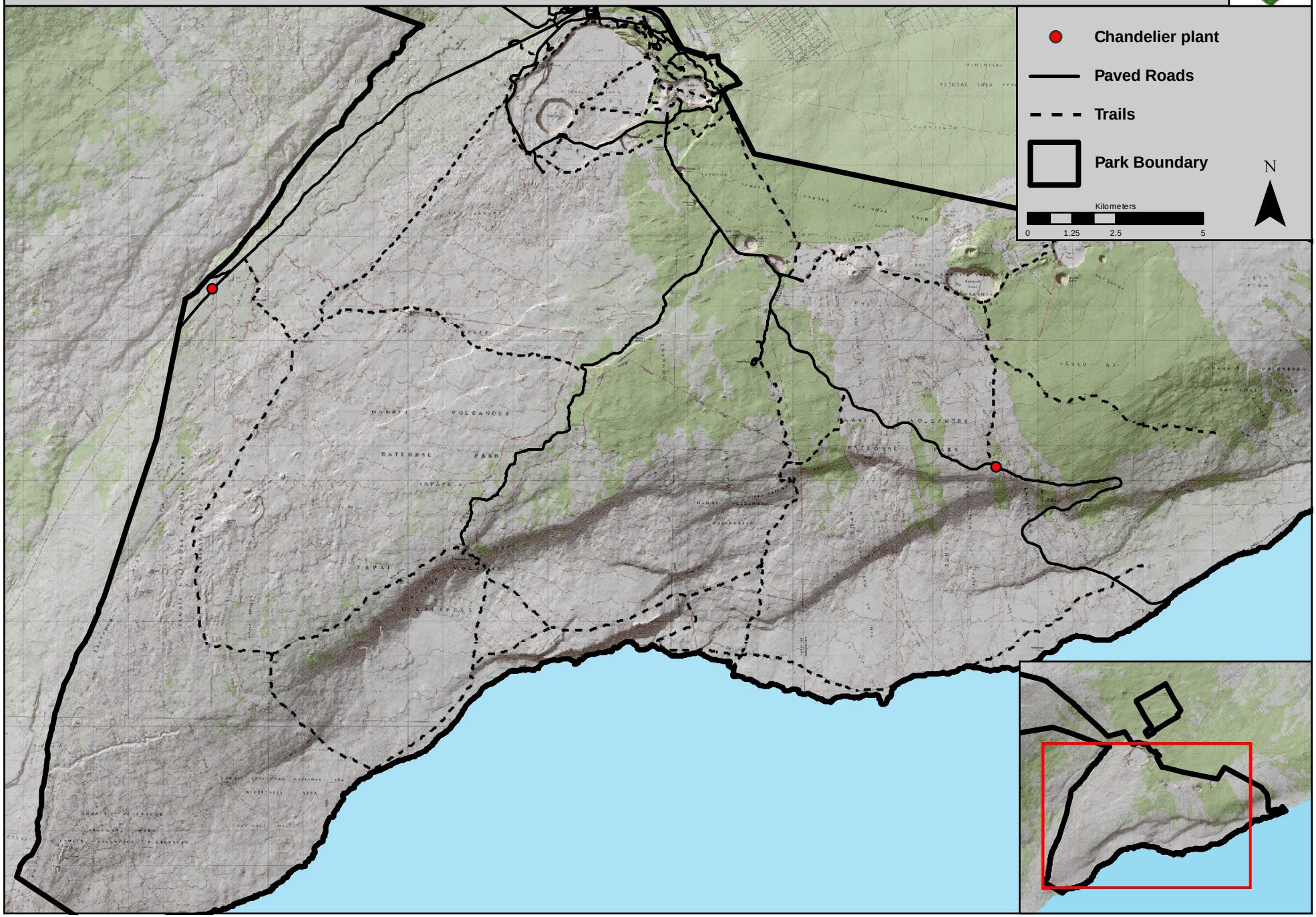
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Century plant (*Agave americana*)



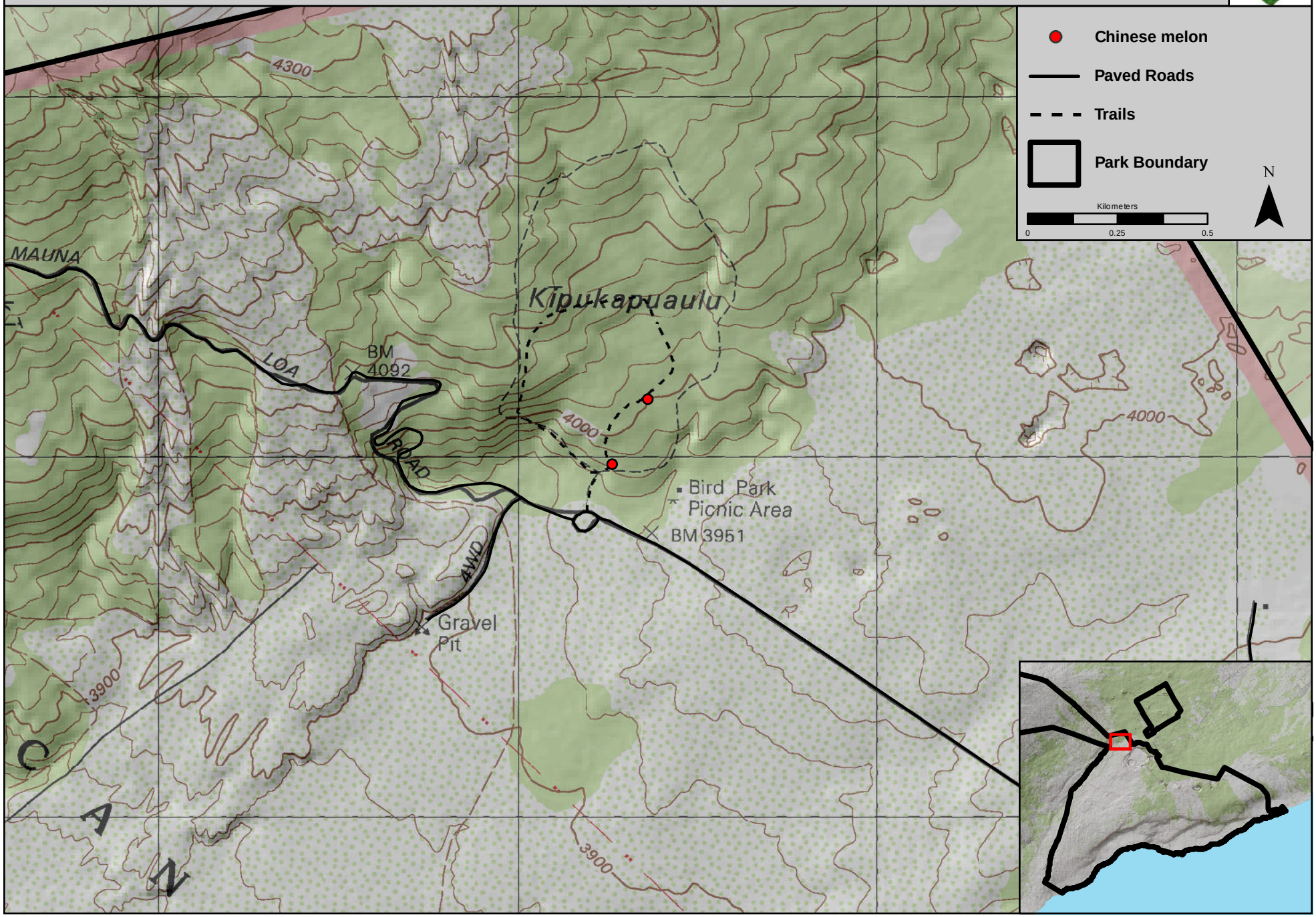
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Chandelier plant (*Kalanchoë tubiflora*)



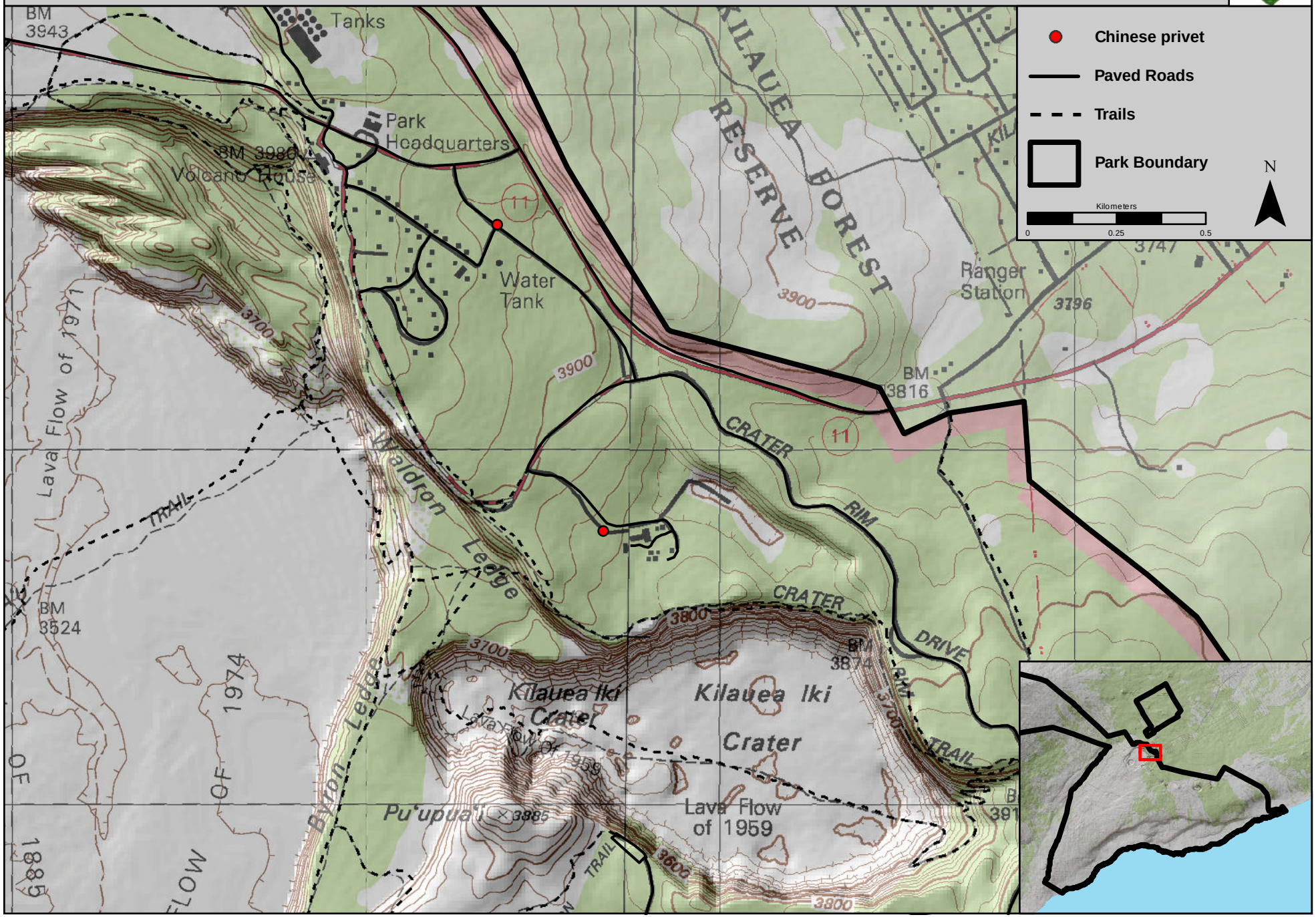
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Chinese melon (*Benincasa hispida*)



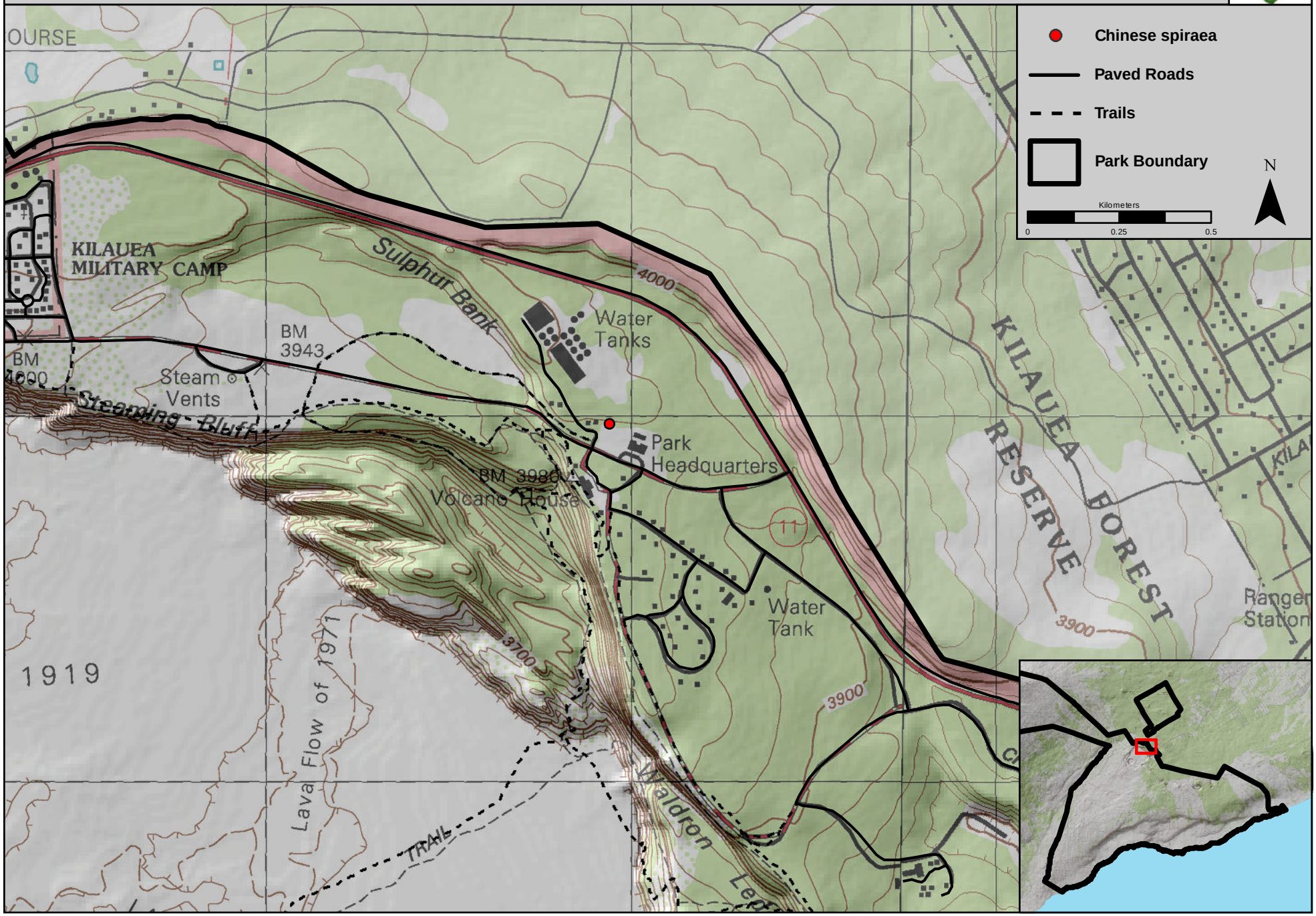
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Chinese privet (*Ligustrum ovalifolium*)



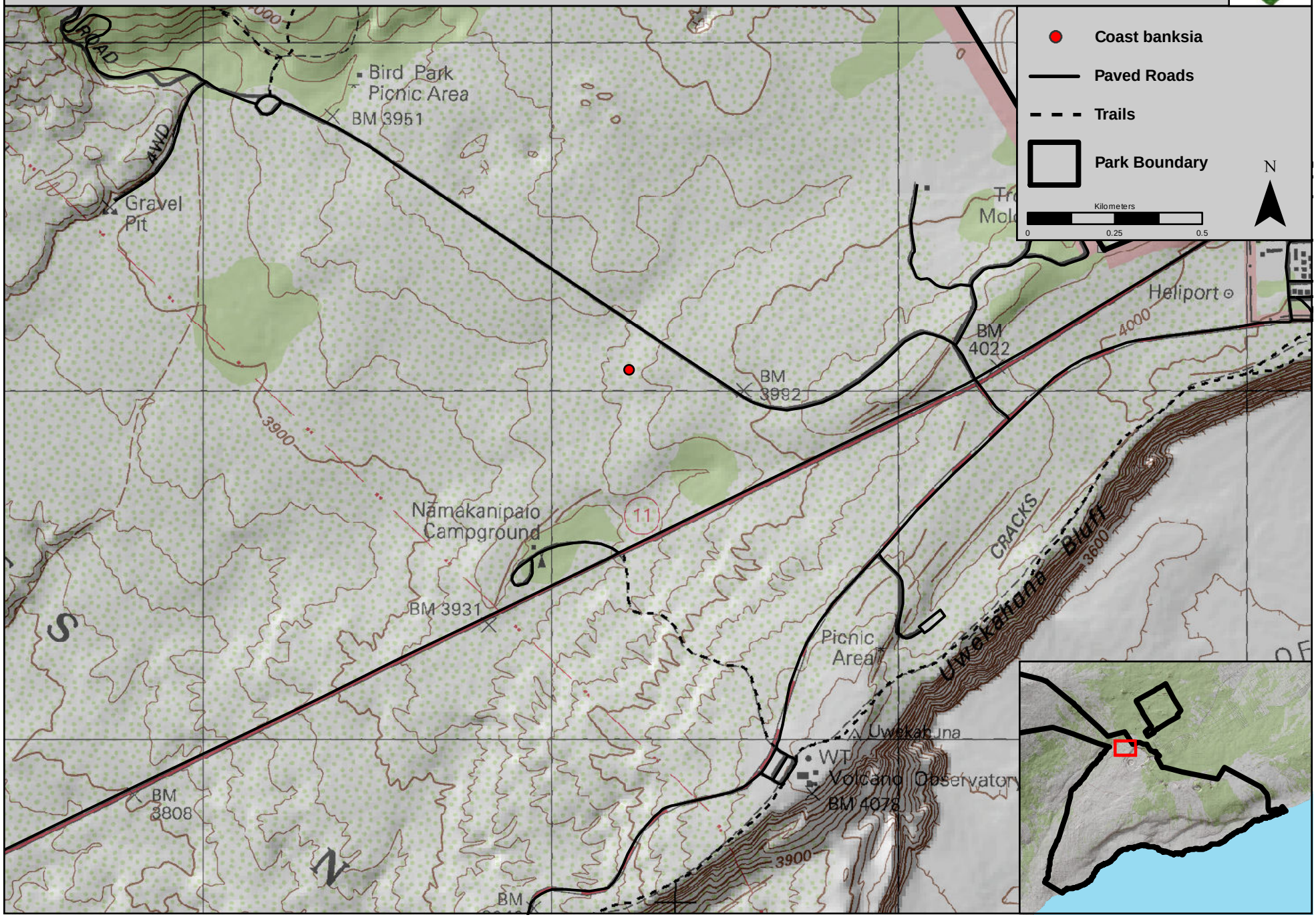
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Chinese spiraea (*Spiraea cantoniensis*)



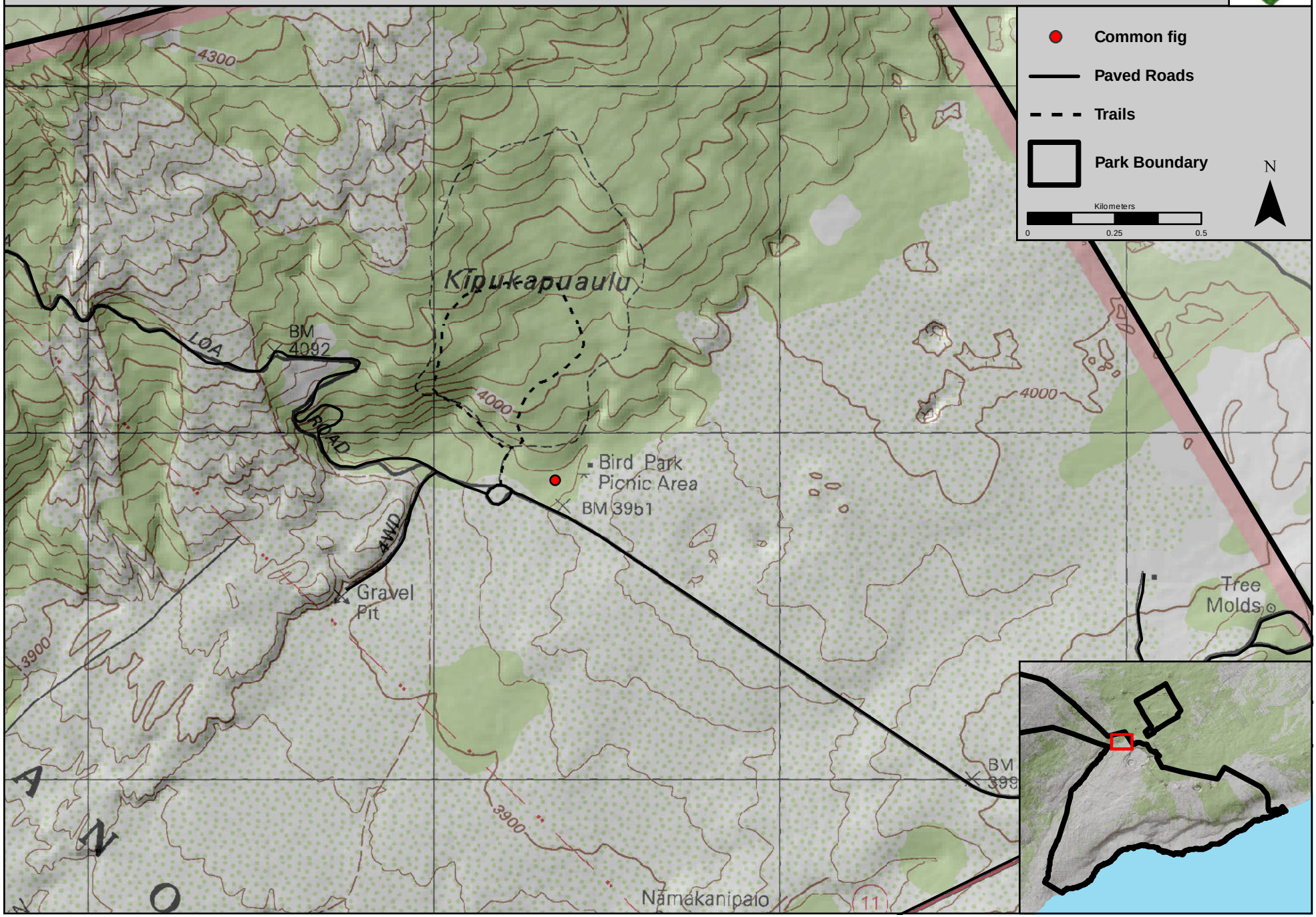
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Coast banksia (*Banksia* cf. *integrifolia*)



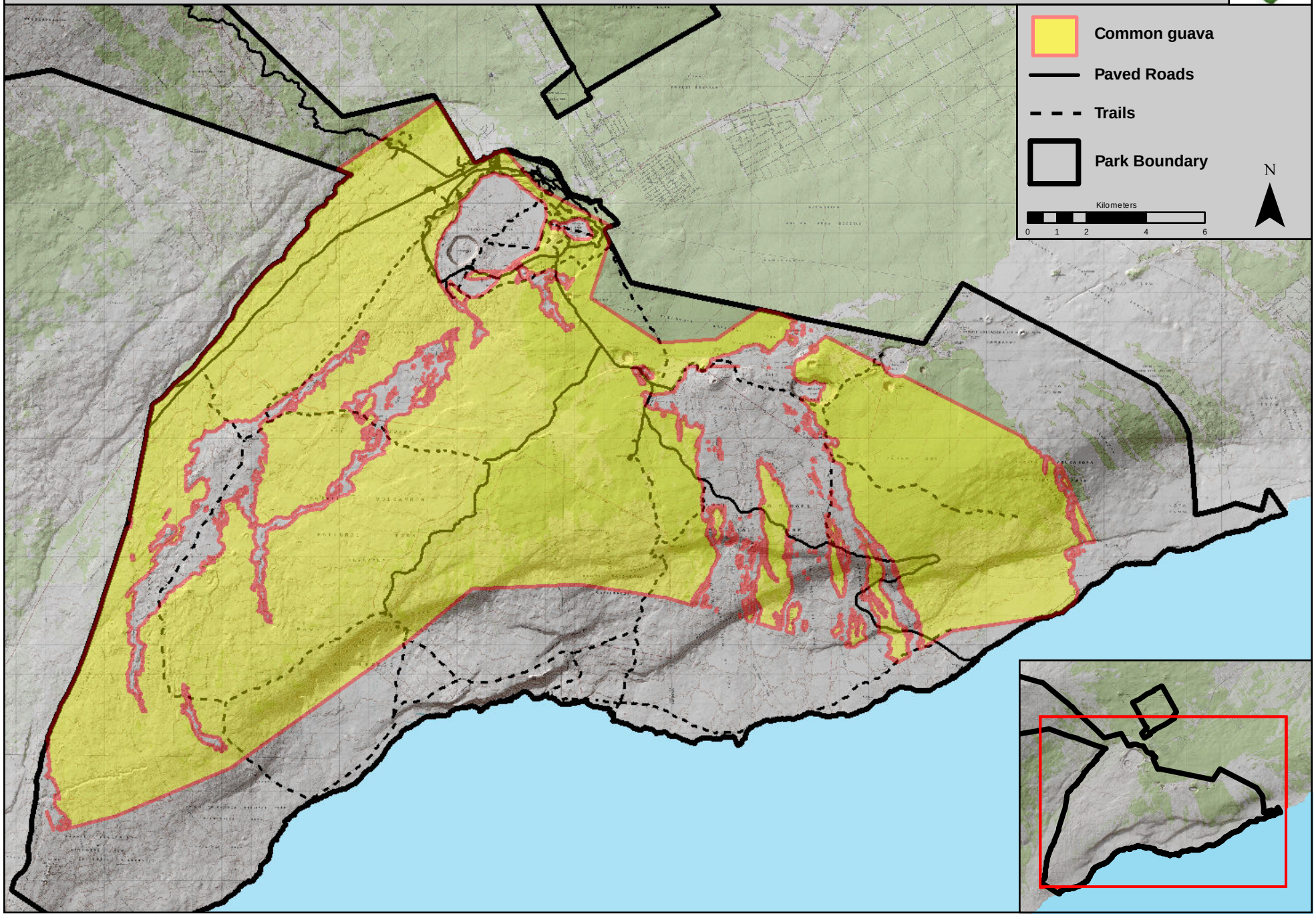
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Common fig (*Ficus carica*)



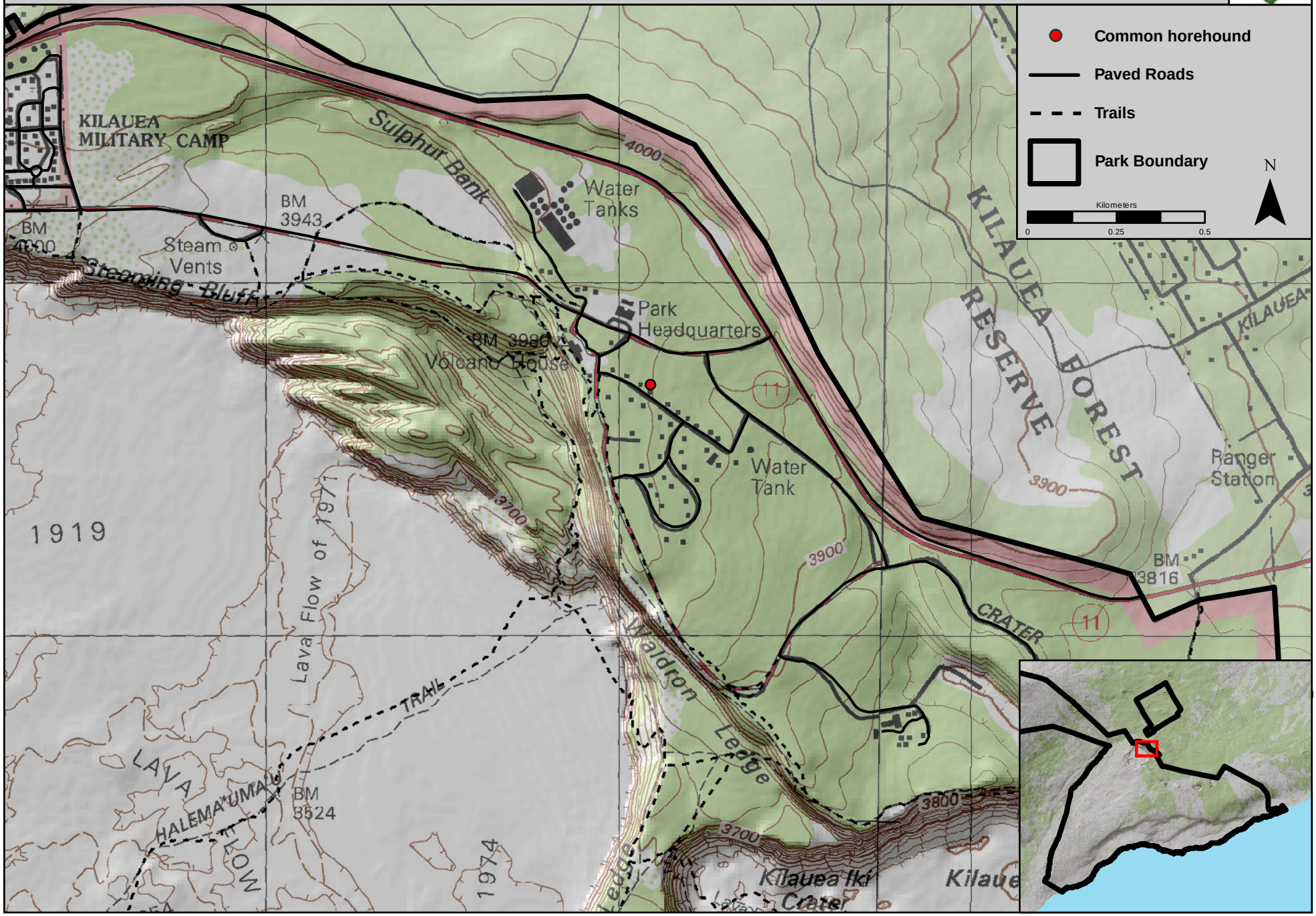
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/13/2011

Common guava (*Psidium guajava*)



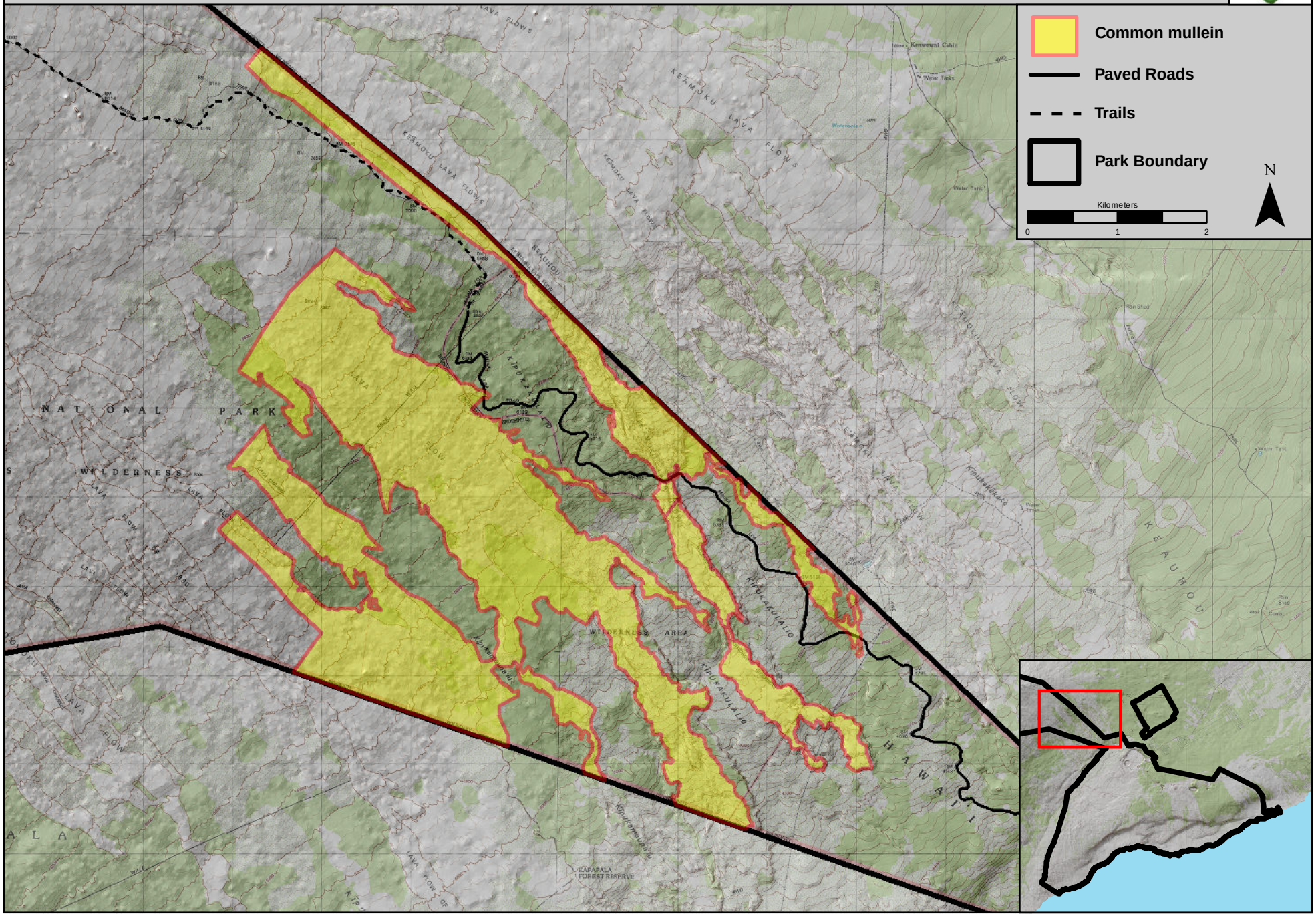
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/23/2011

Common horehound (*Marrubium vulgare*)



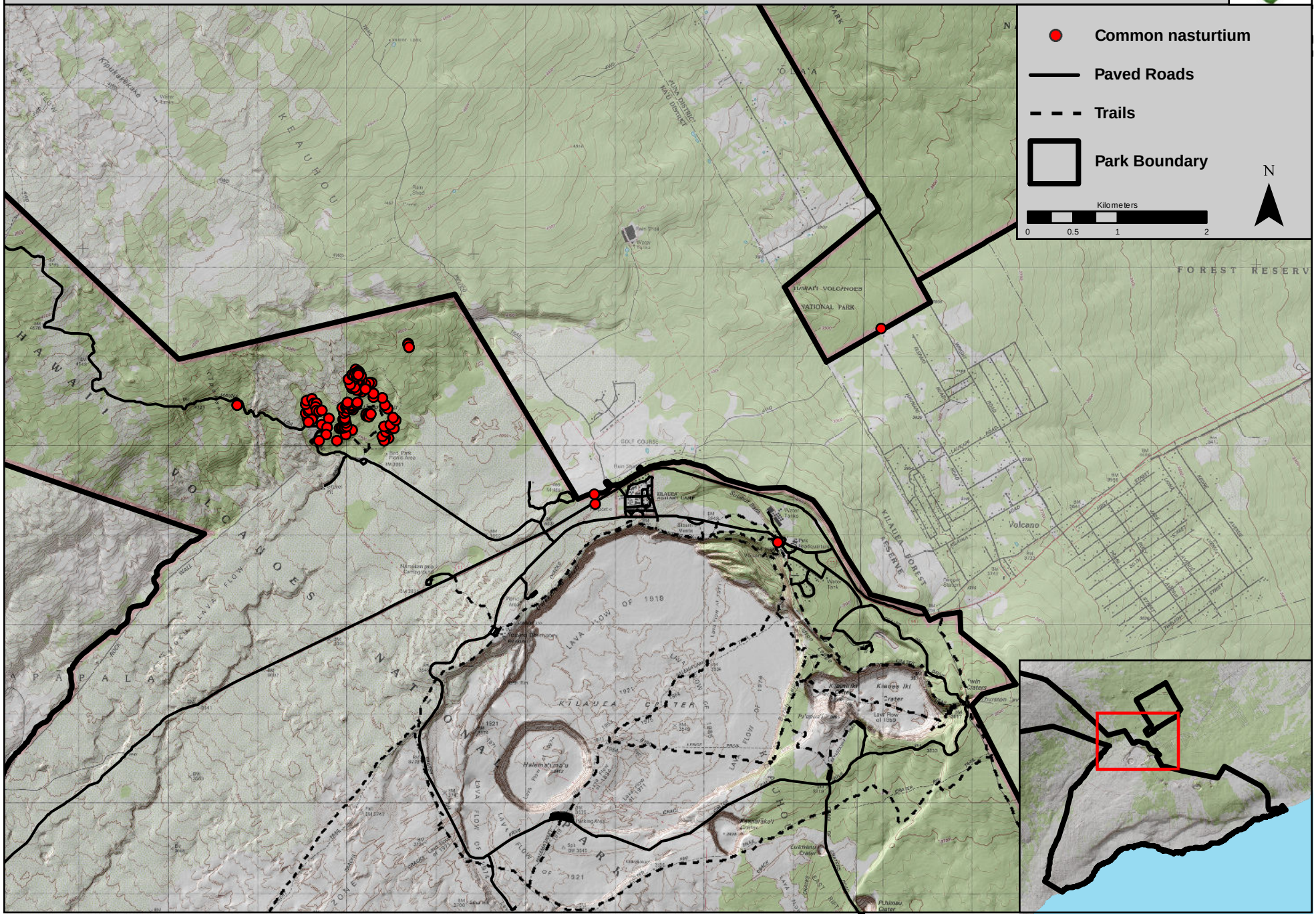
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Common mullein (*Verbascum thapsus*)



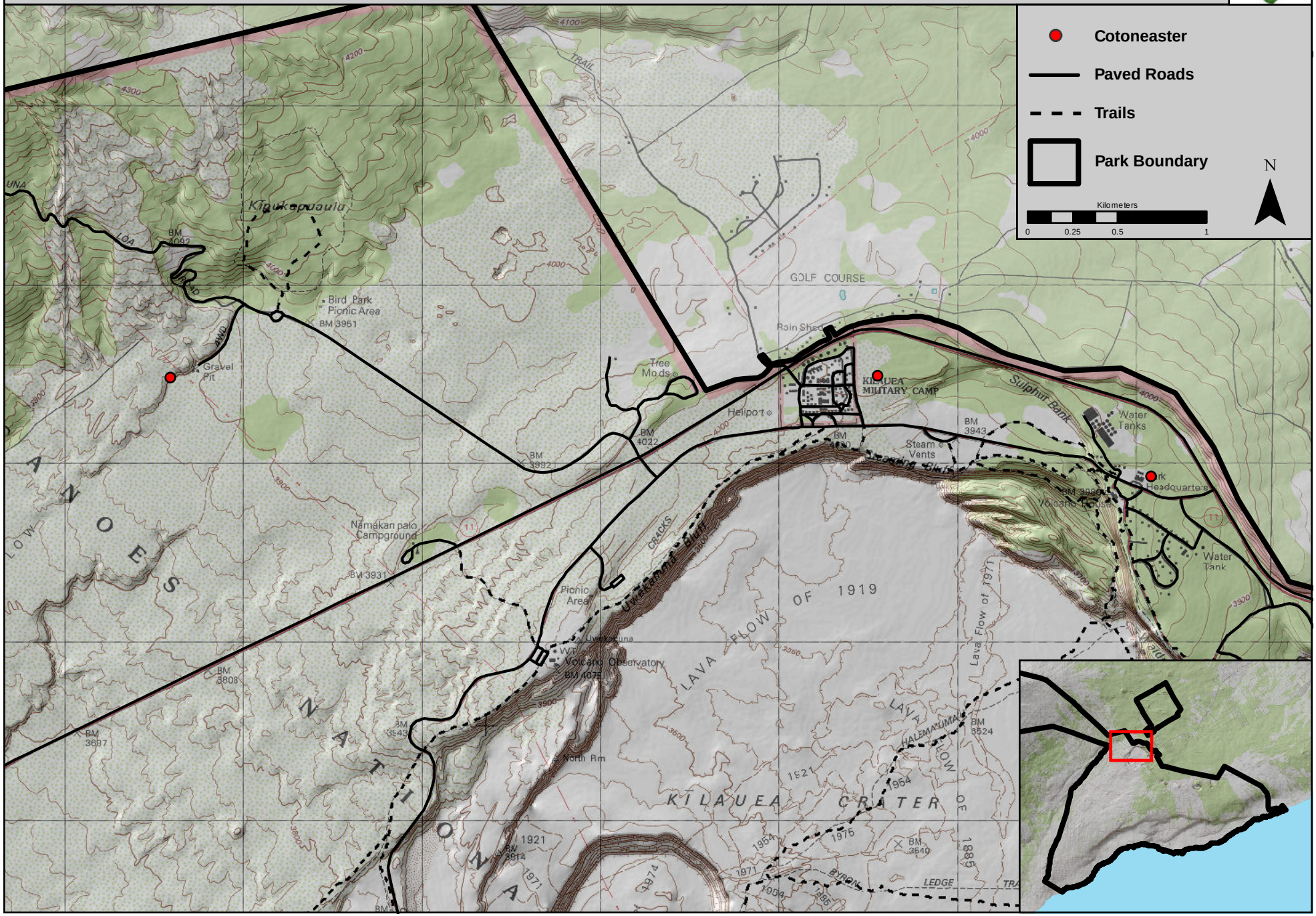
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/22/2011

Common nasturtium (*Tropaeolum majus*)



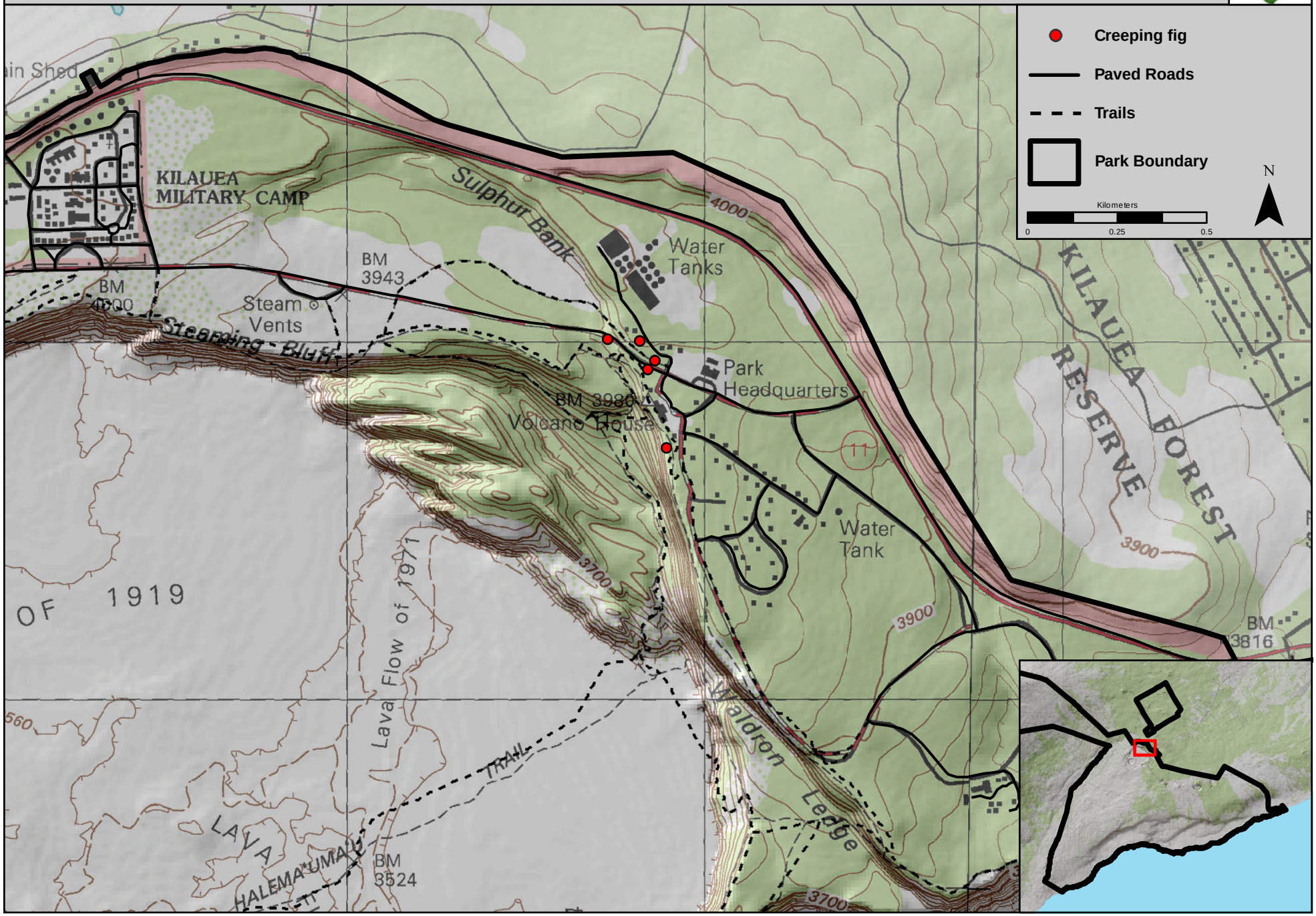
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Cotoneaster (*Cotoneaster pannosa*)



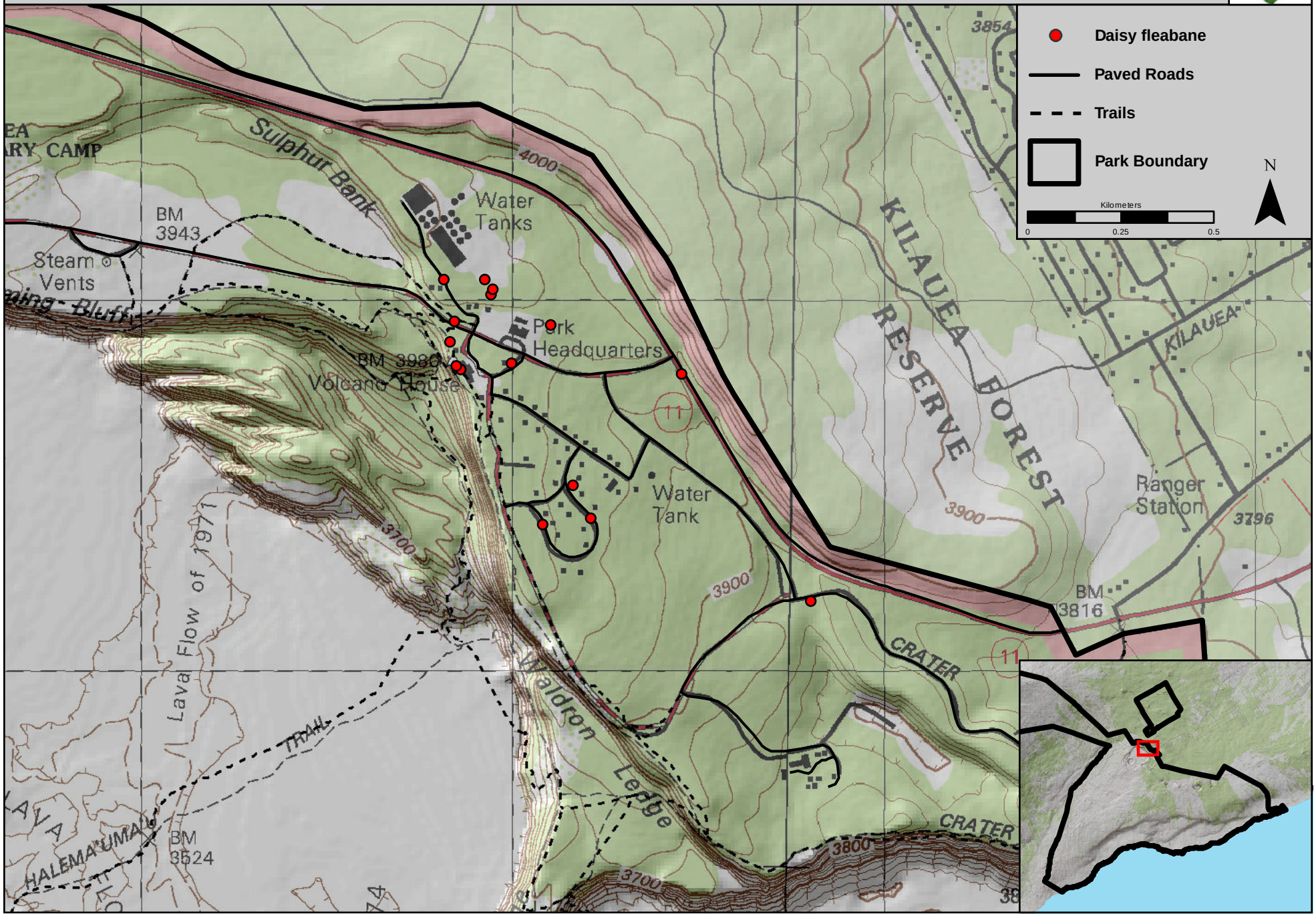
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/13/2011

Creeping fig (*Ficus pumilla*)



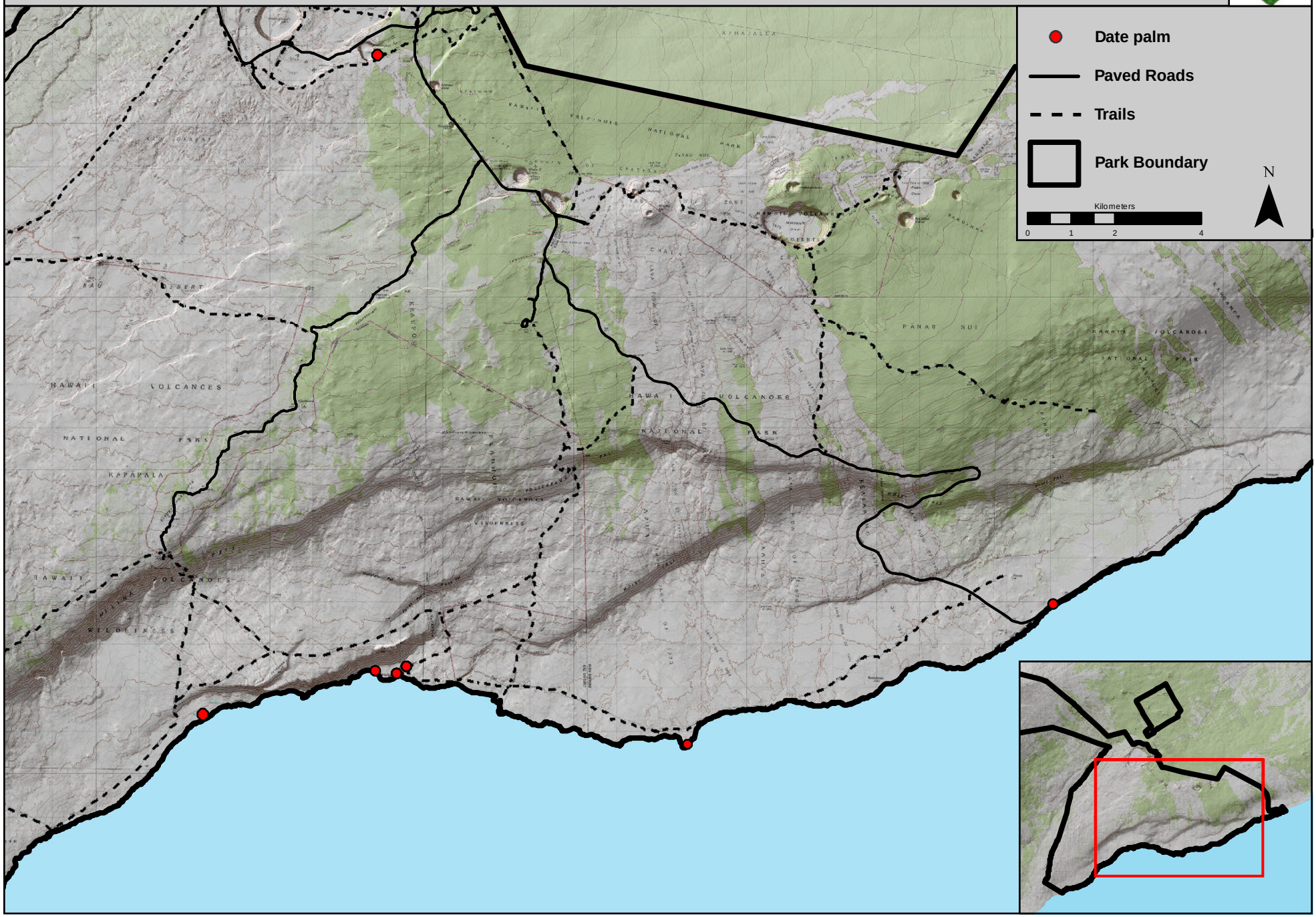
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Daisy fleabane (*Erigeron karvinskianus*)



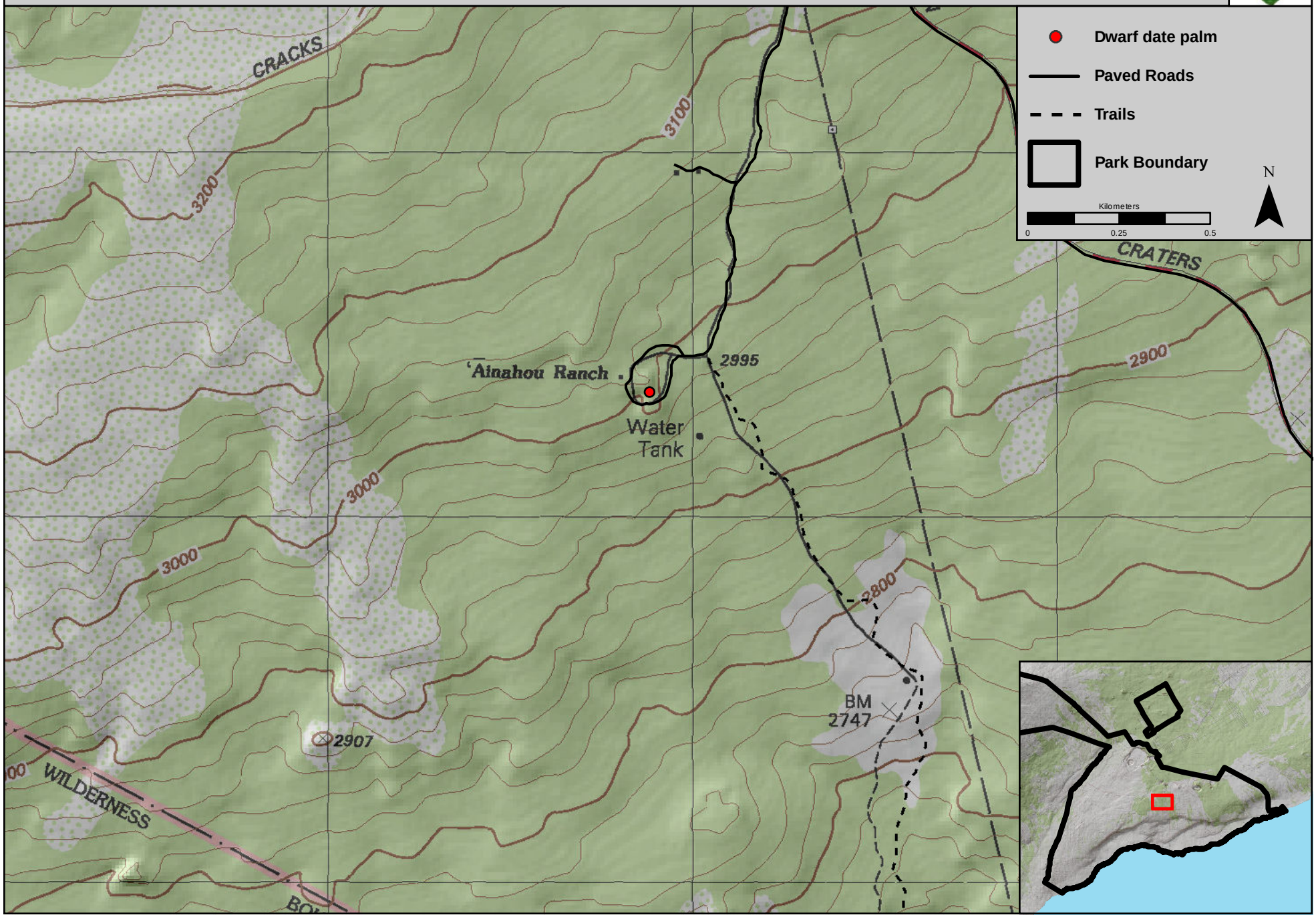
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Date palm (*Phoenix dactylifera*)



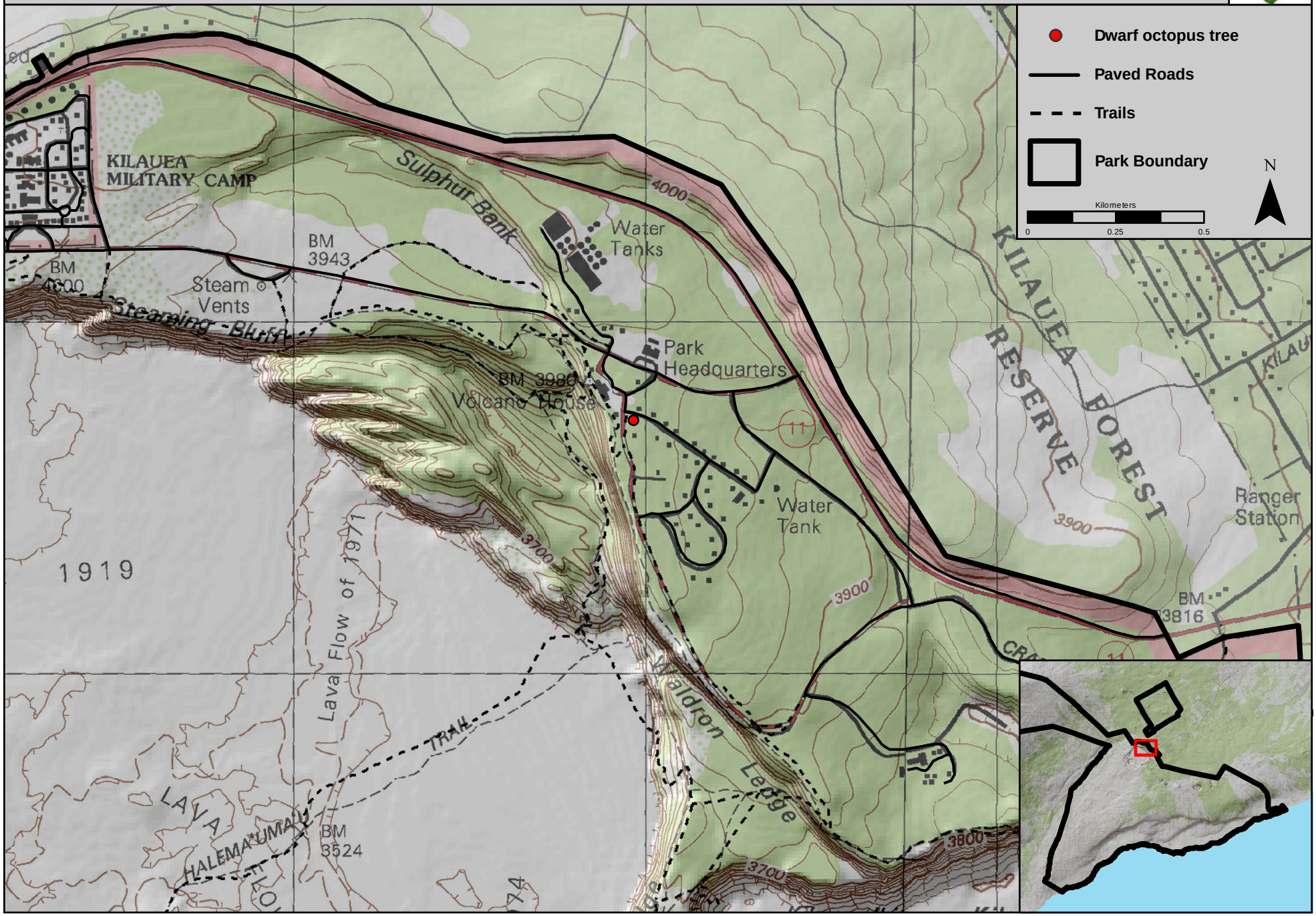
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Dwarf date palm (*Phoenix robelenii*)



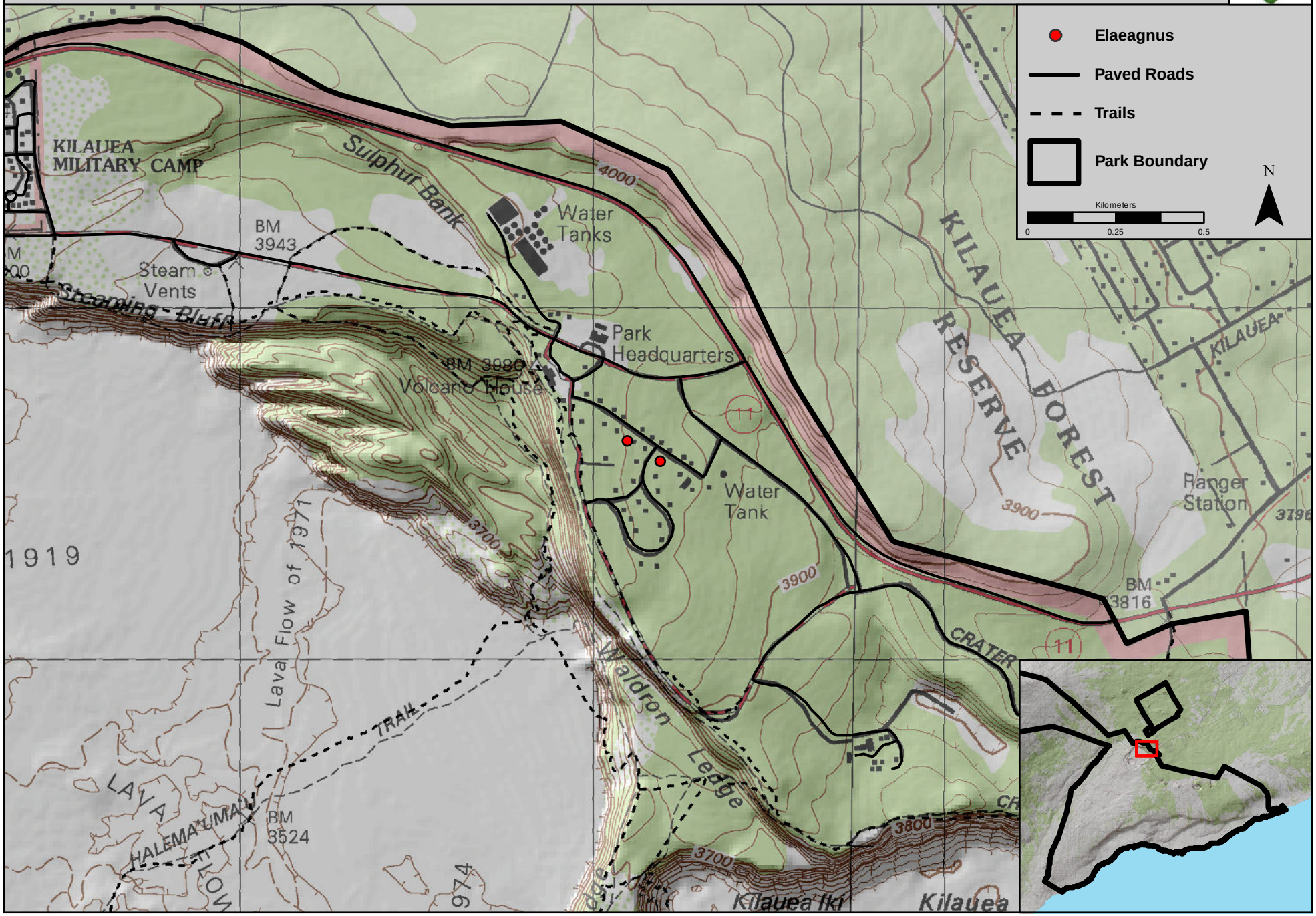
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Dwarf octopus tree (*Schefflera arboricola*)



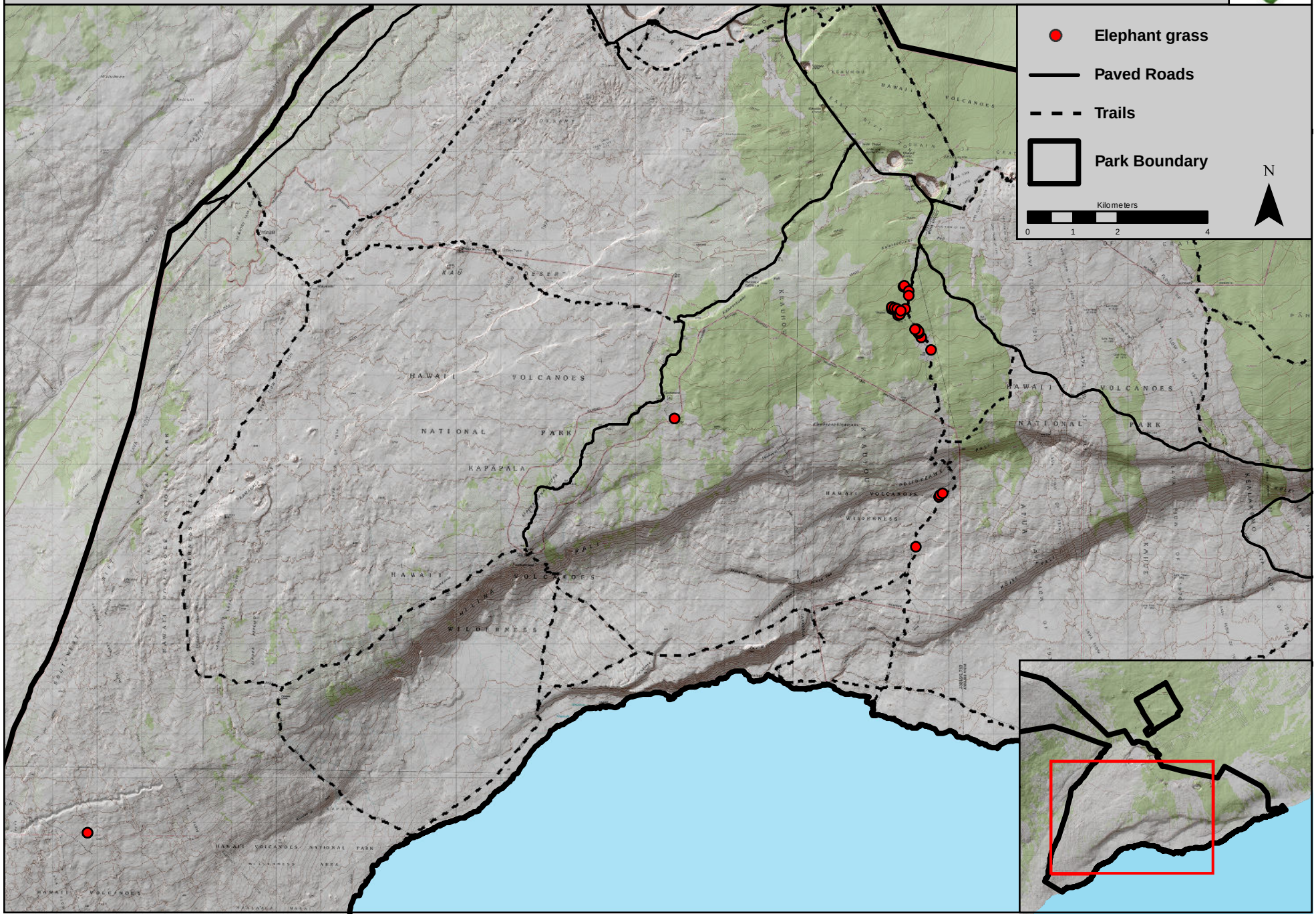
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Elaeagnus (*Eleagnus umbellata*)



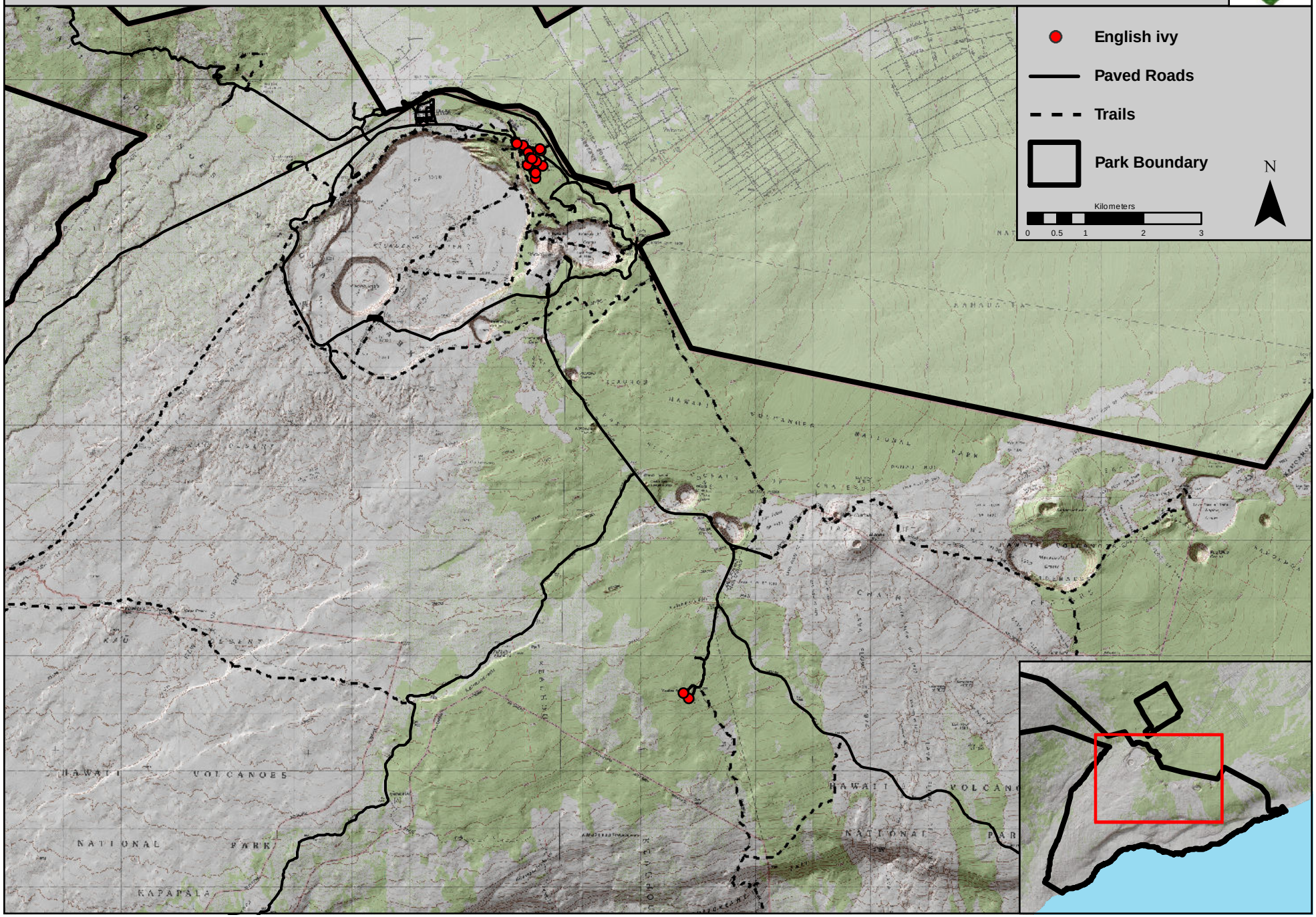
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Elephant grass (*Pennisetum purpureum*)



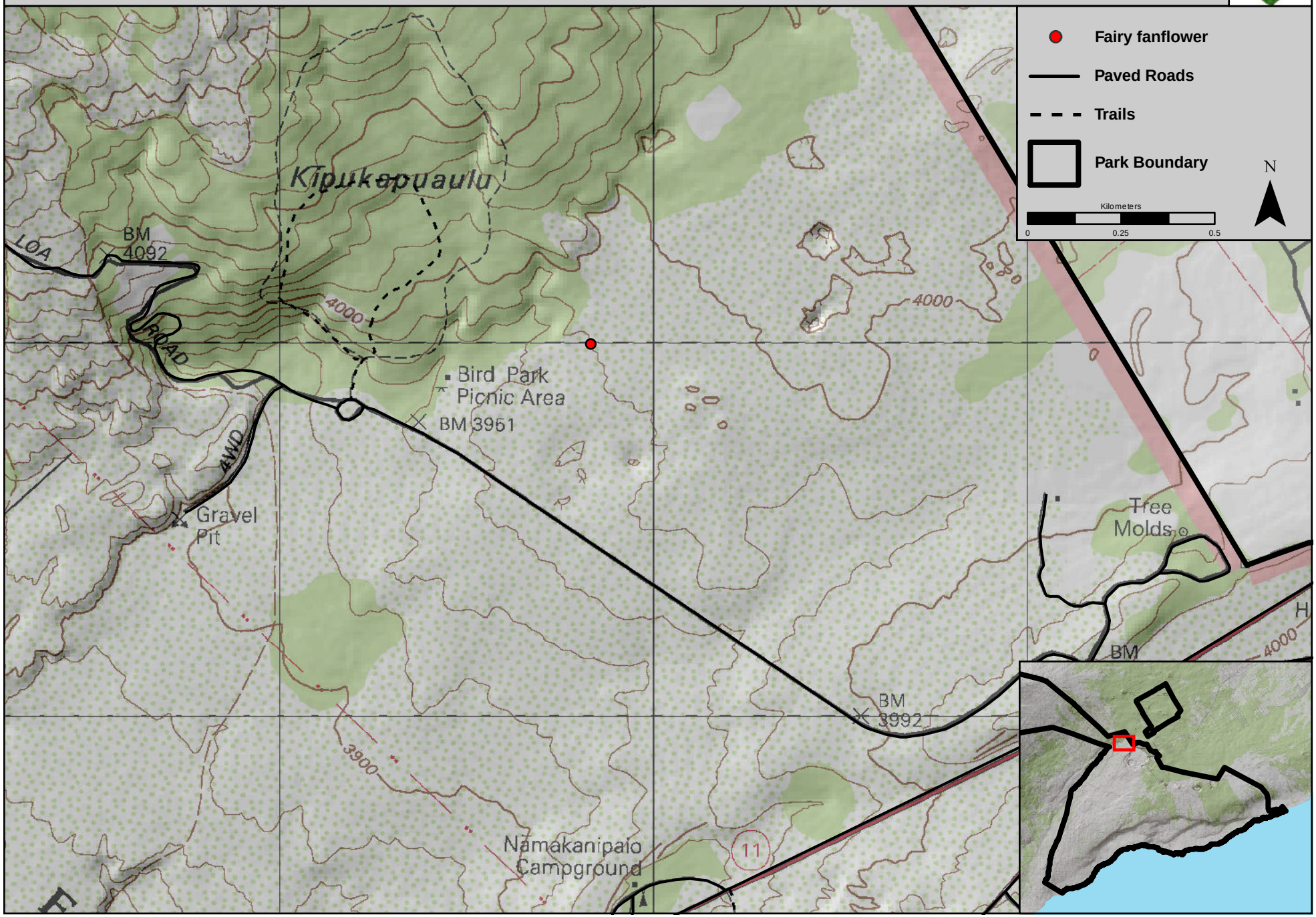
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

English ivy (*Hedera helix*)



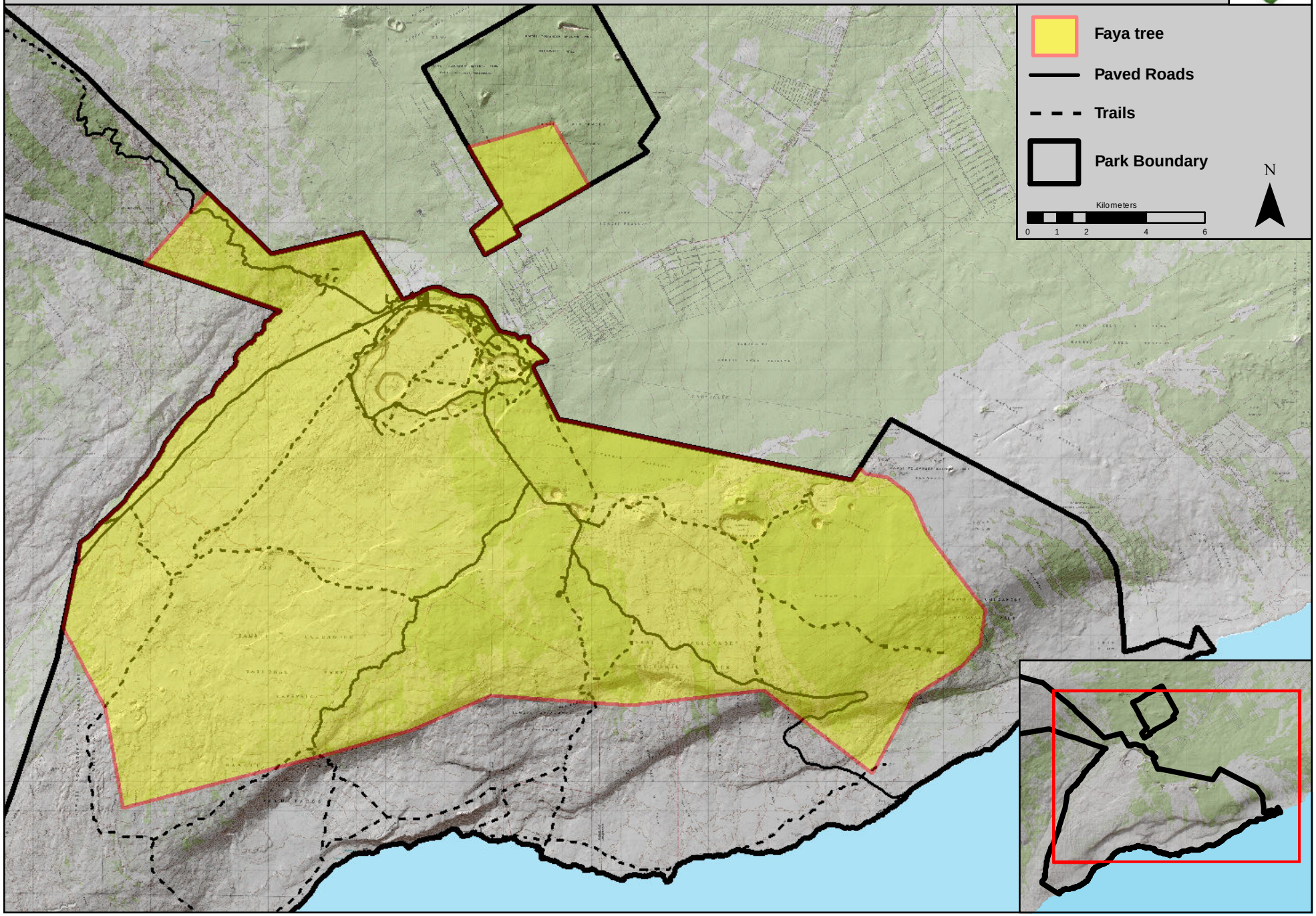
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Fairy fanflower (*Scaevola cf. aemula*)



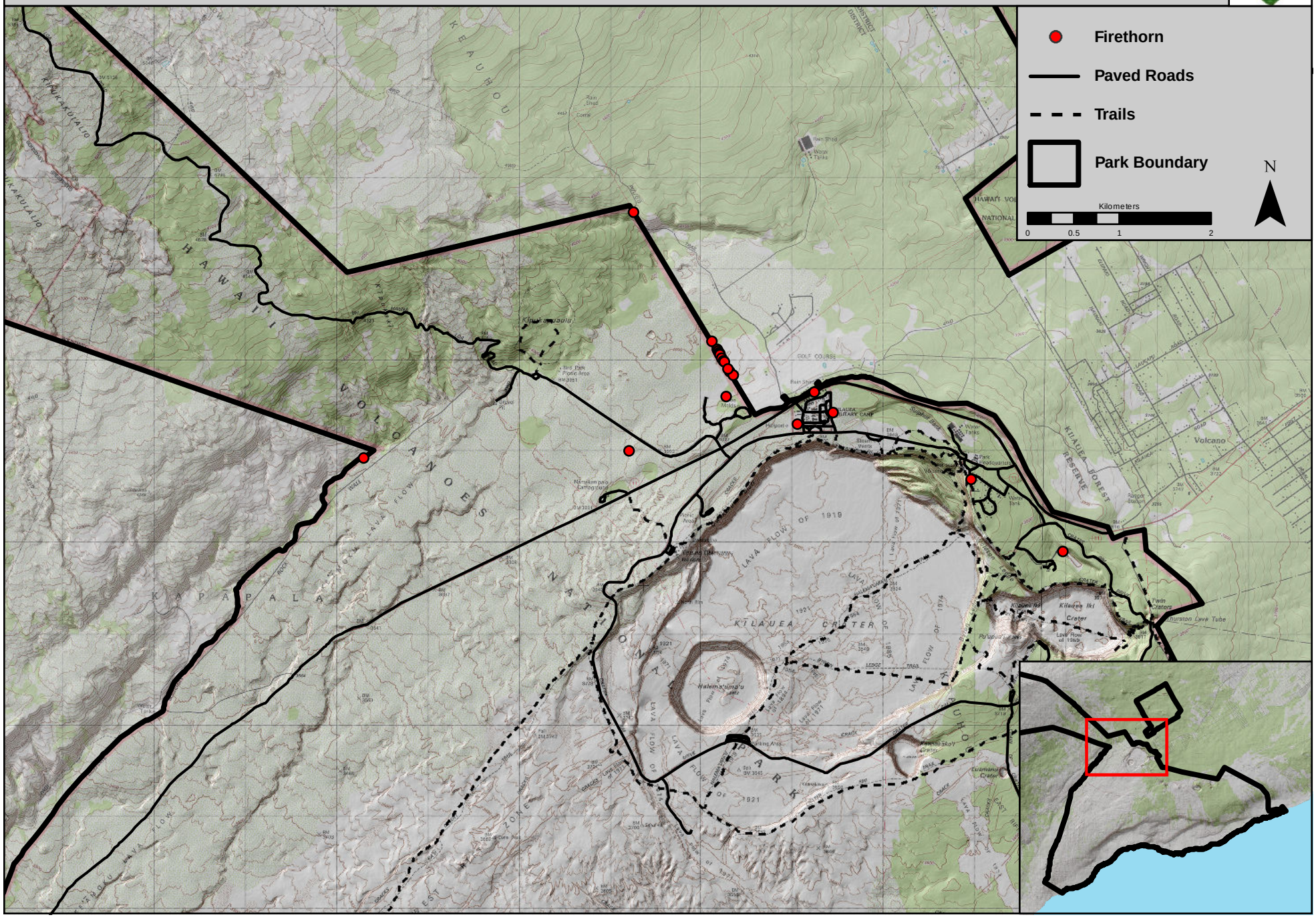
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Faya tree (*Morella faya*)



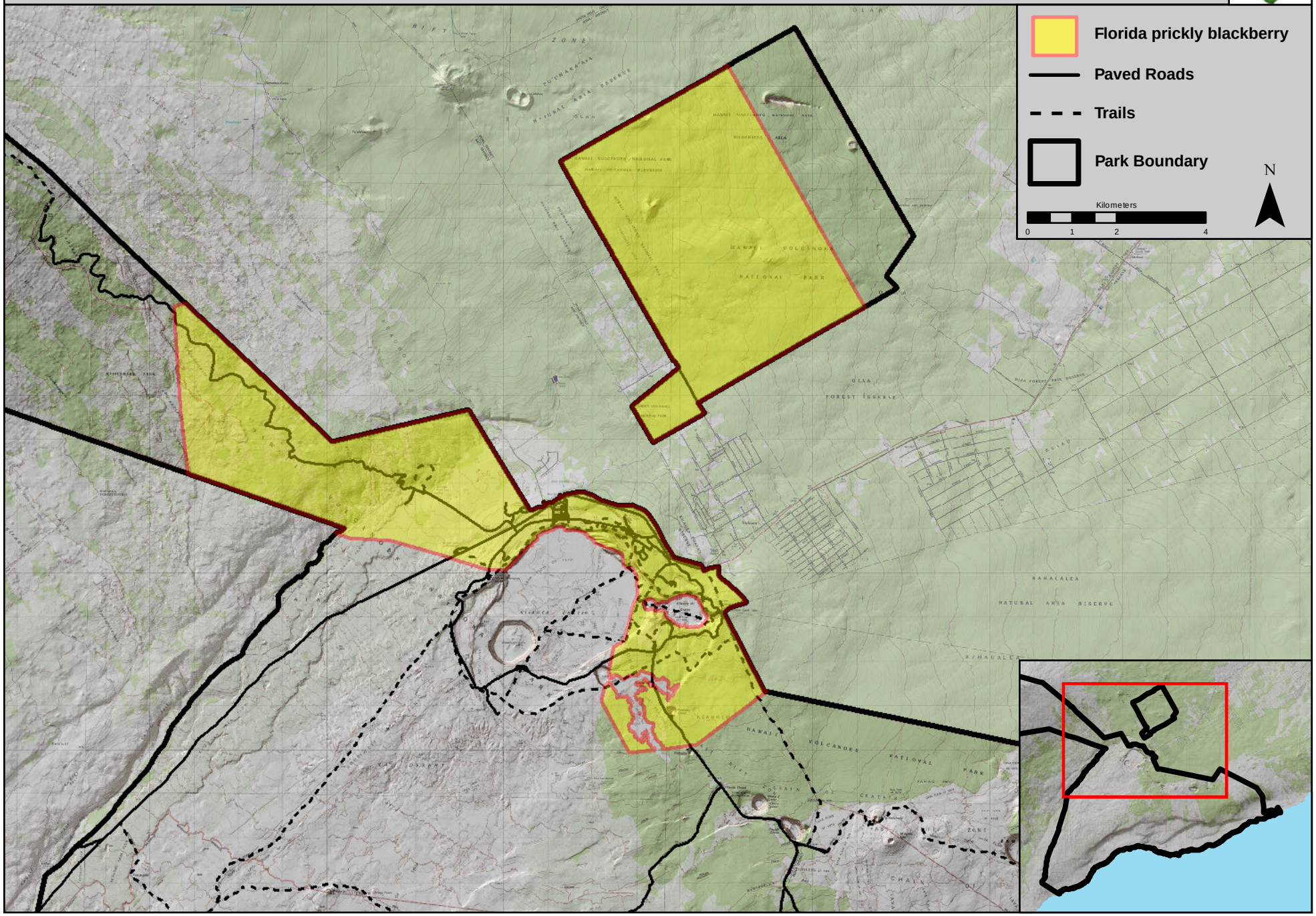
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/23/2011

Firethorn (*Pyracantha koidzumii*)



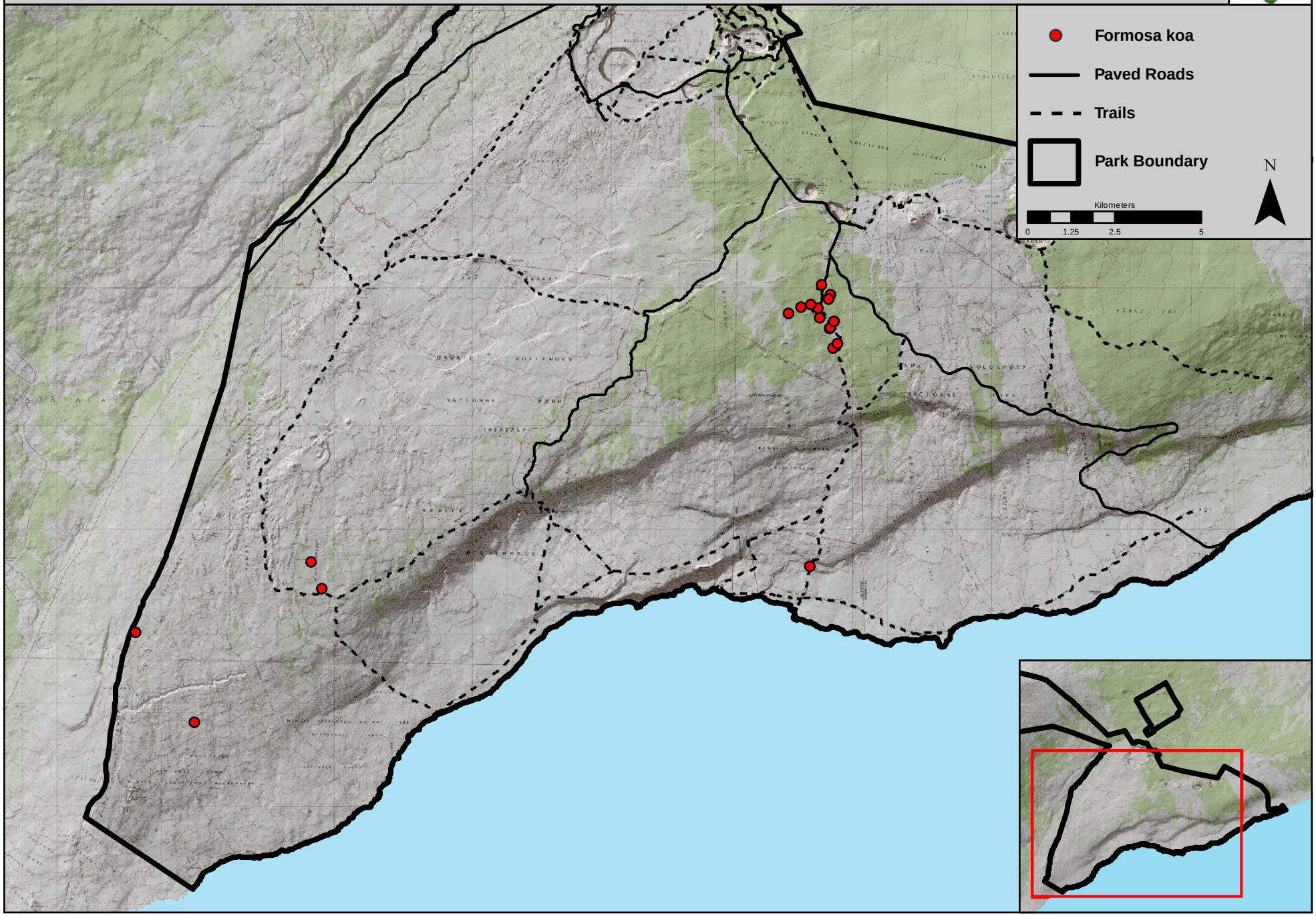
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/13/2011

Florida prickly blackberry (*Rubus argutus*)



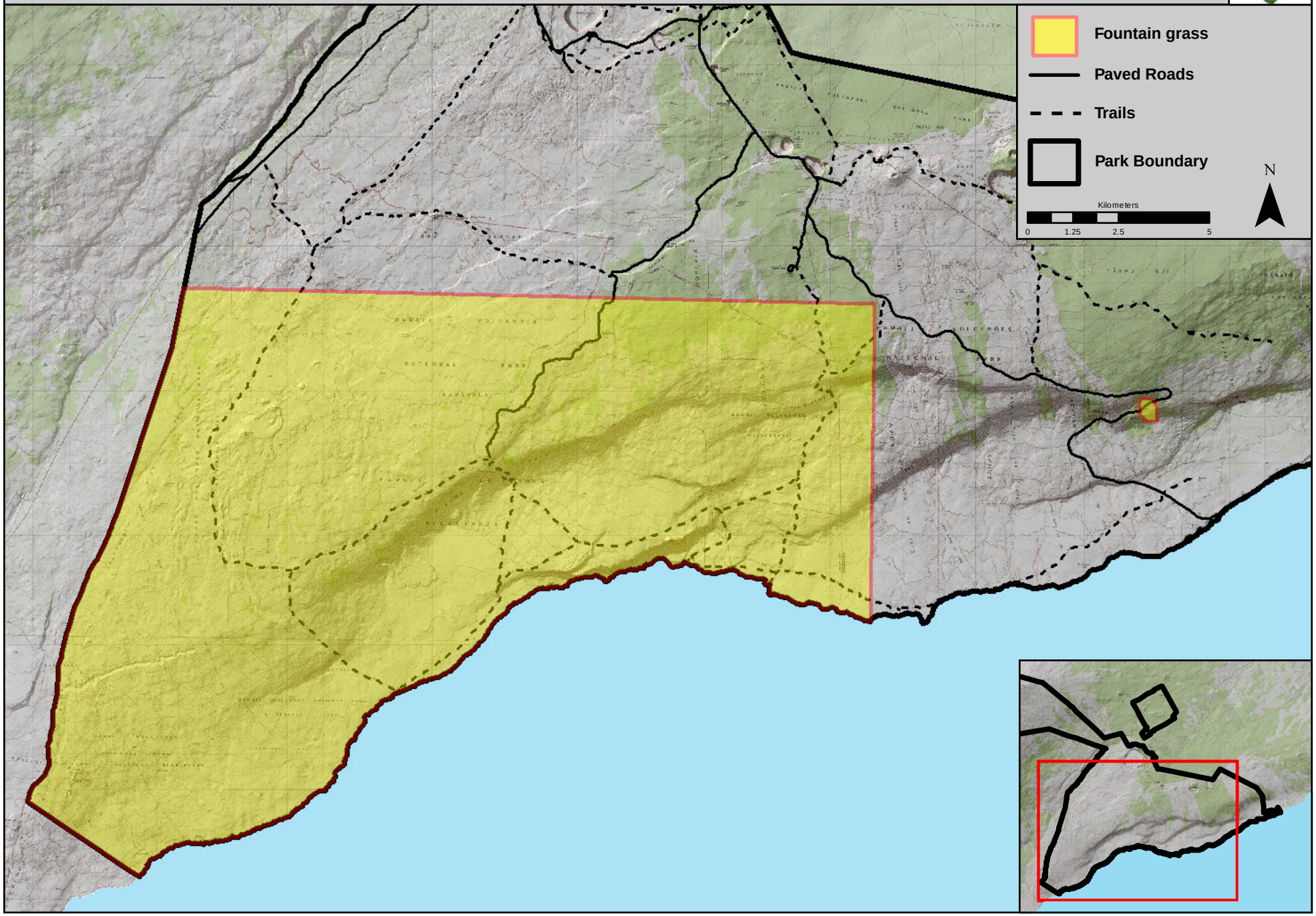
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/23/2011

Formosa koa (*Acacia confusa*)



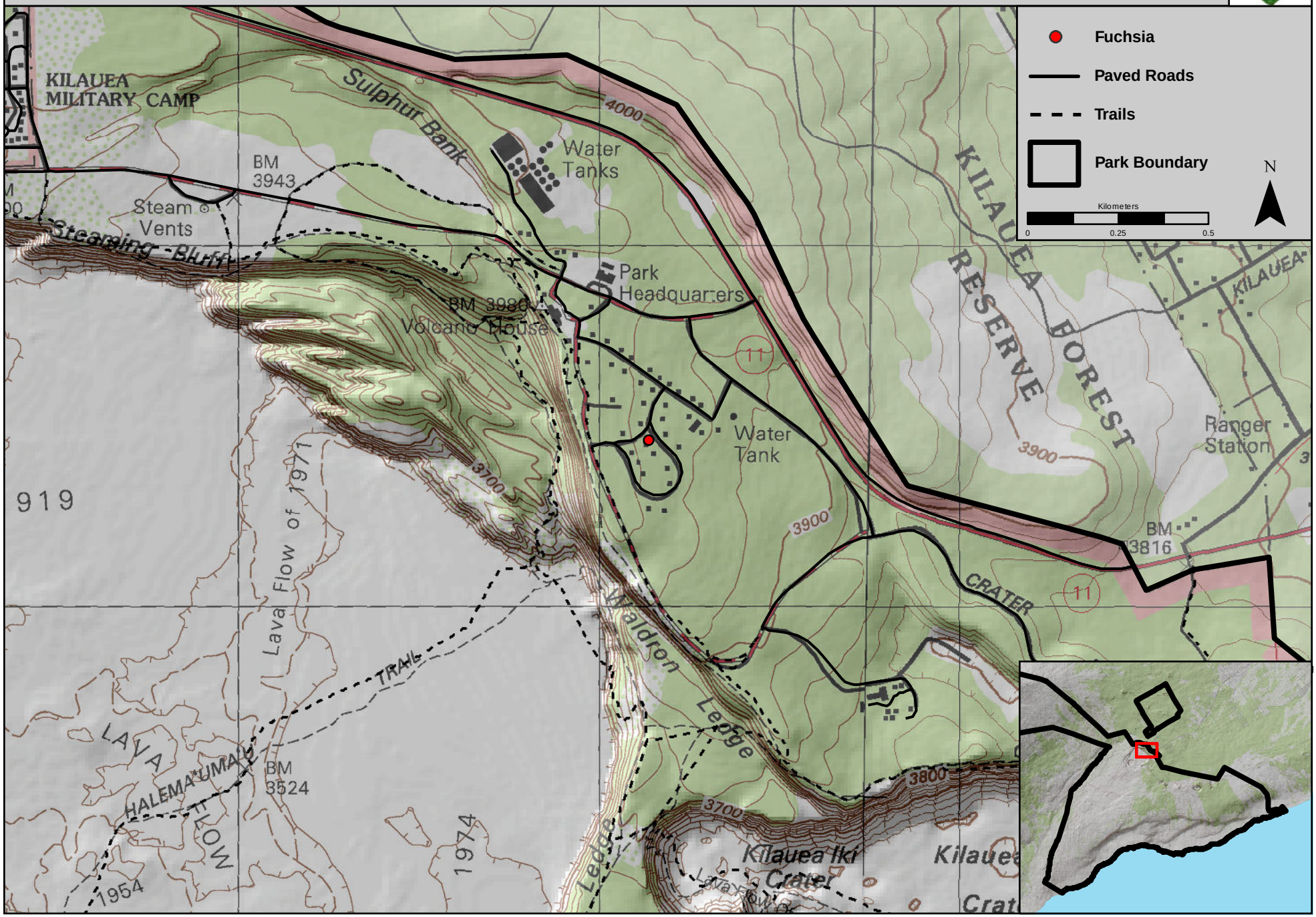
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Fountain grass (*Pennisetum setaceum*)



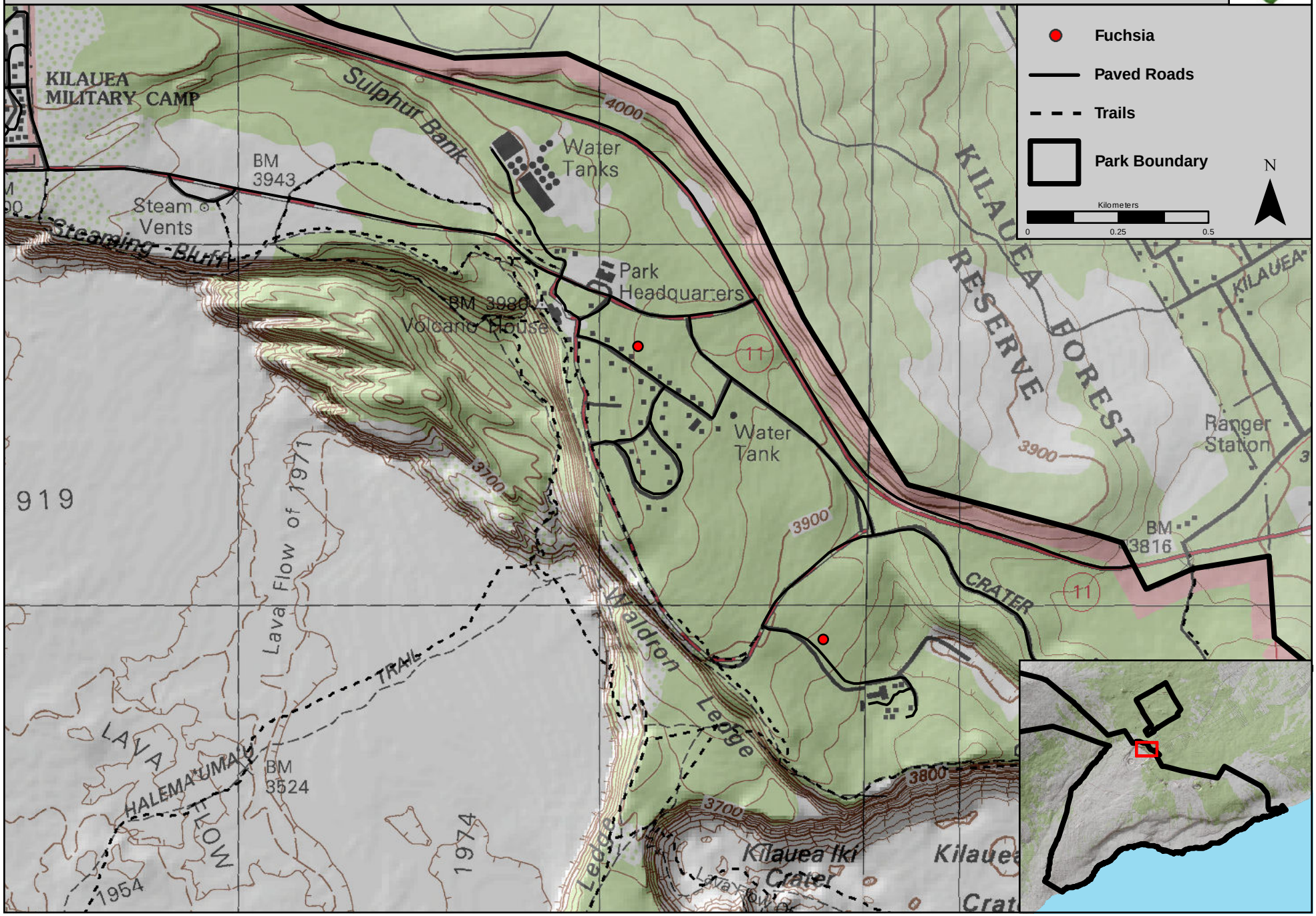
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/23/2011

Fuchsia (*Fuchsia hybrida*)



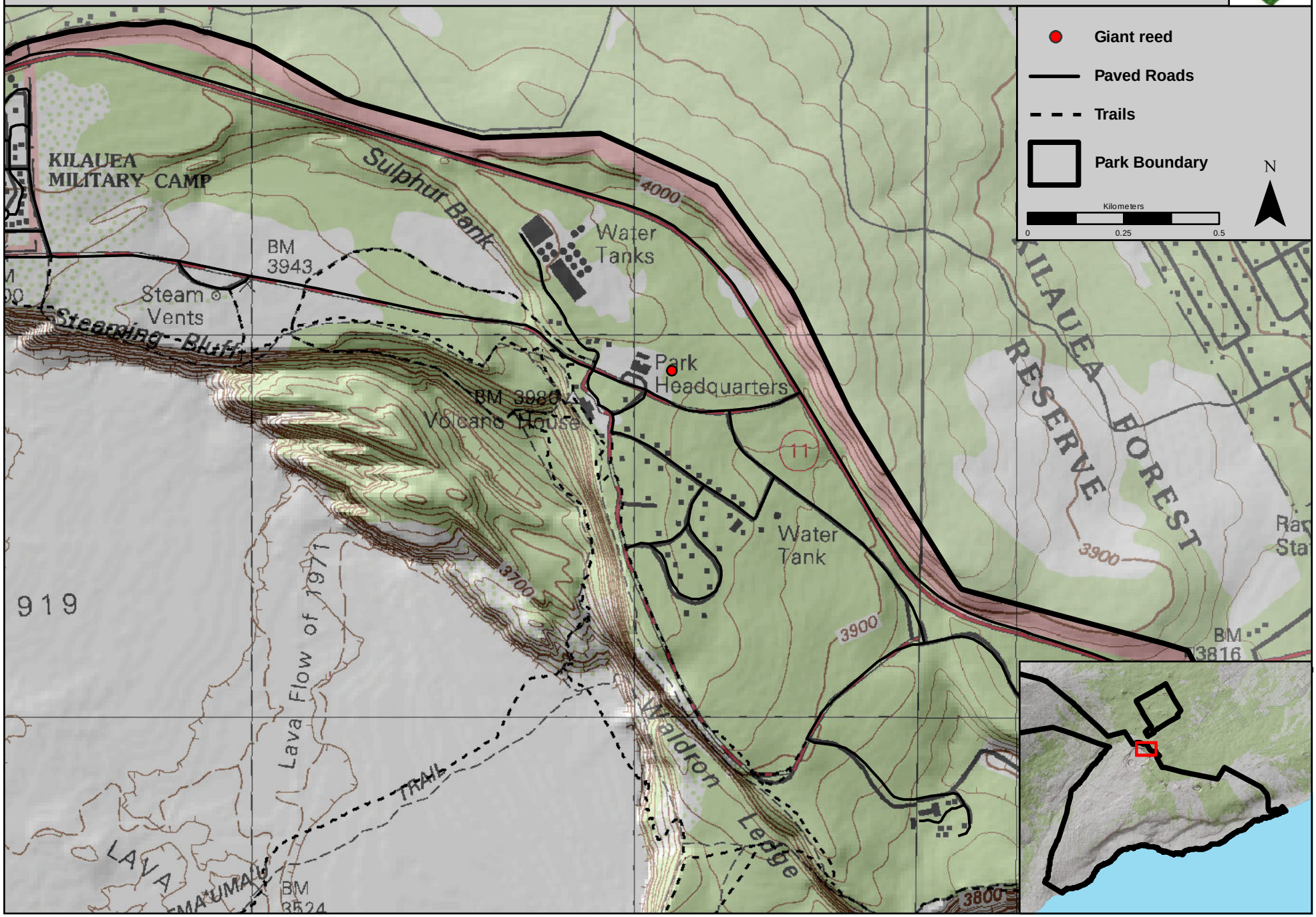
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Fuchsia (*Fucshia paniculata*)



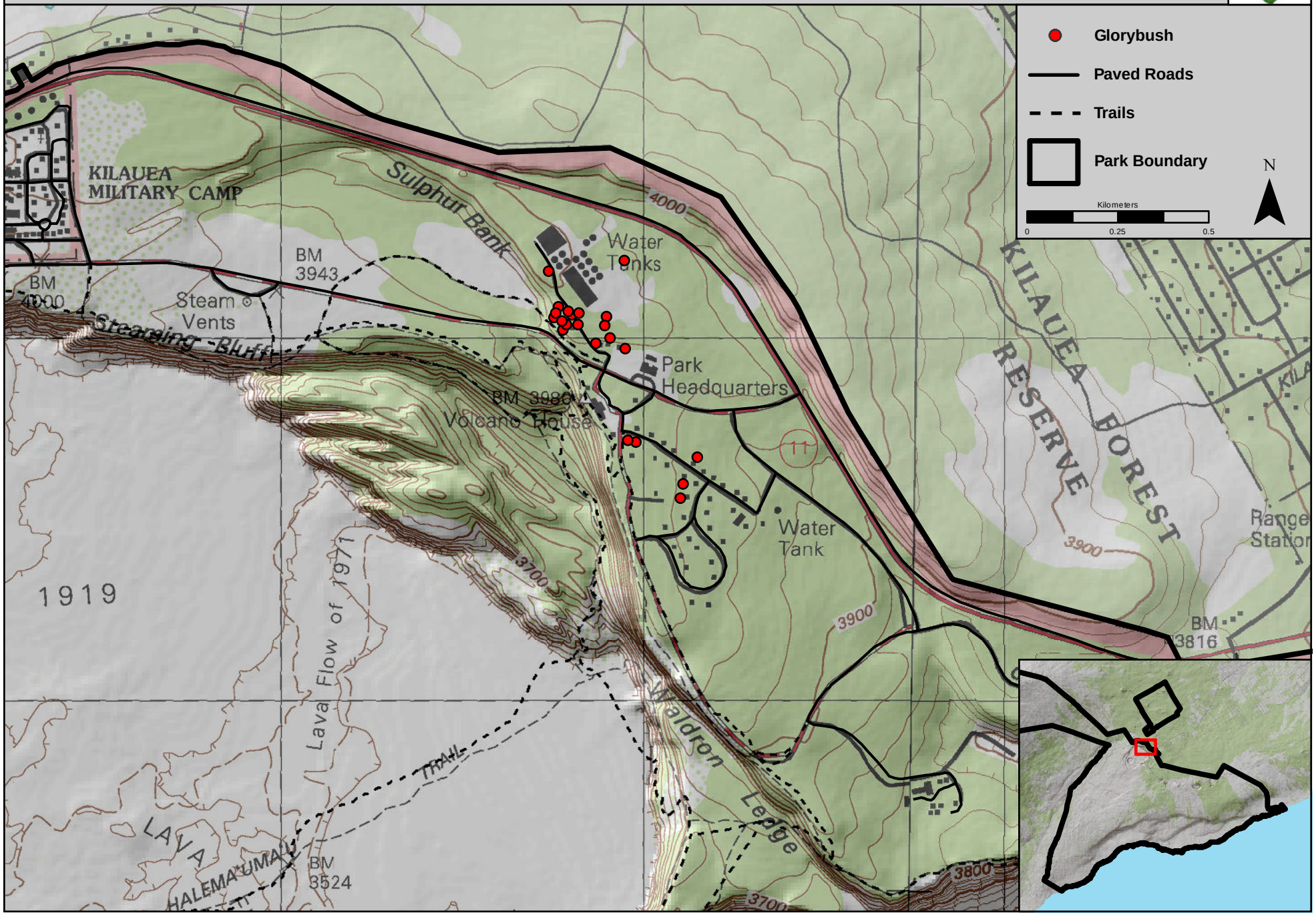
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/201

Giant reed (*Arundo donax*)



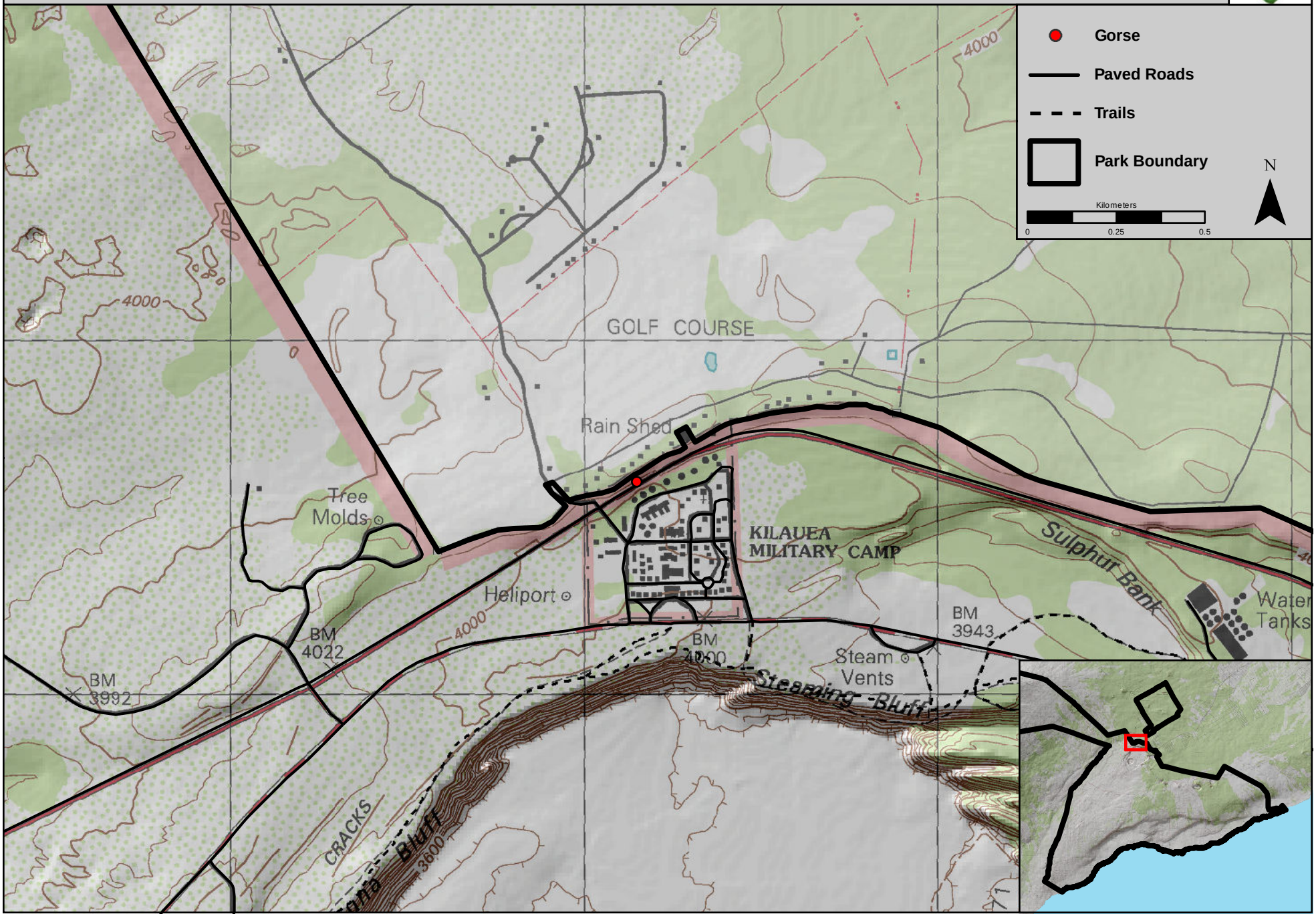
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/10/2011

Glorybush (*Tibouchina urvilleana*)



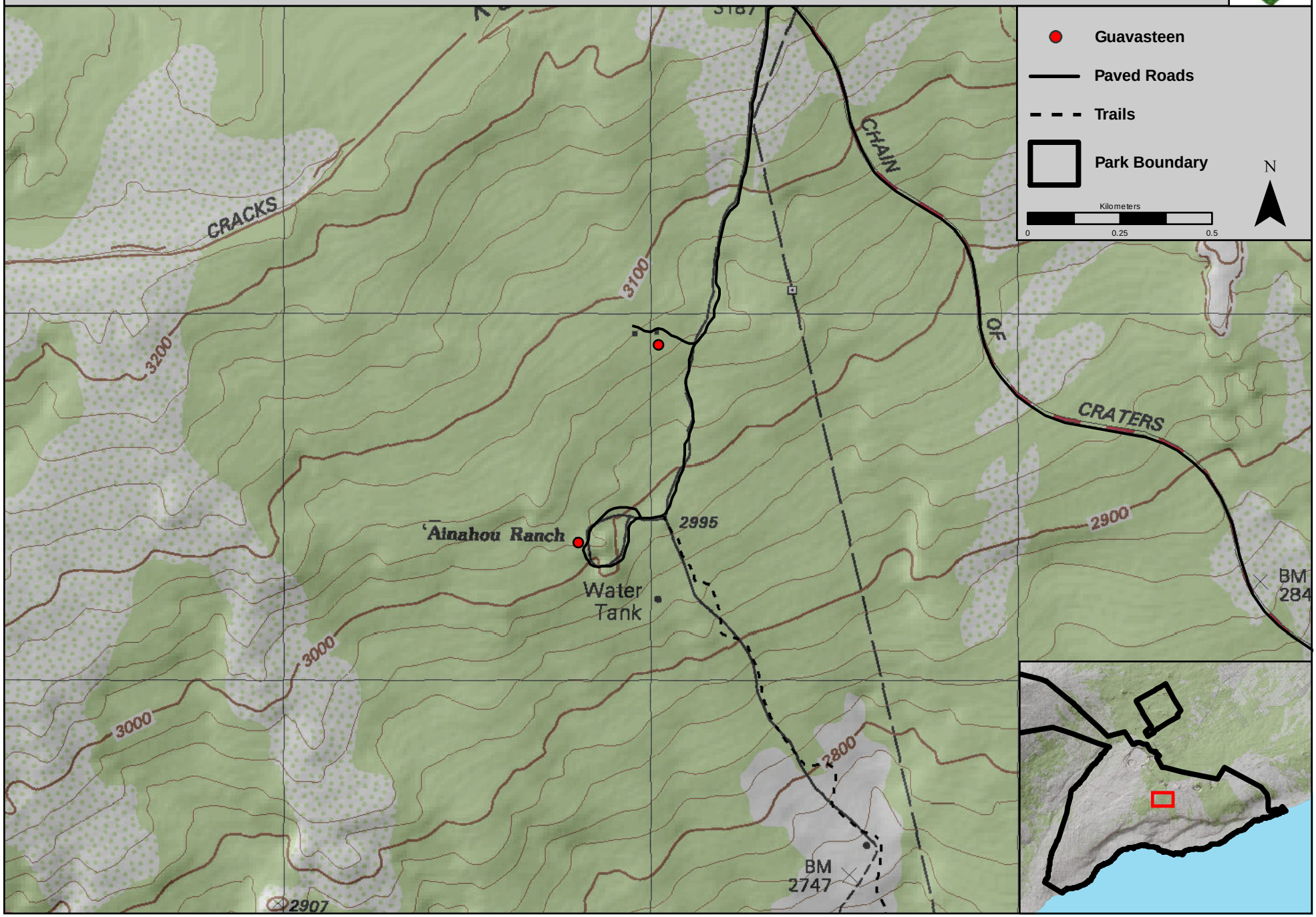
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Gorse (*Ulex europaeus*)



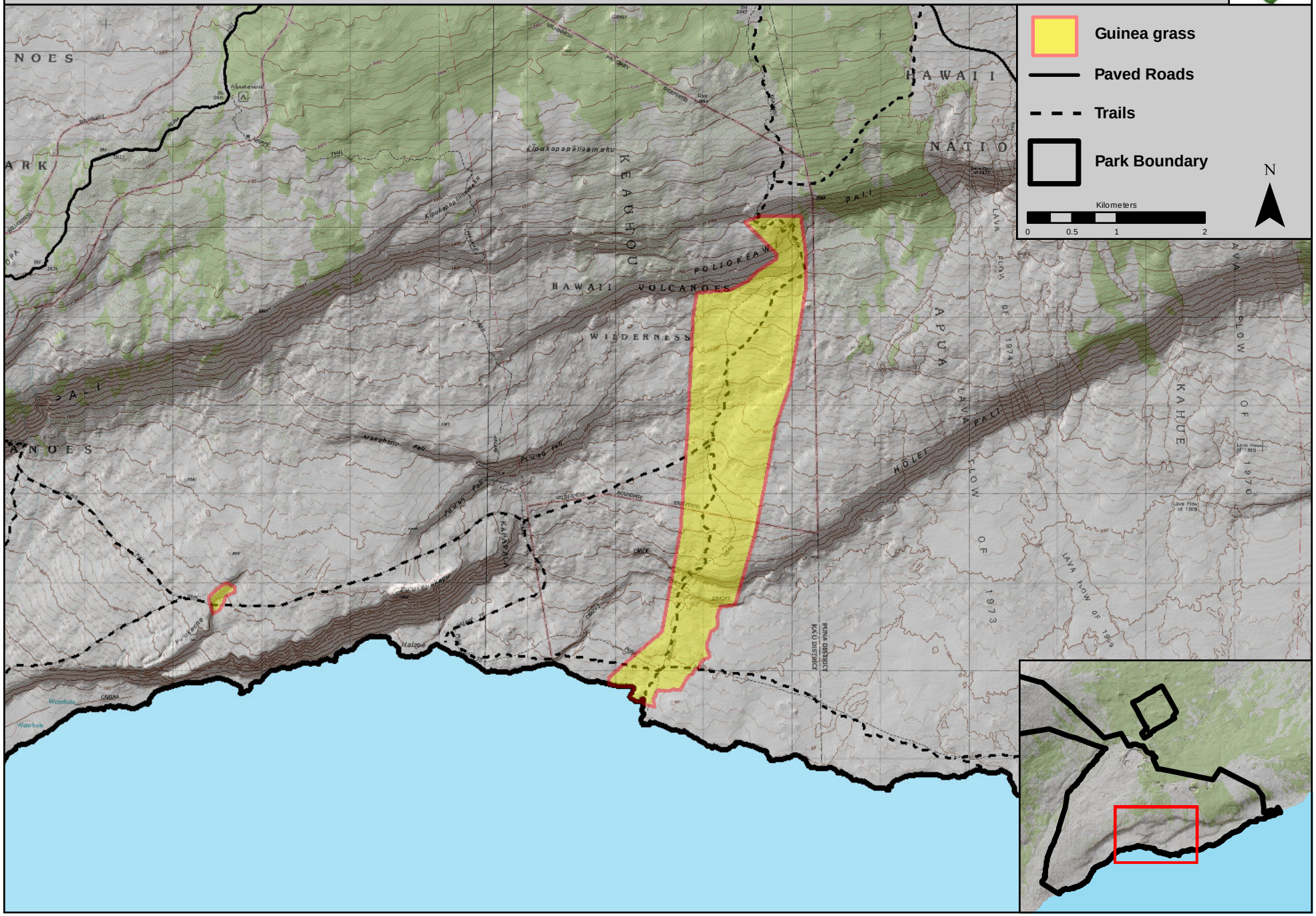
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Guavasteen (*Acca sellowiana*)



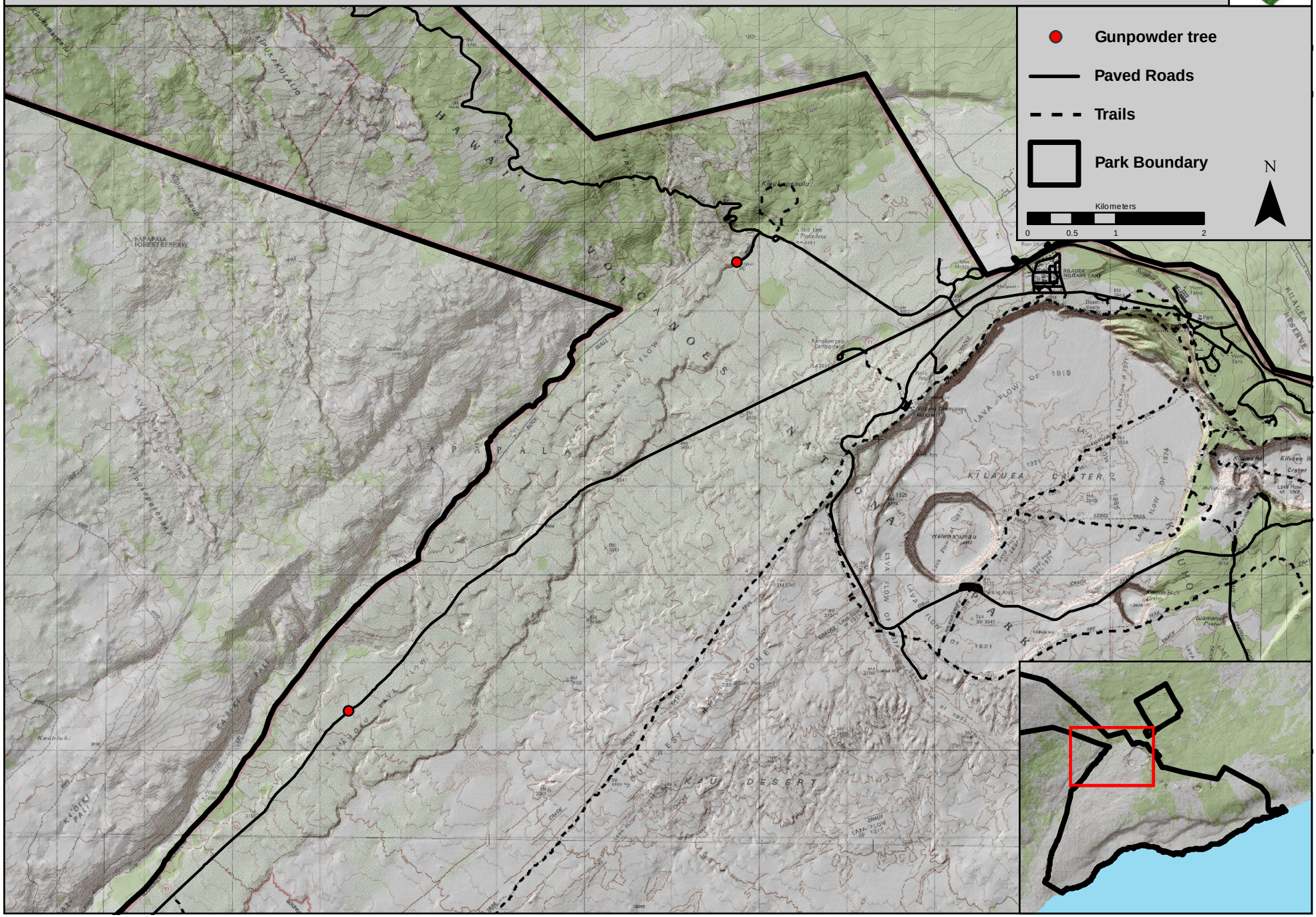
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/13/2011

Guinea grass (*Panicum maximum*)



Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/23/2011

Gunpowder tree (*Trema orientalis*)

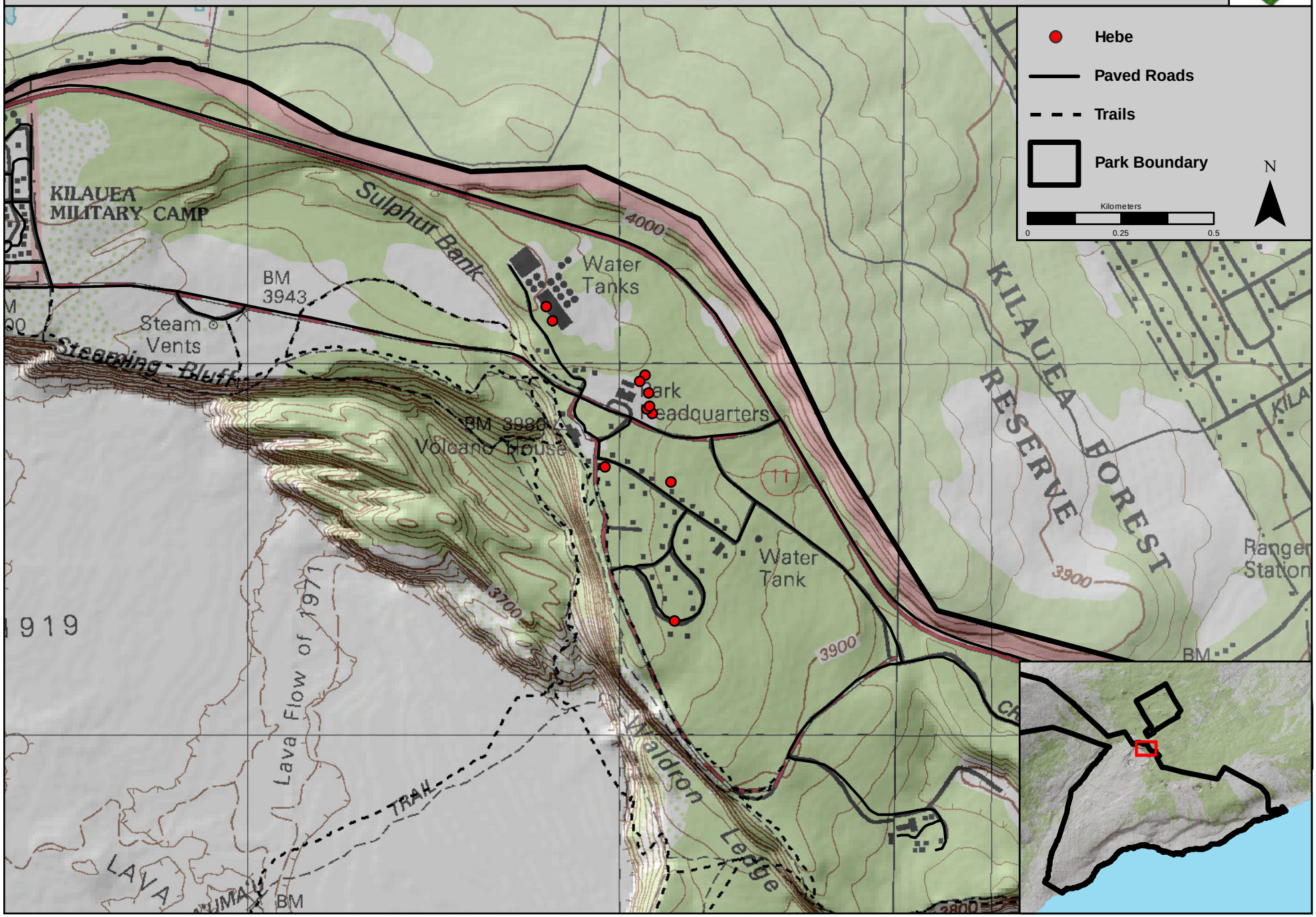


Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Hardy fuchsia (*Fuchsia magellanica*)

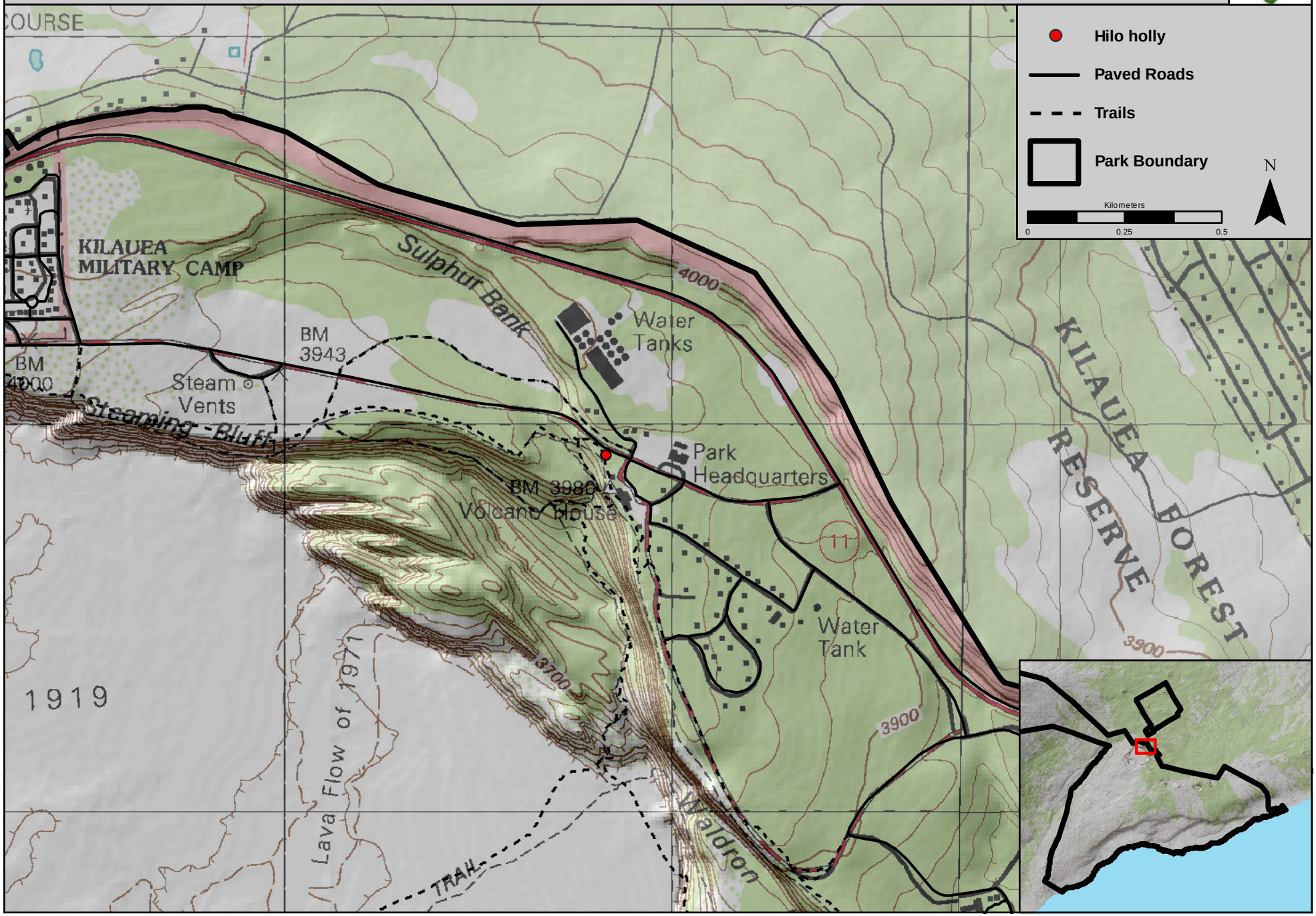
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/13/2011

Hebe (*Hebe speciosa*)



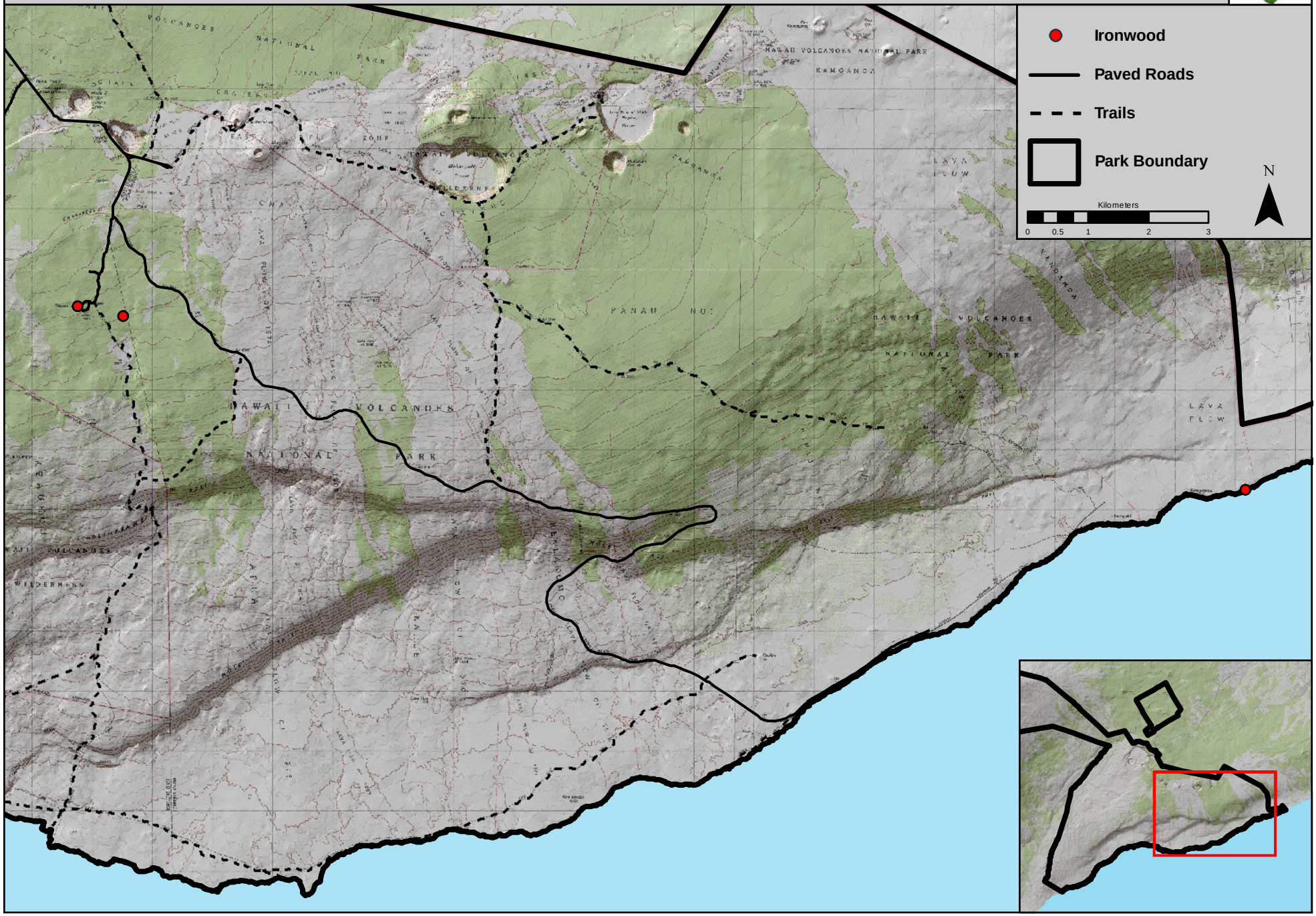
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/13/2011

Hilo holly (*Ardisia crenata*)



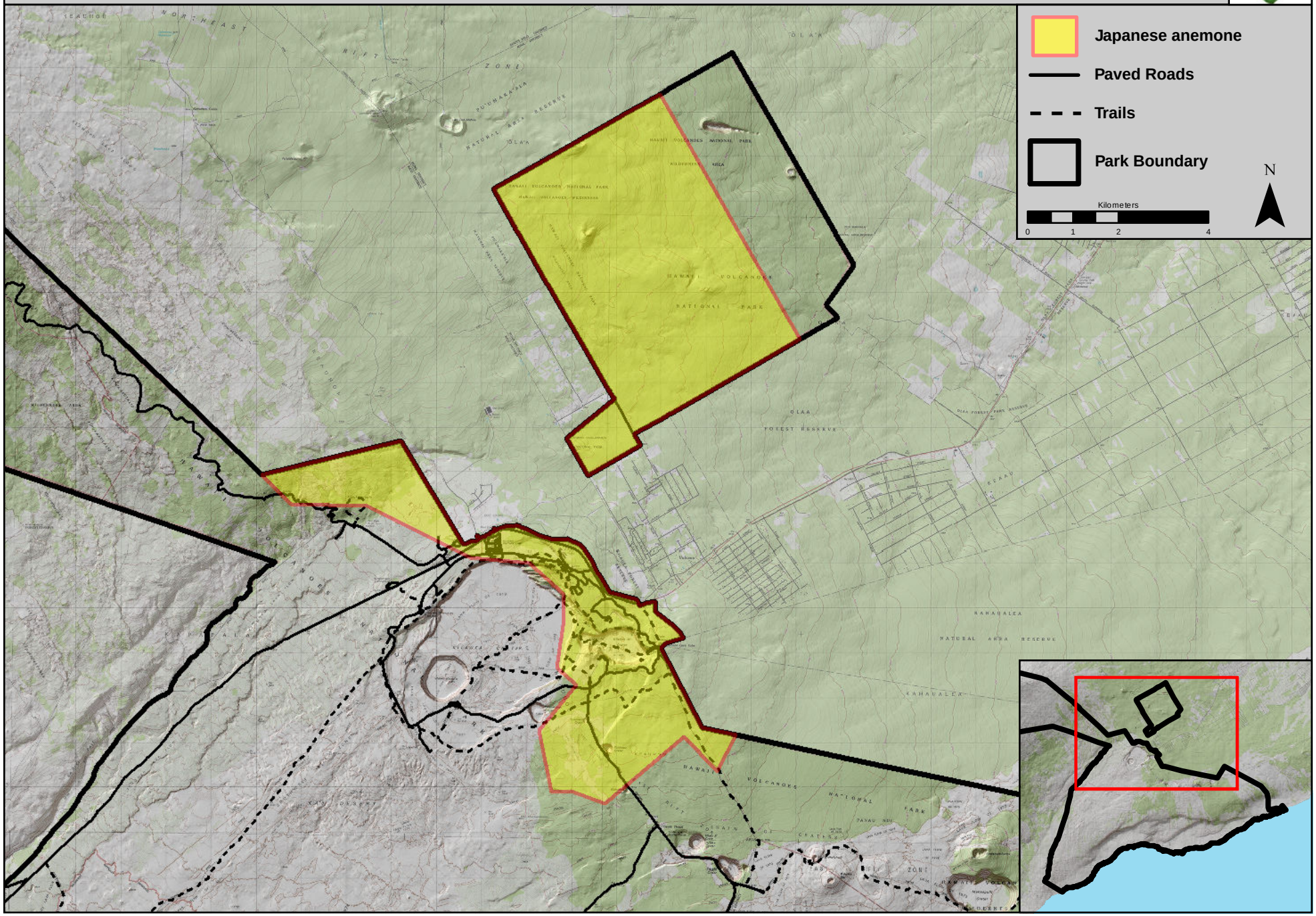
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/13/2011

Ironwood (*Casuarina equisetifolia*)



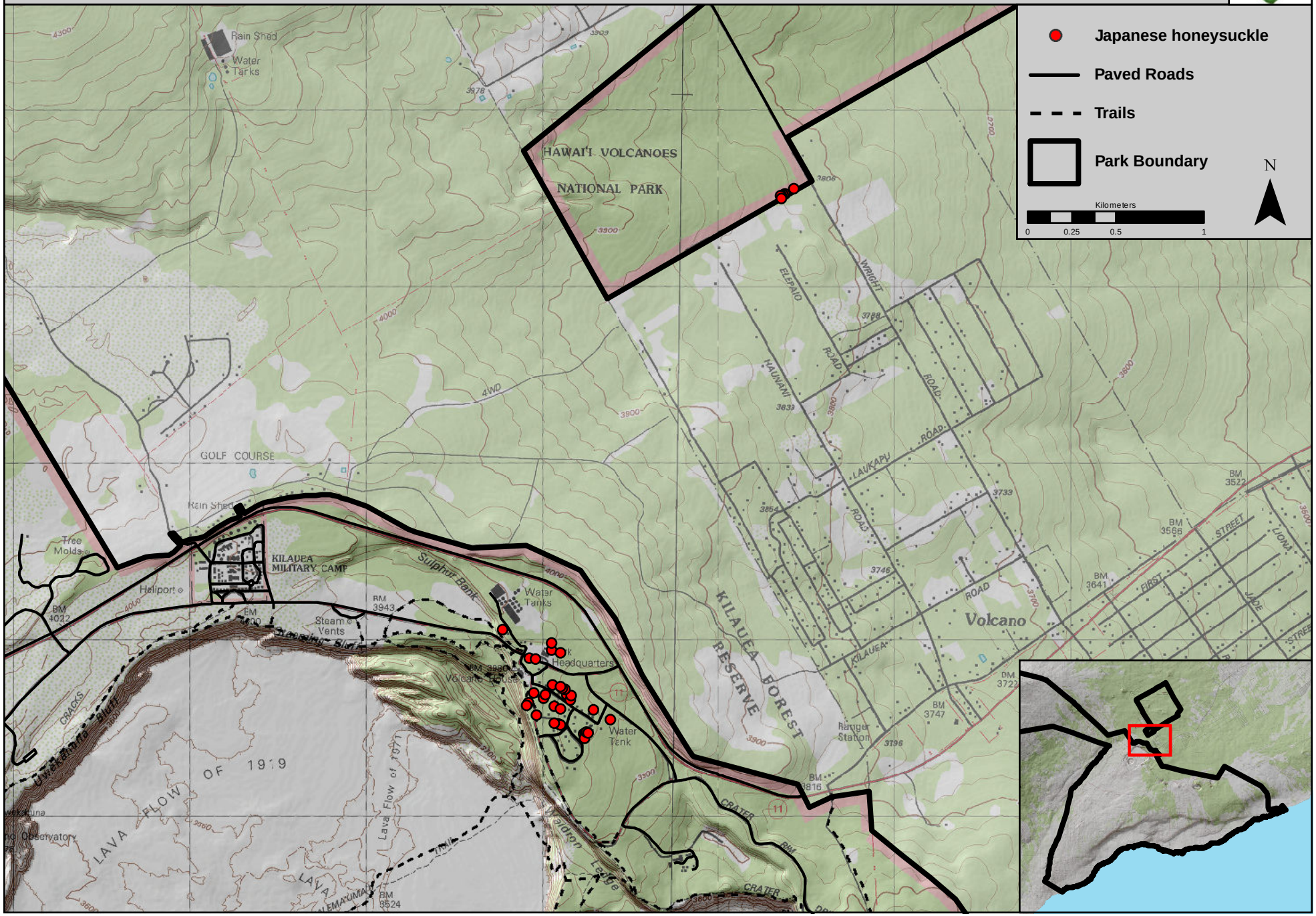
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Japanese anemone (*Anemone hupehensis*)



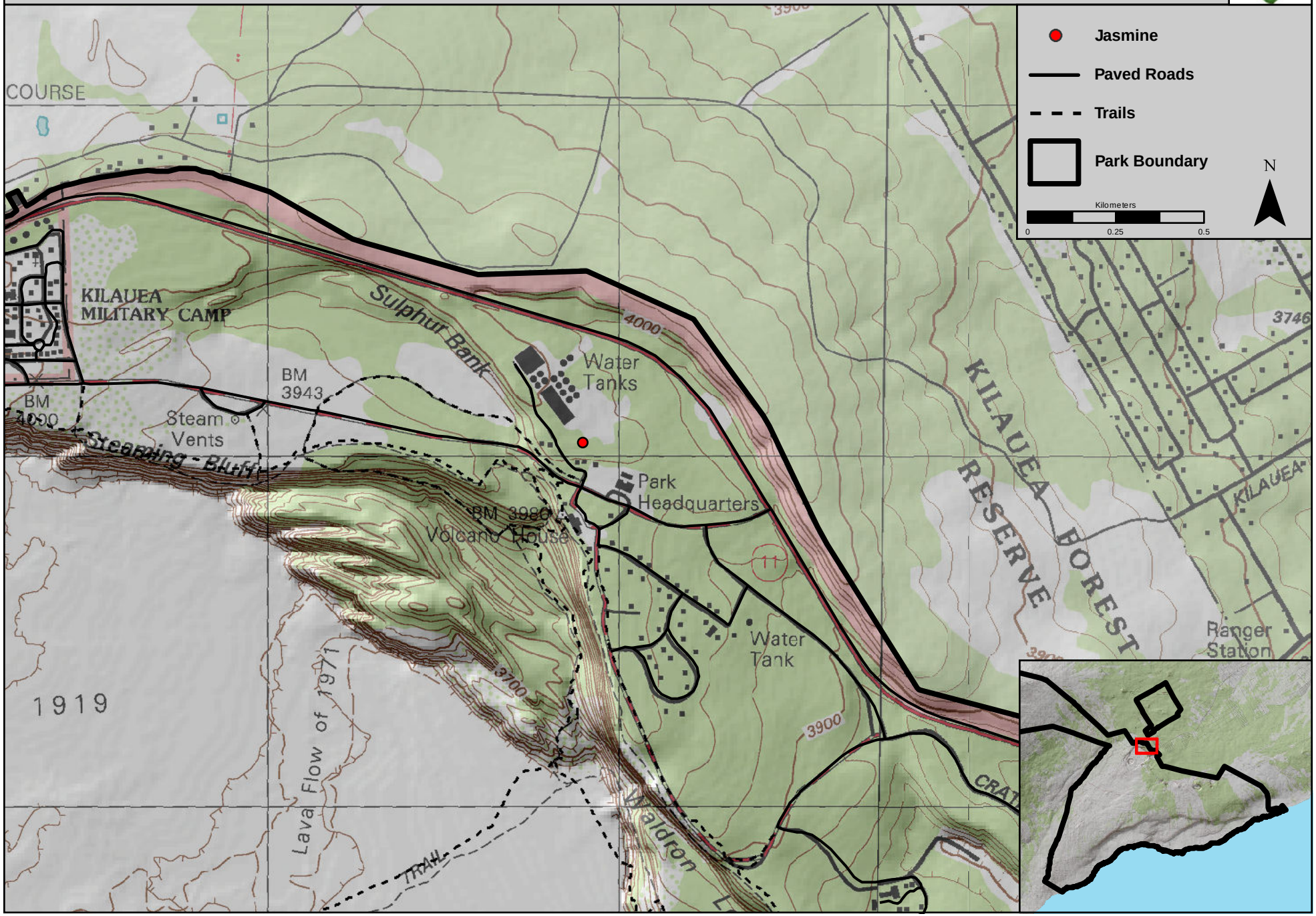
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/20/2011

Japanese honeysuckle (*Lonicera japonica*)



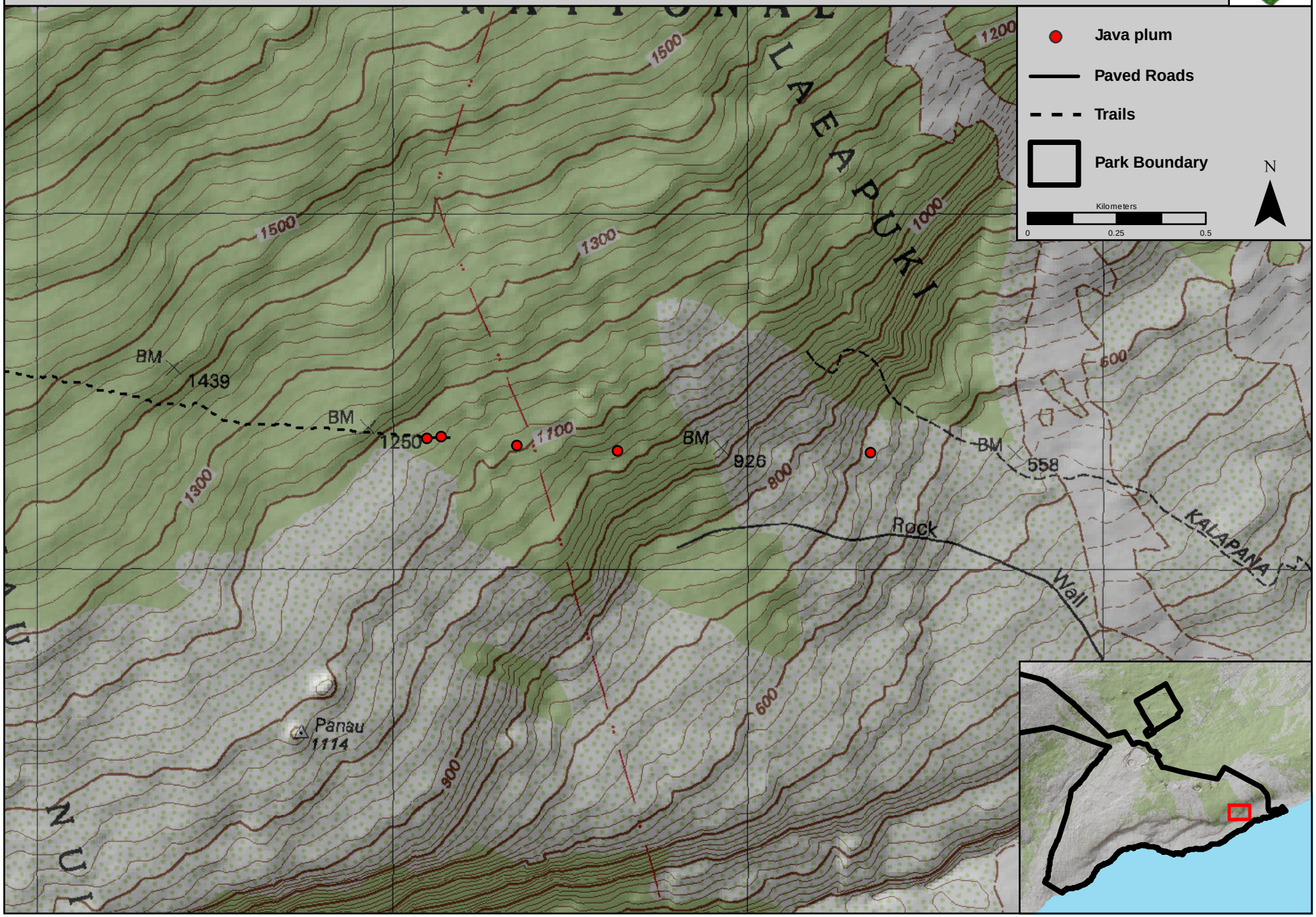
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Jasmine (*Jasminum humile*)



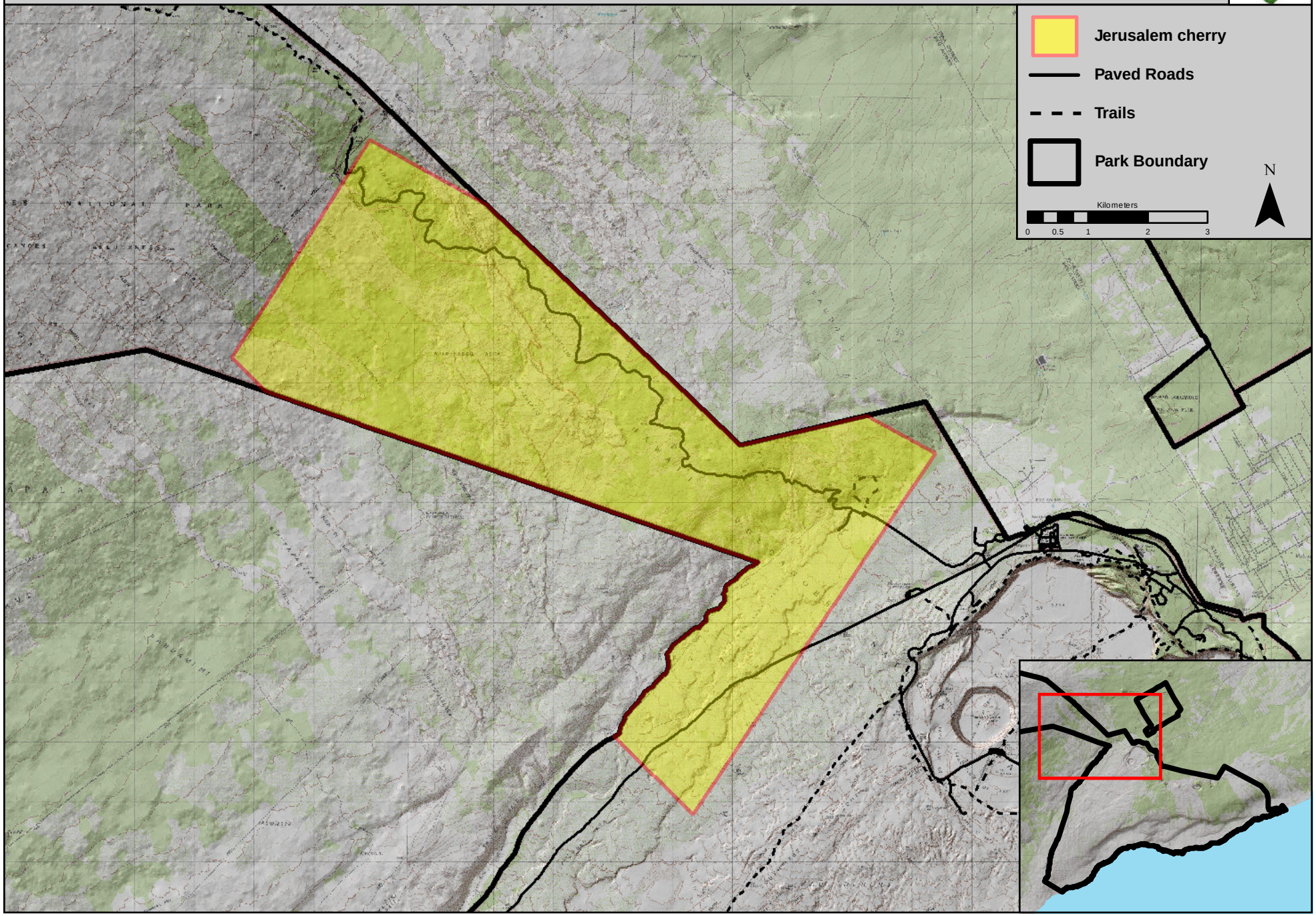
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Java plum (*Syzygium cumini*)



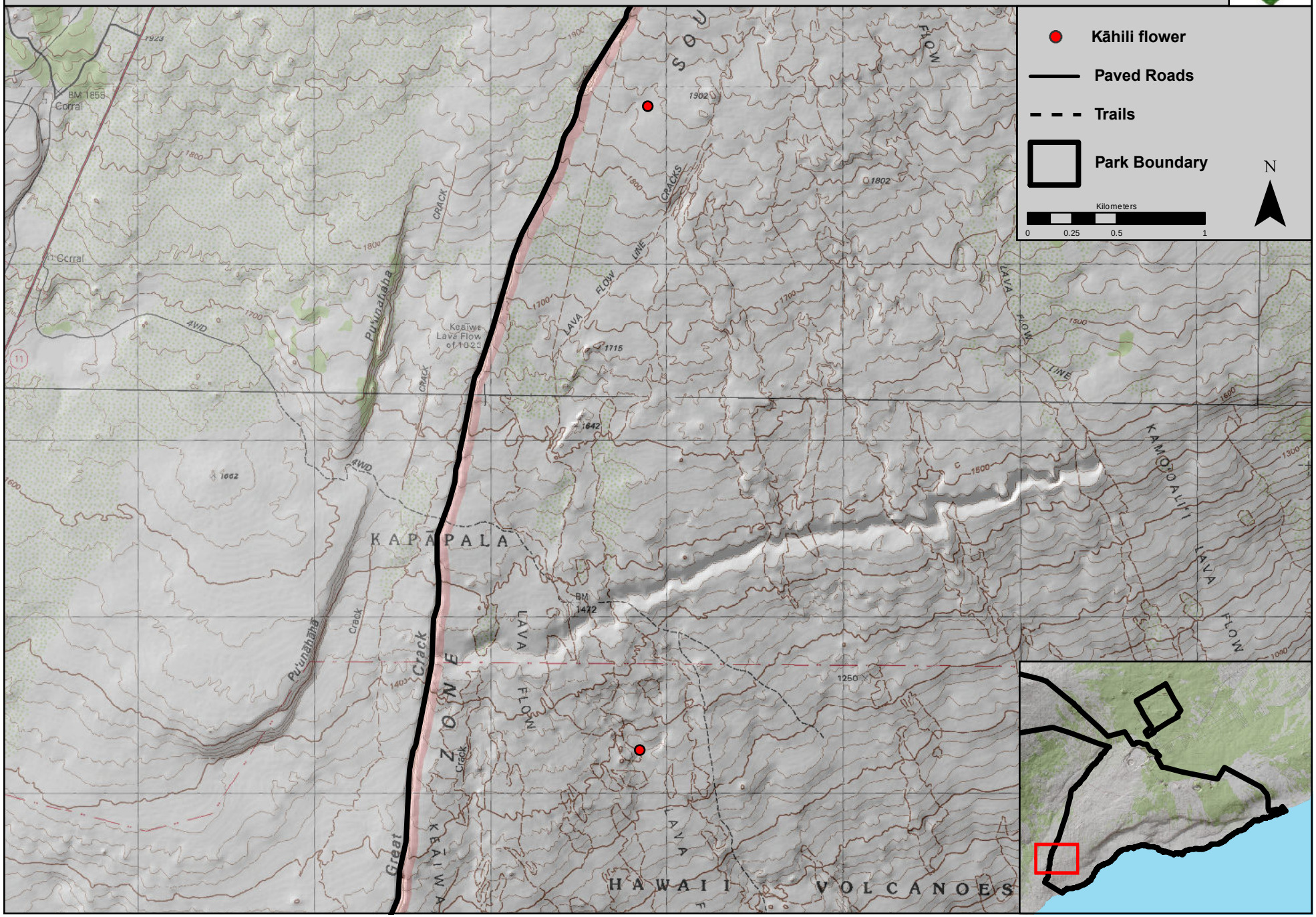
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Jerusalem cherry (*Solanum pseudocapsicum*)



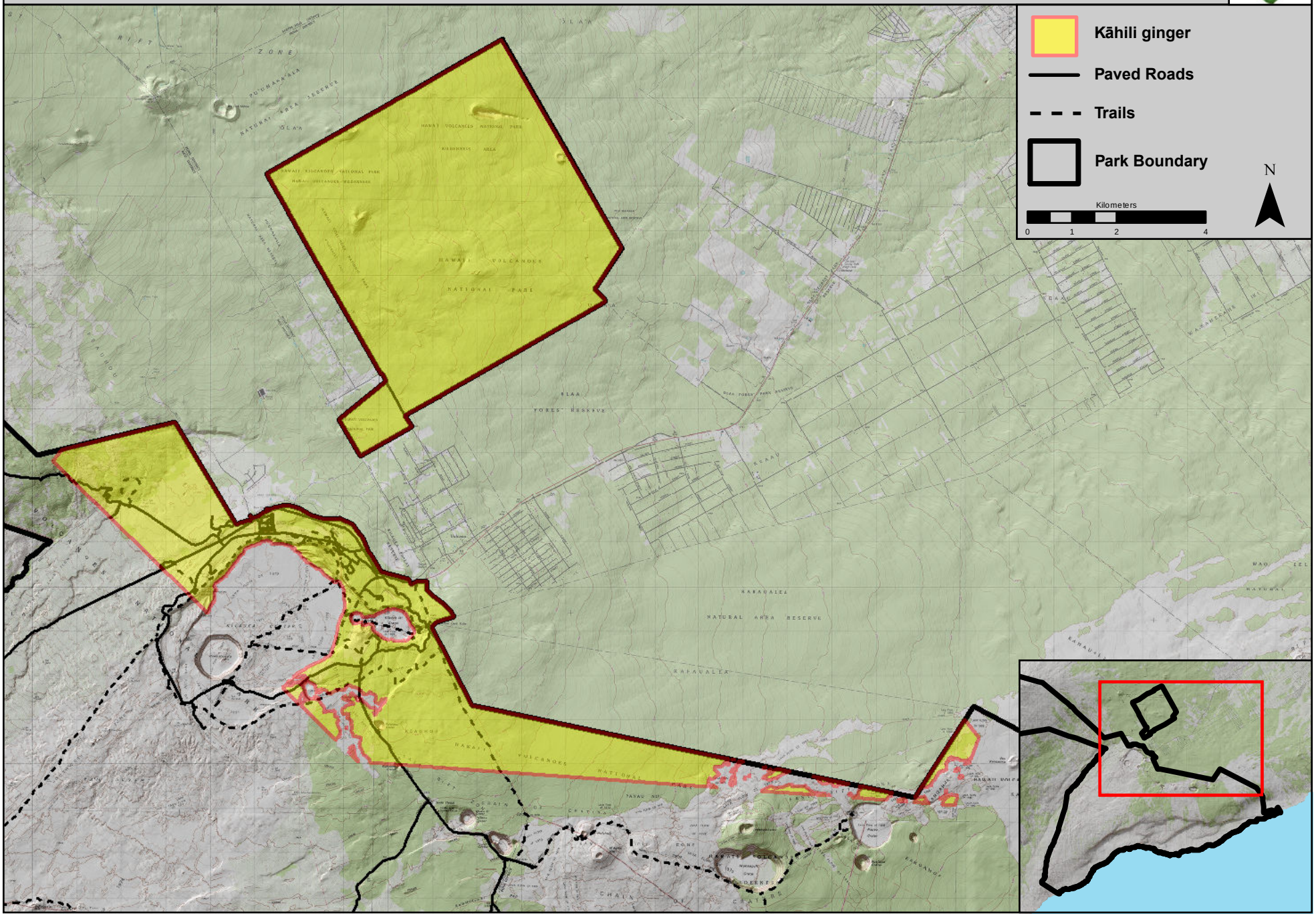
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/20/2011

Kāhili flower (*Grevillea banksii*)



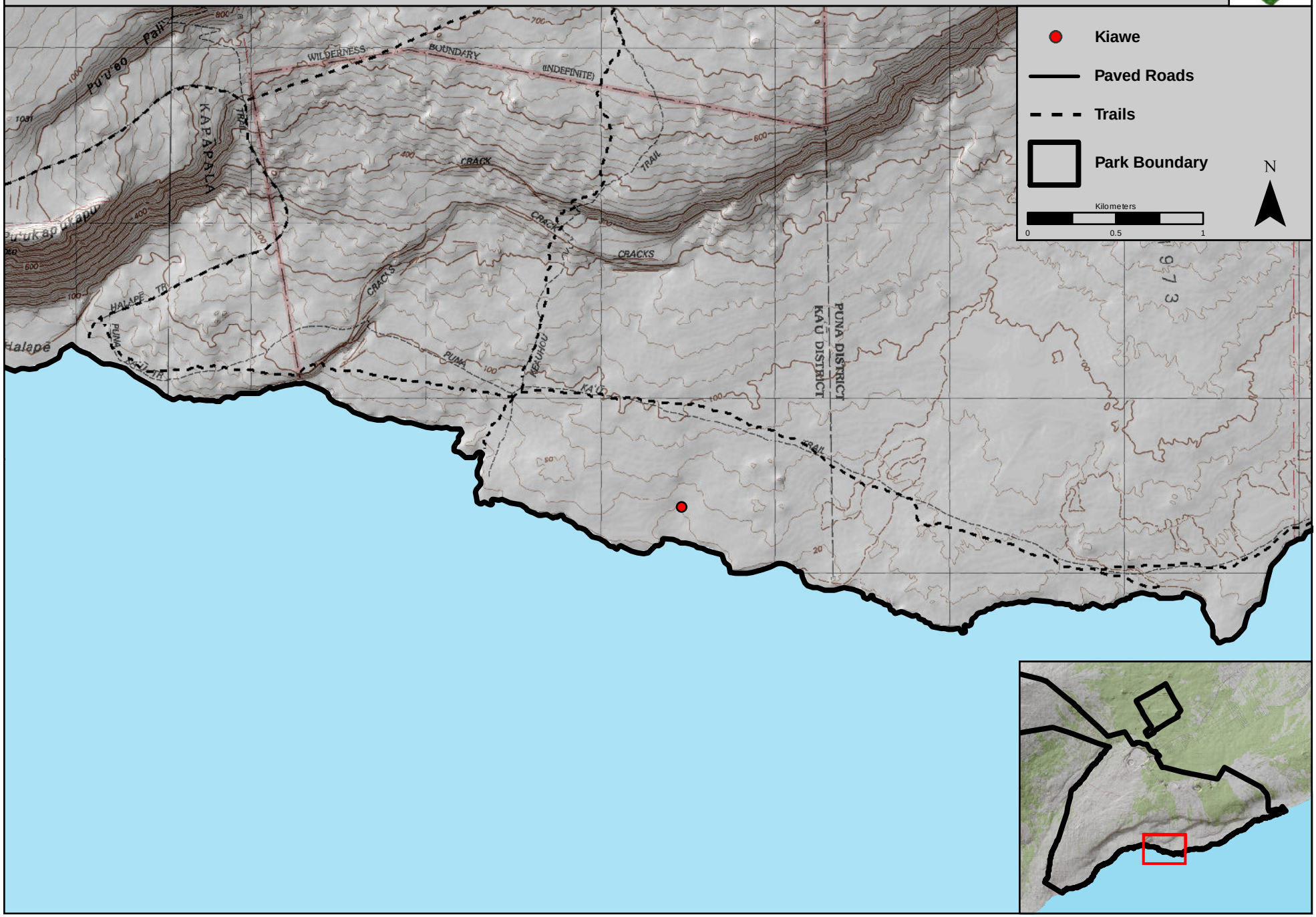
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Kāhili ginger (*Hedychium gardnerianum*)



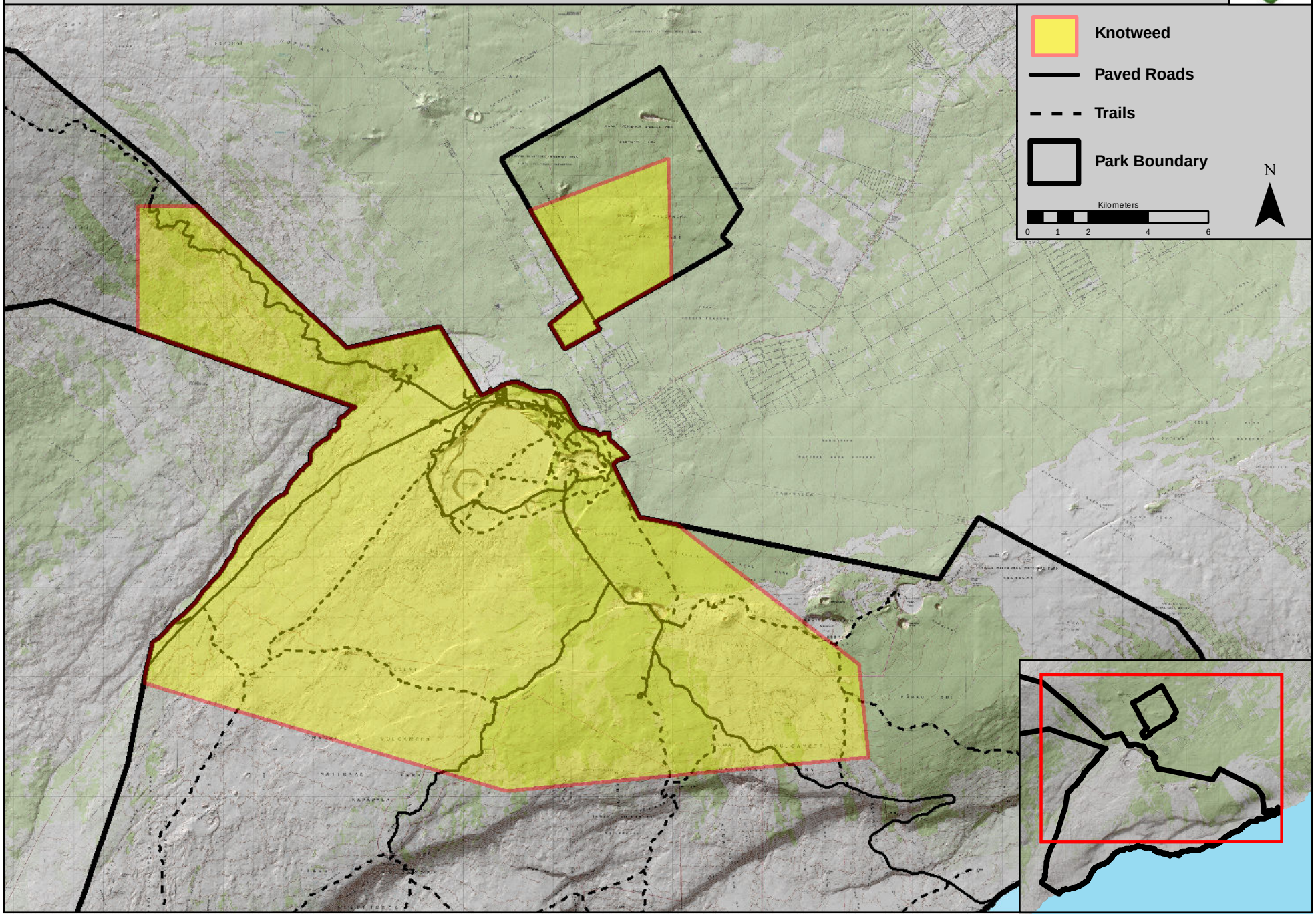
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/22/2011

Kiawe (*Prosopsis pallida*)



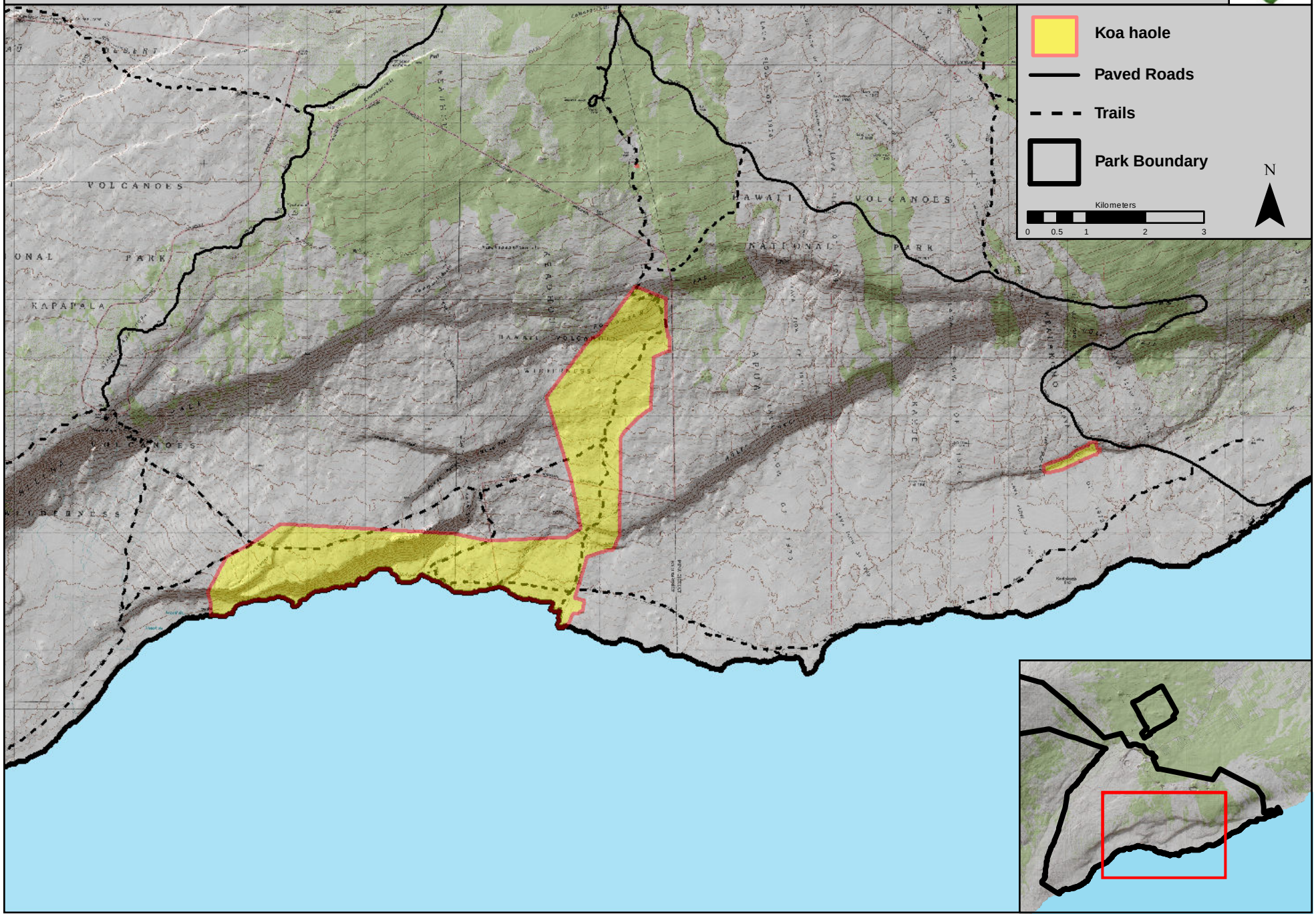
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Knotweed (*Persicaria capitata*)



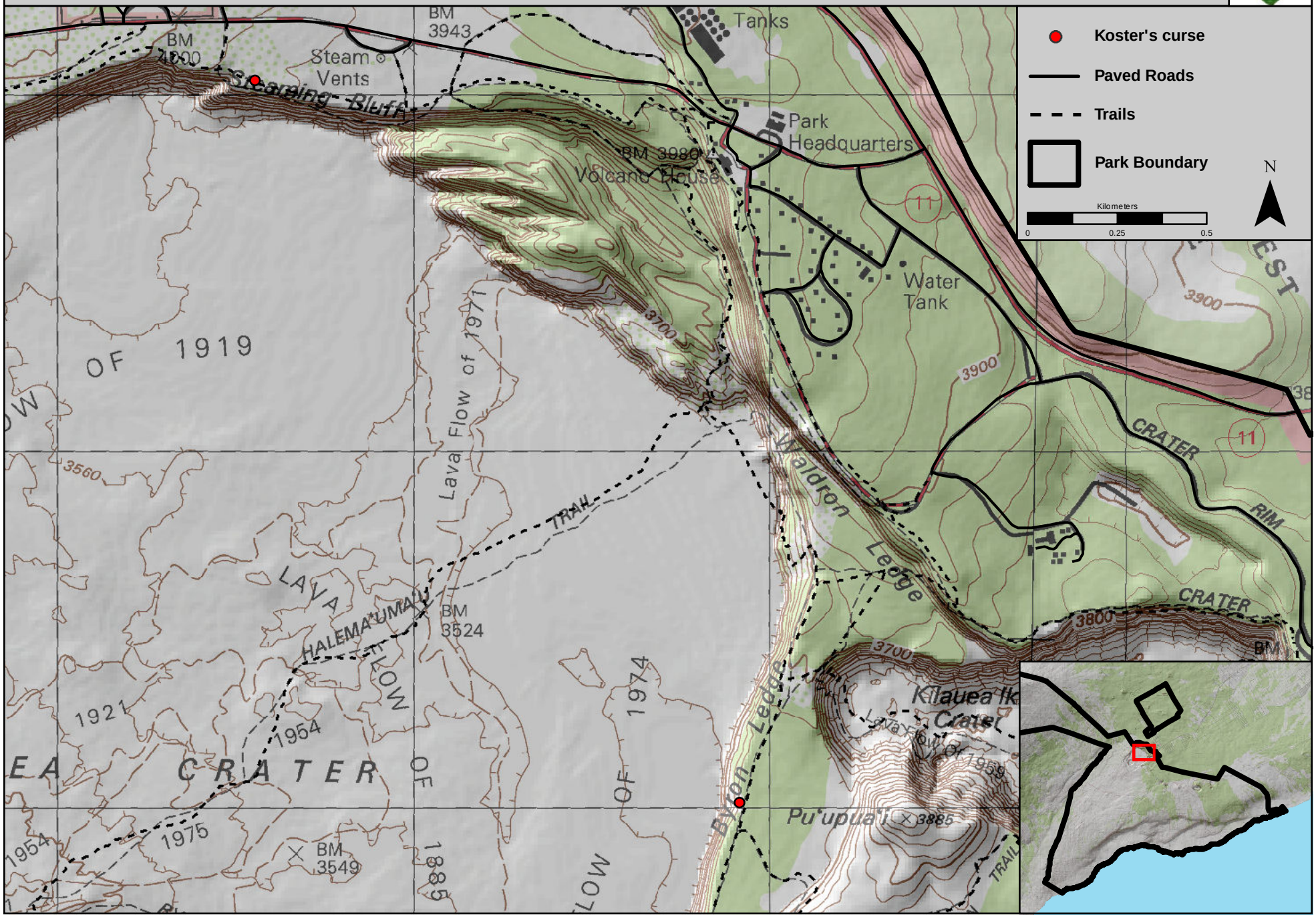
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/22/2011

Koa haole (*Leucaena leucocephala*)



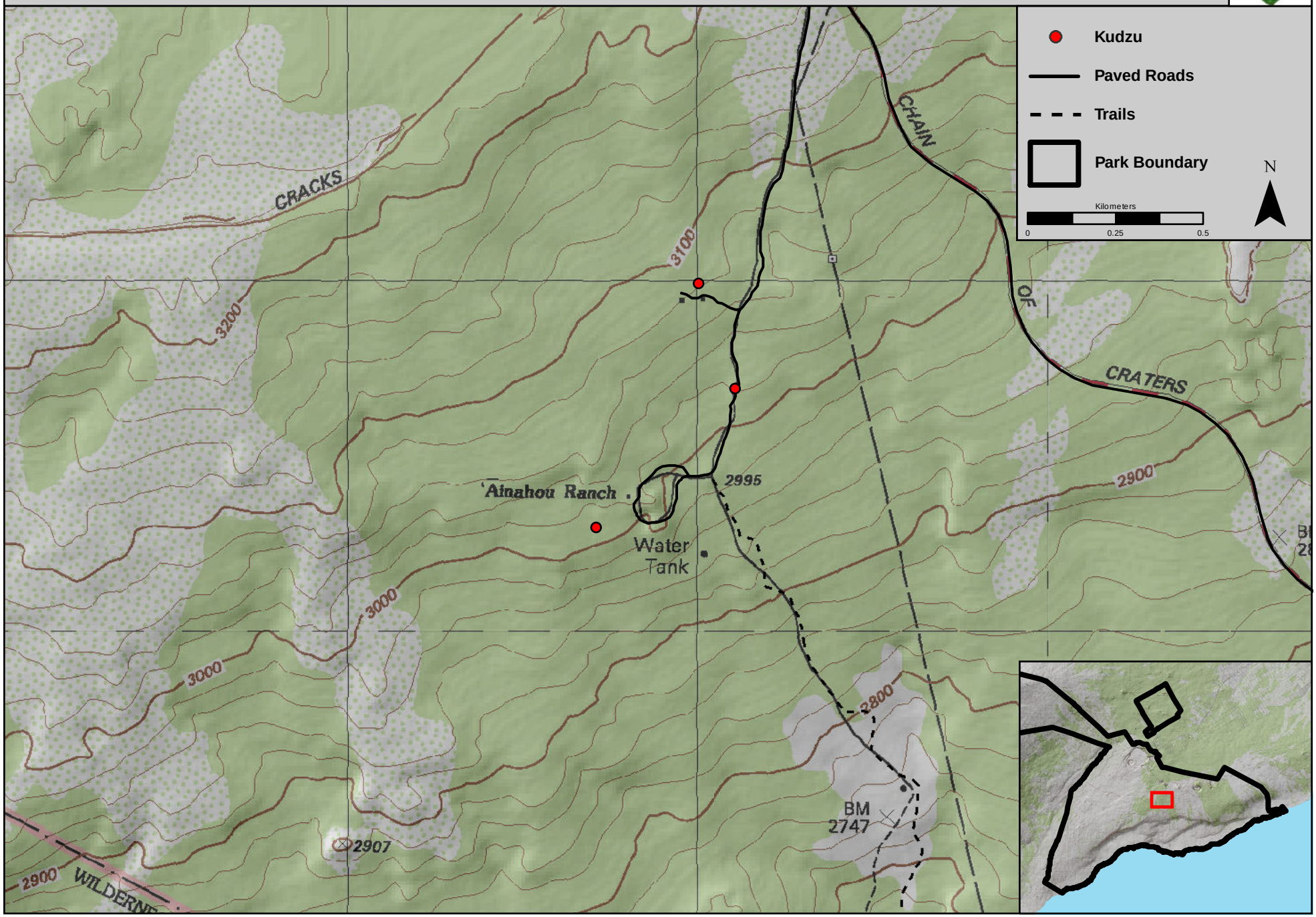
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/22/2011

Koster's curse (*Clidemia hirta*)



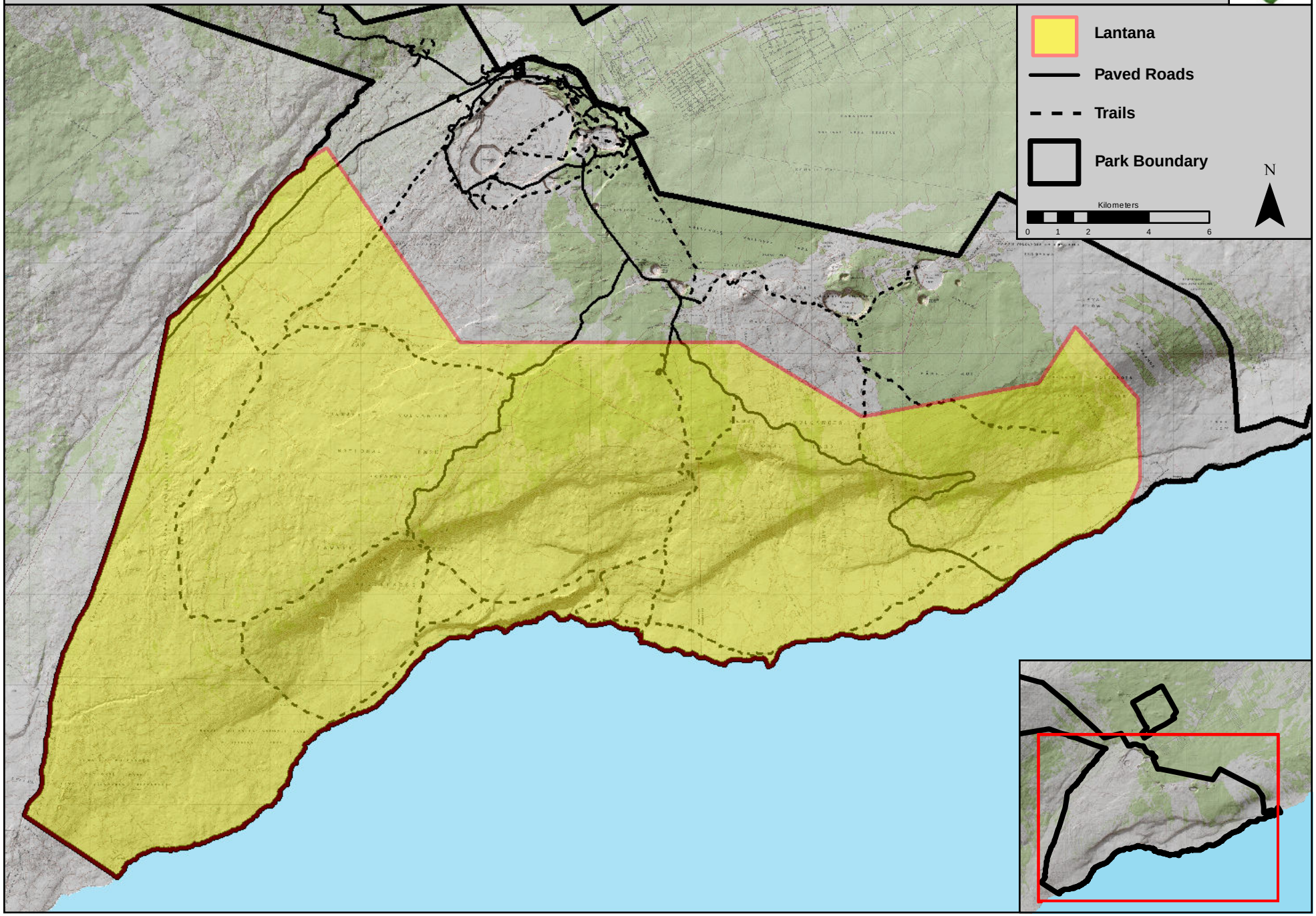
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/13/2011

Kudzu (*Pueraria lobata*)



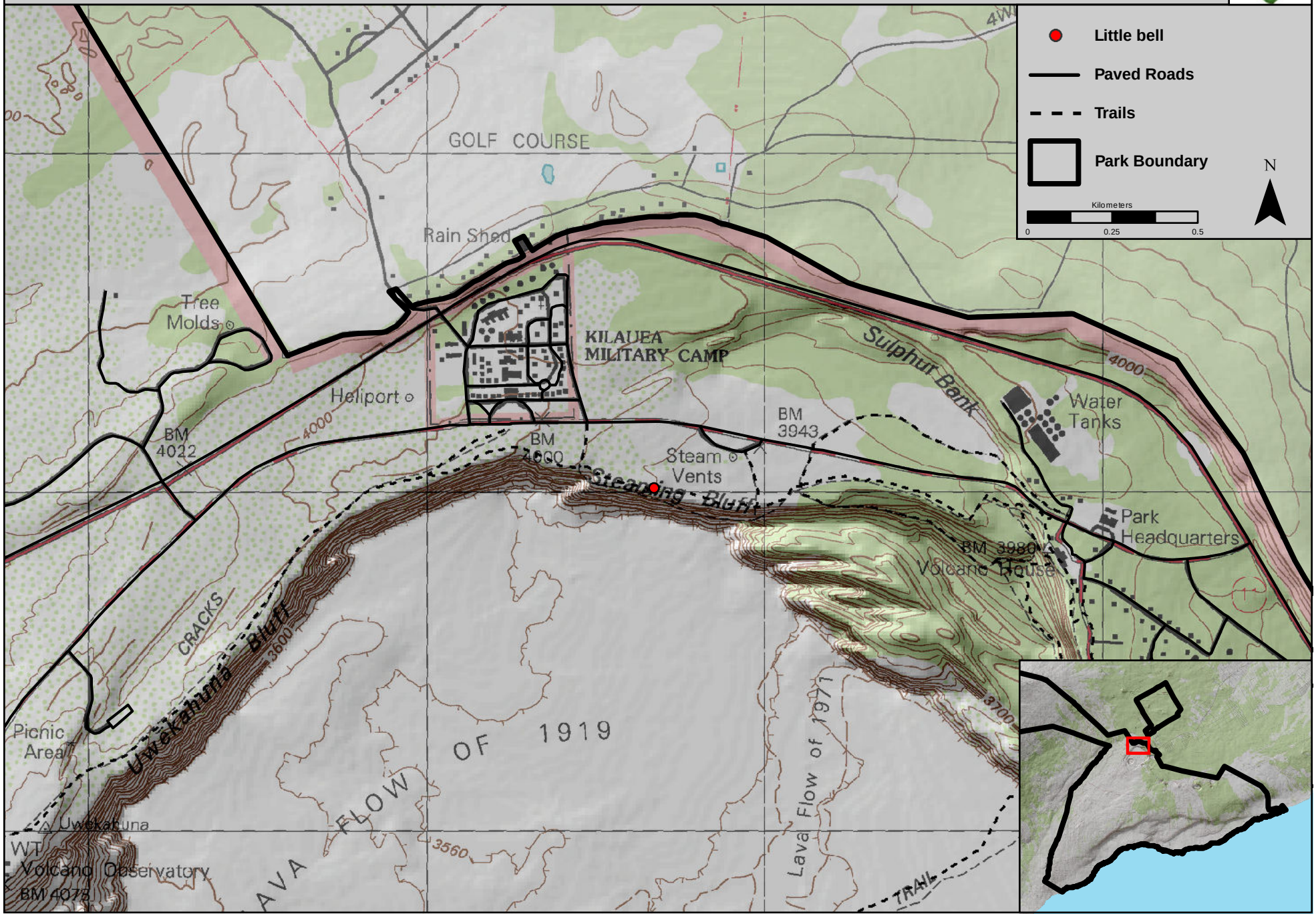
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Lantana (*Lantana camara*)



Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/22/2011

Little bell (*Ipomea triloba*)



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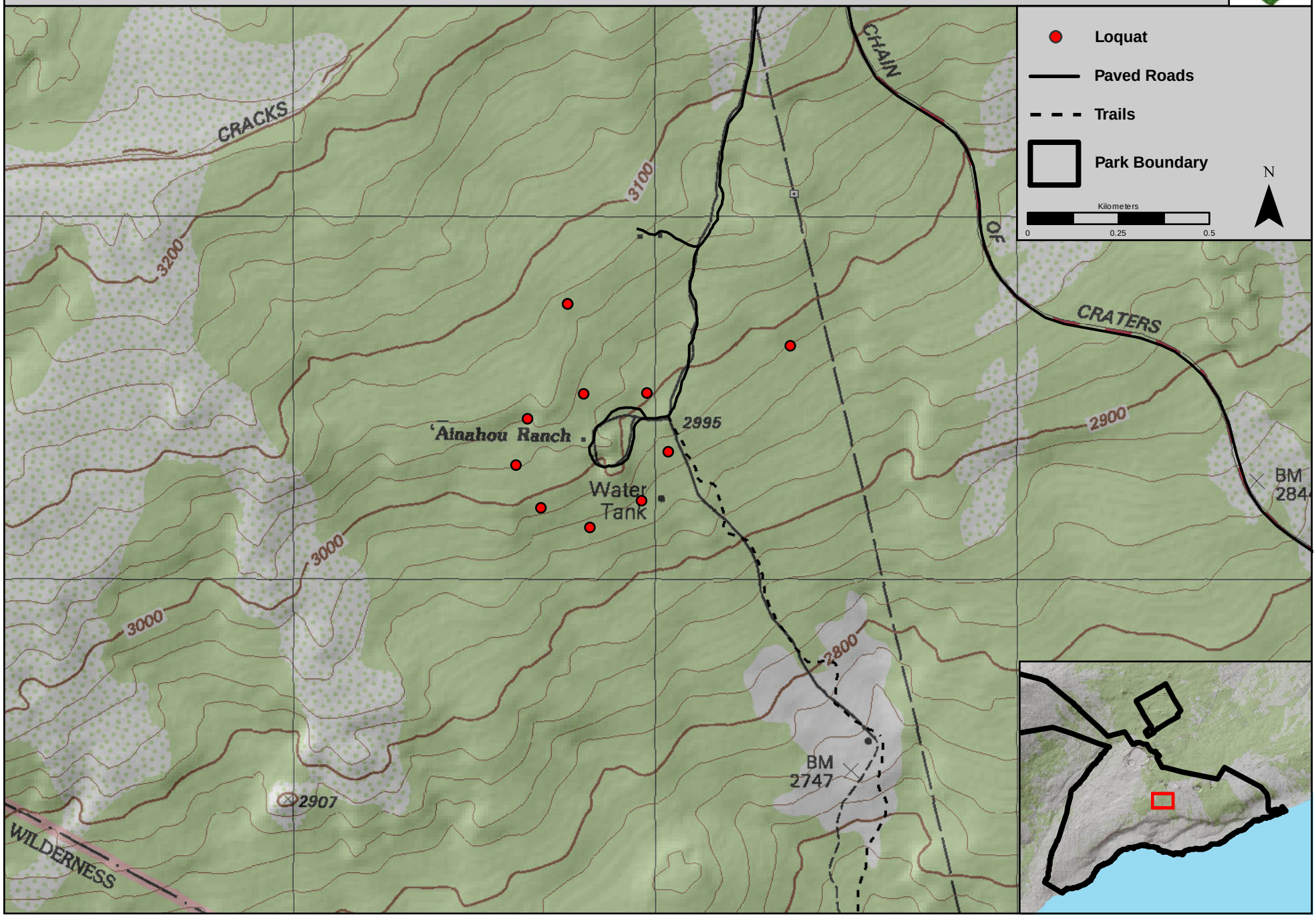
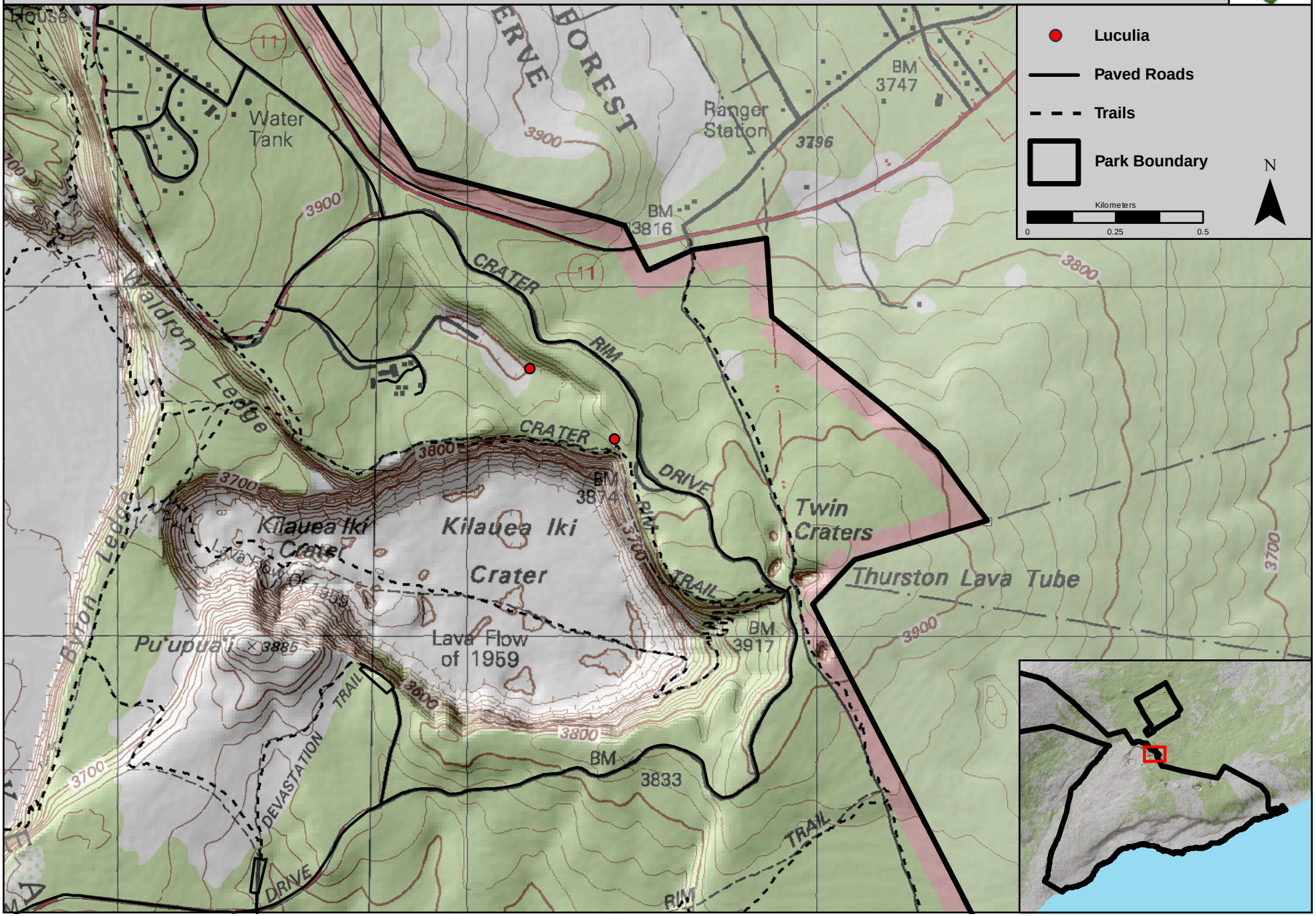
Loquat (*Eriobotria japonica*)



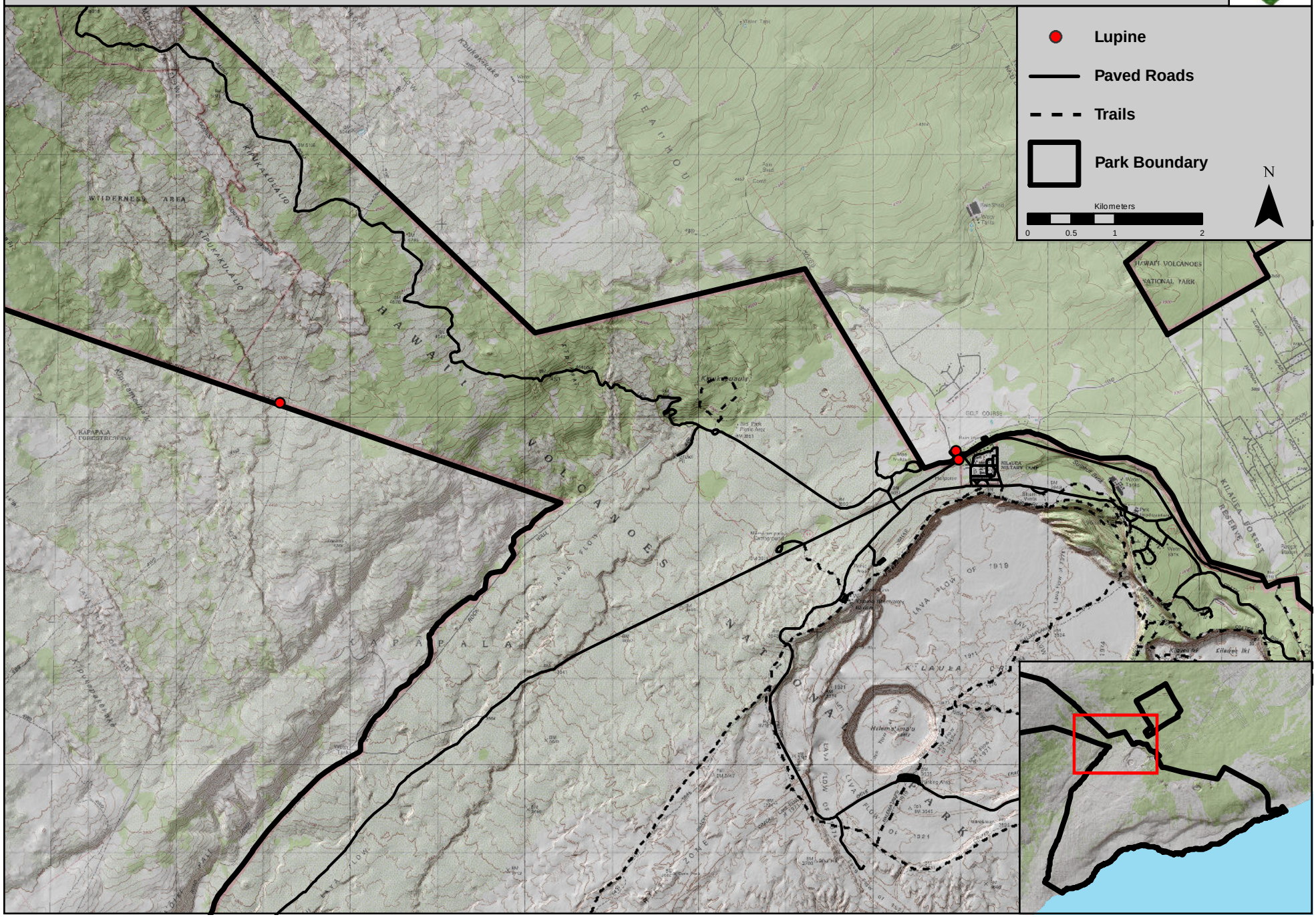
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Luculia (*Luculia gratissima*)



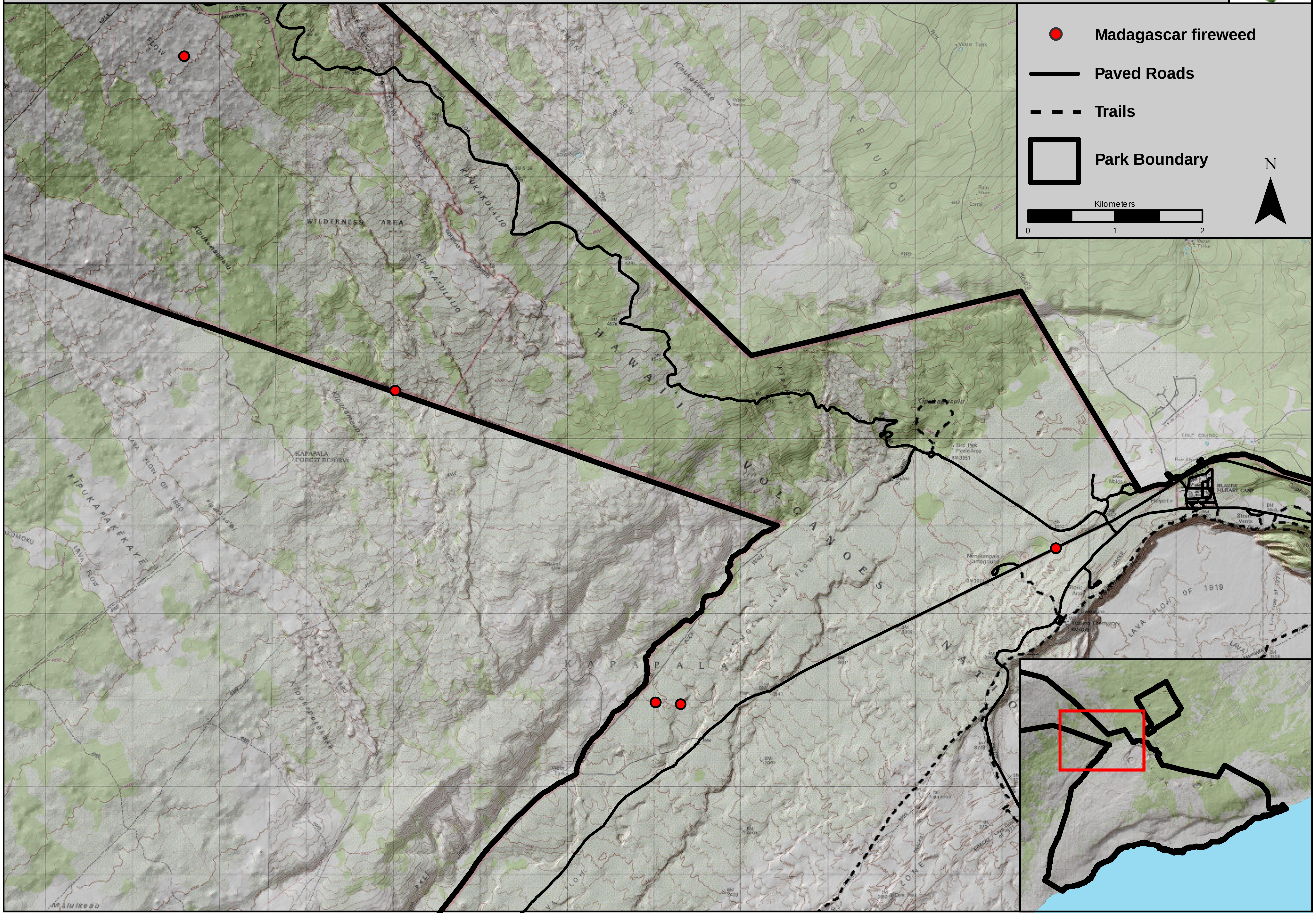
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Lupine (*Lupinus hybridus*)



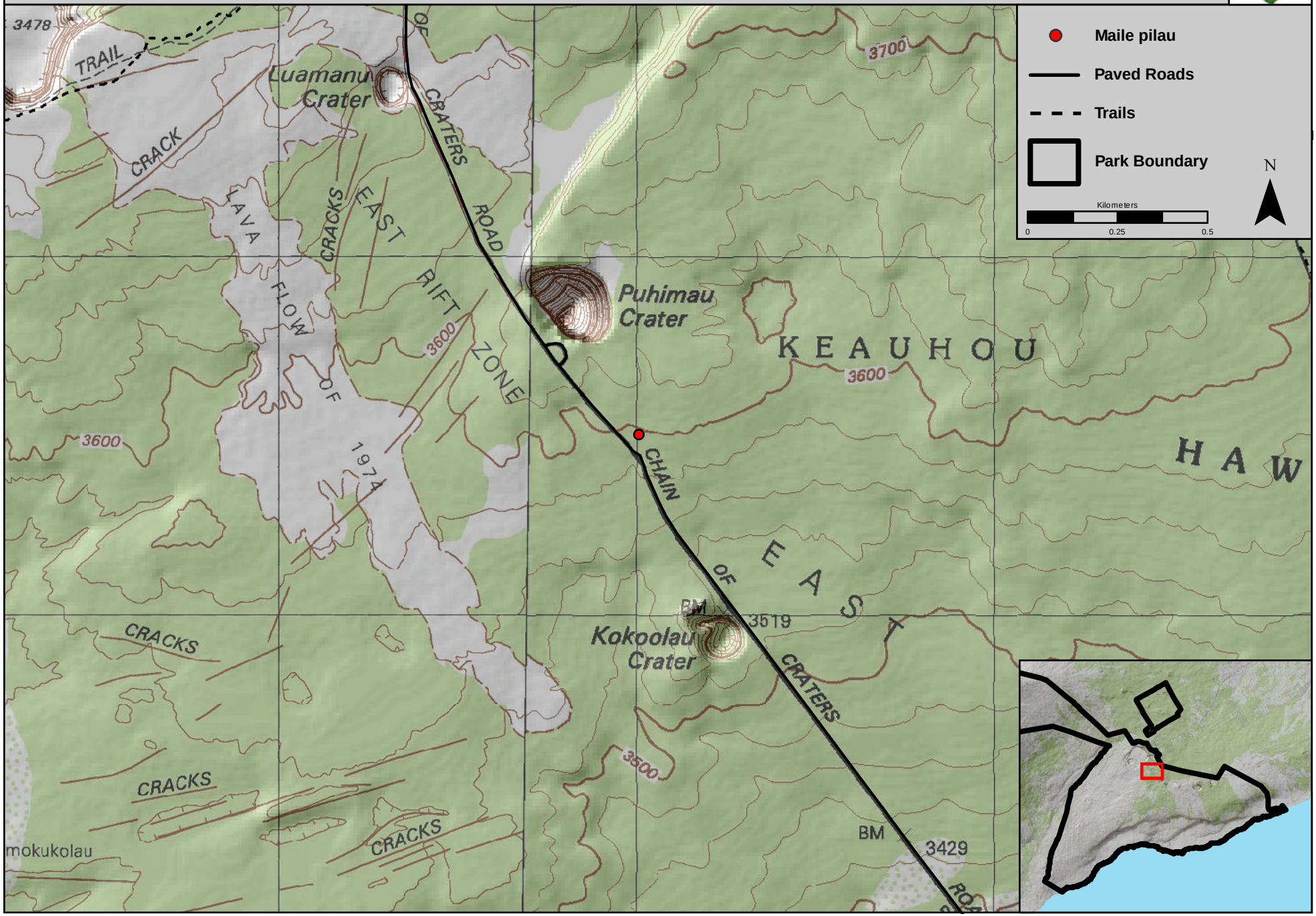
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Madagascar fireweed (*Senecio madagascariensis*)



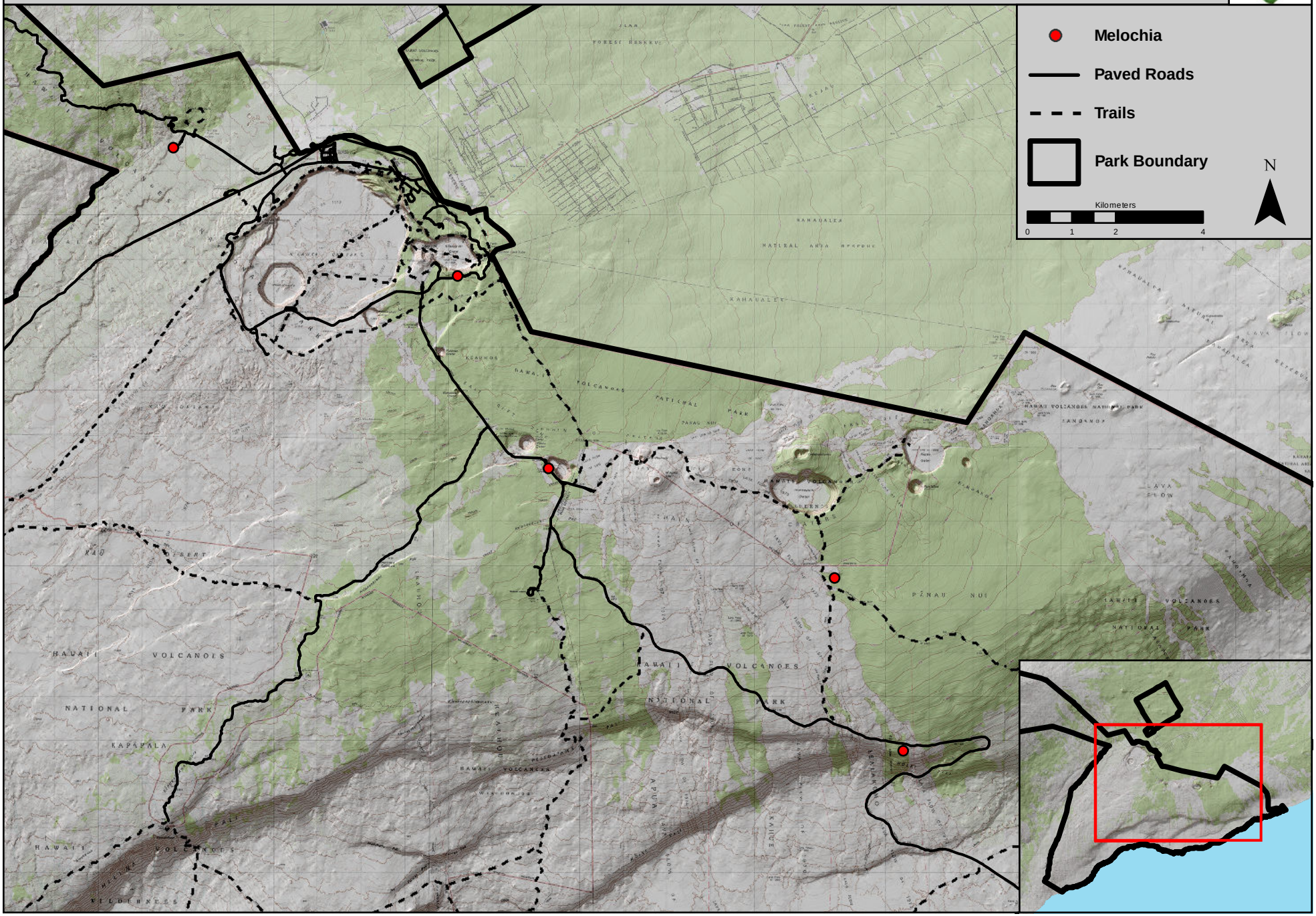
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Maile pilau (*Paederia foetida*)



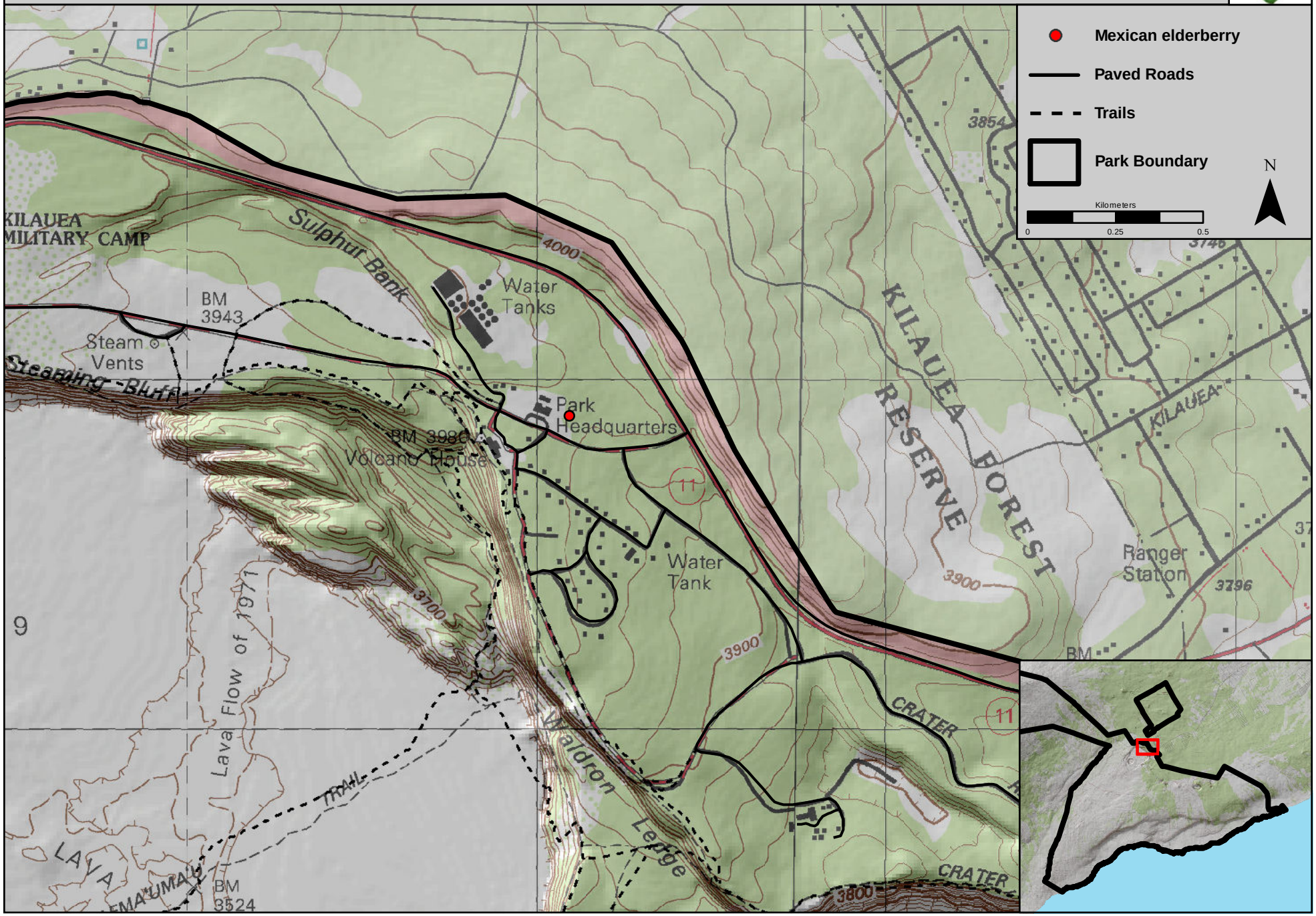
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Melochia (*Melochia umbellata*)



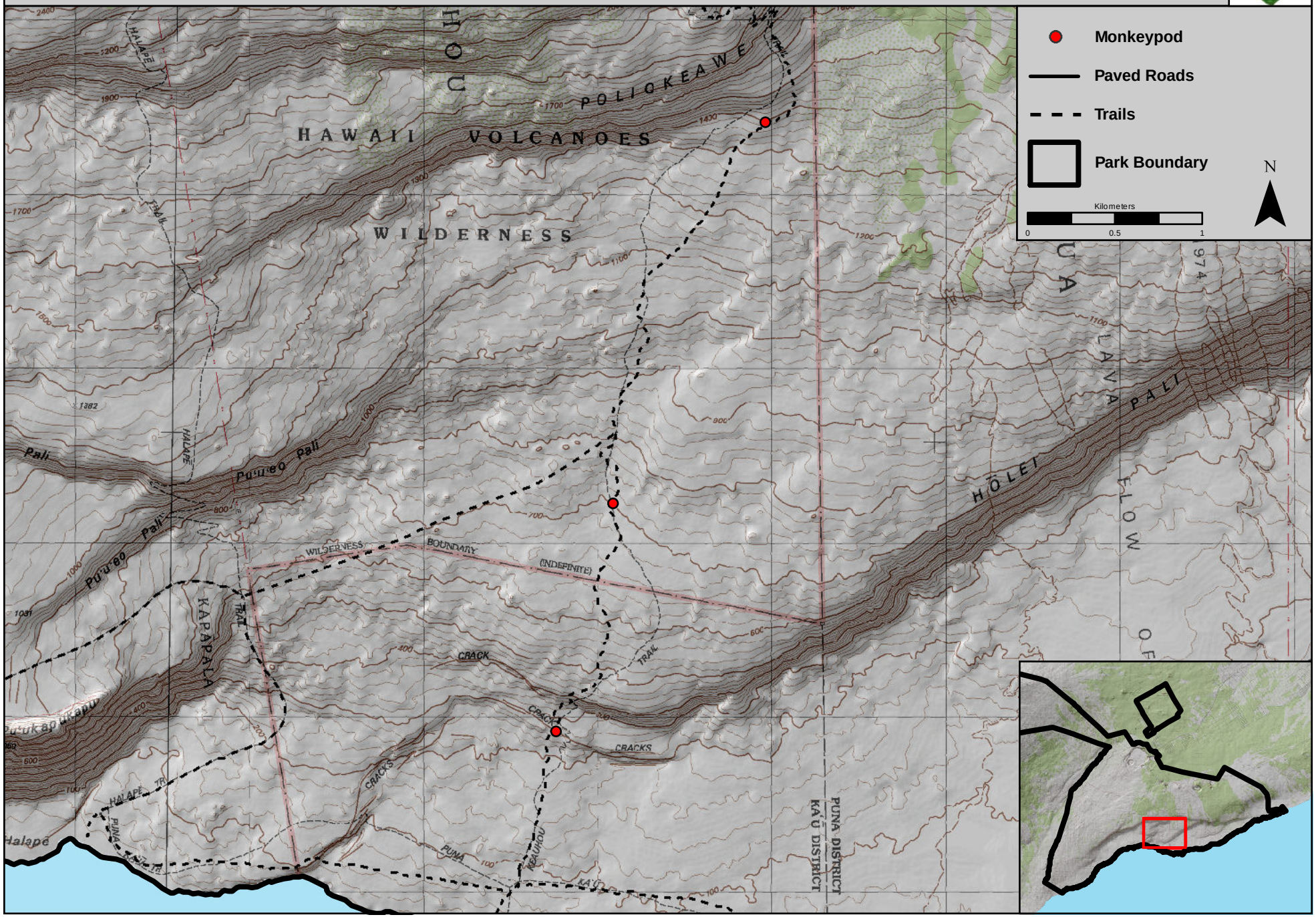
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Mexican elderberry (*Sambucus mexicanus*)



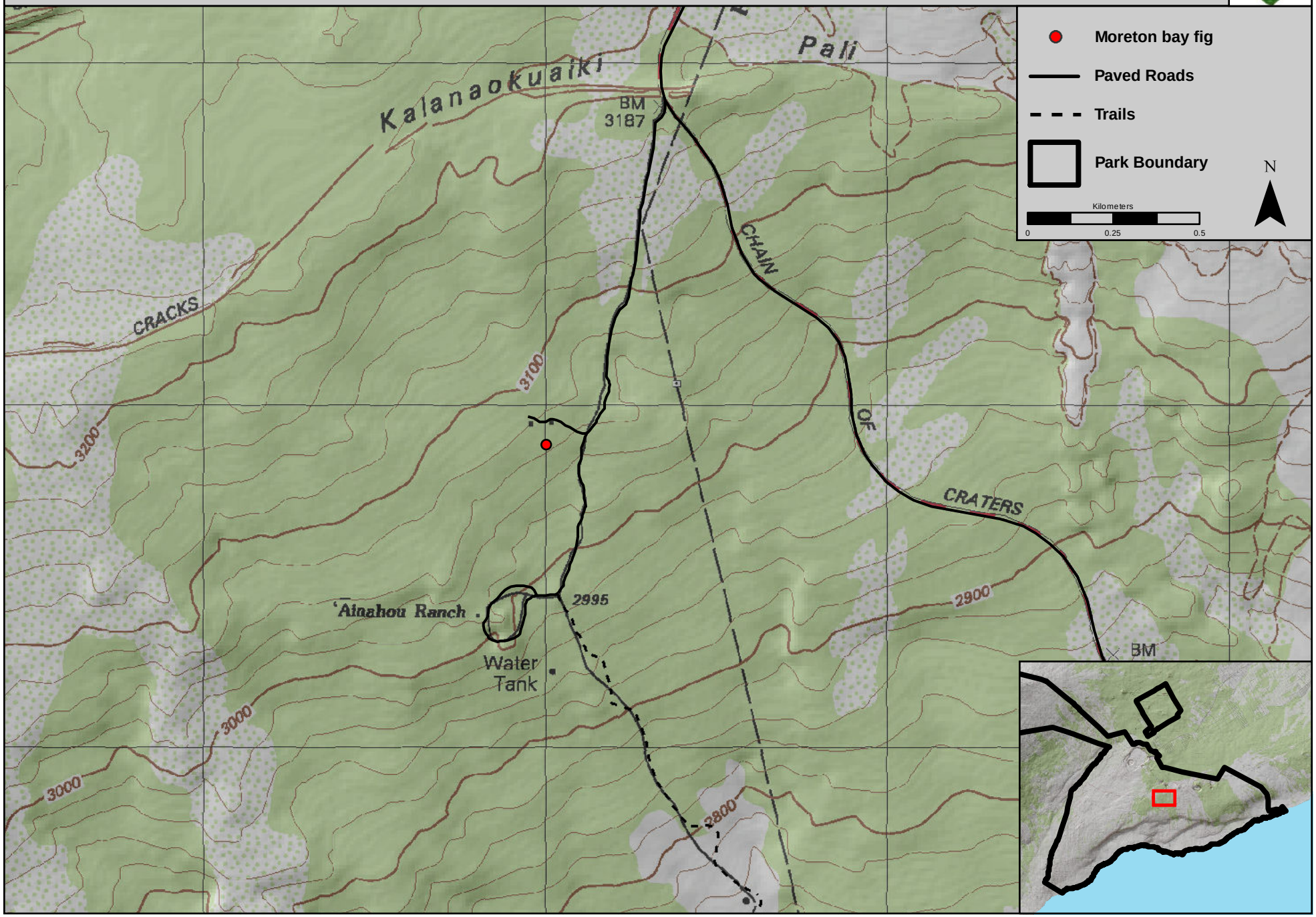
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Monkeypod (*Samanea saman*)



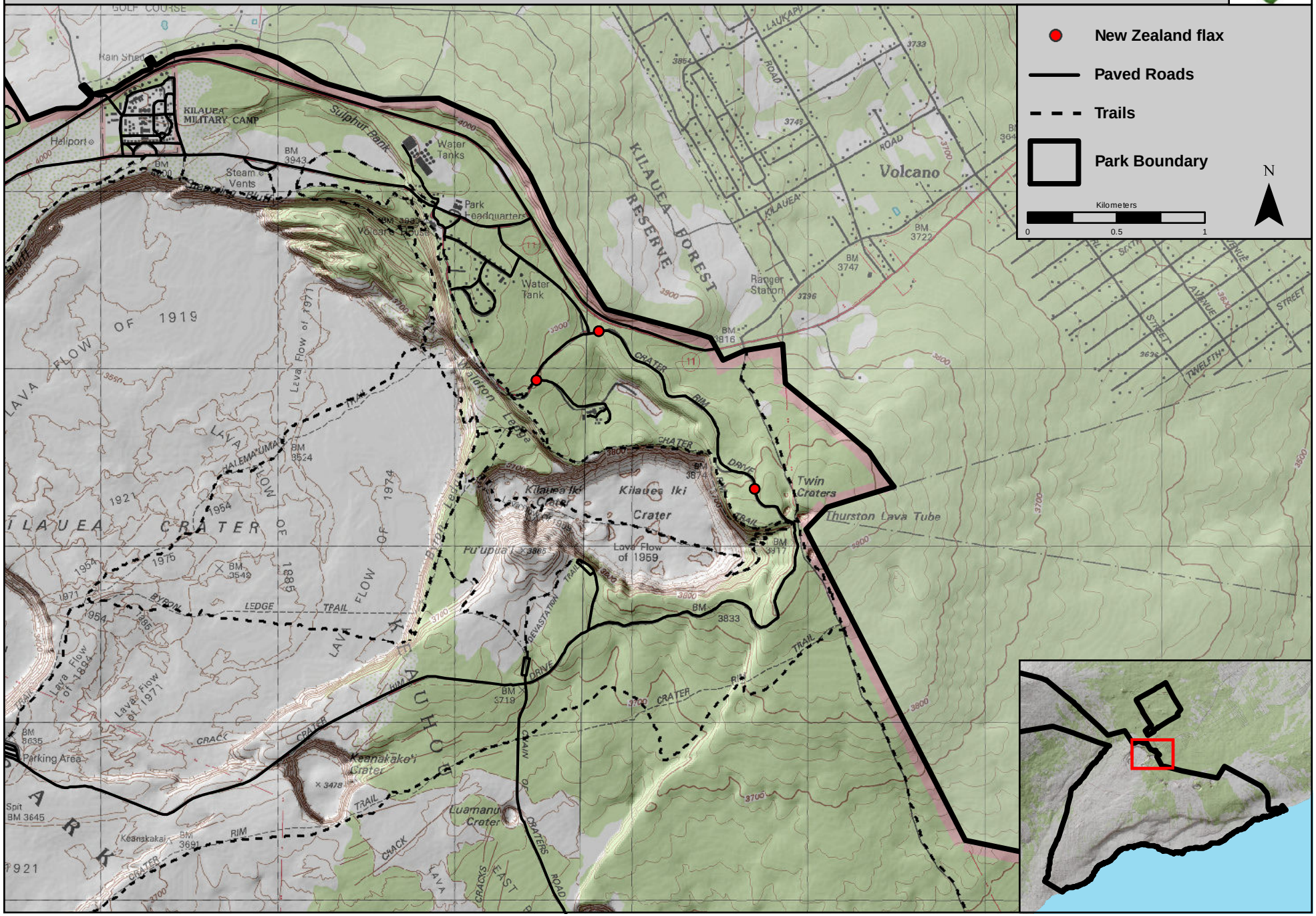
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Moreton bay fig (*Ficus macrophylla*)



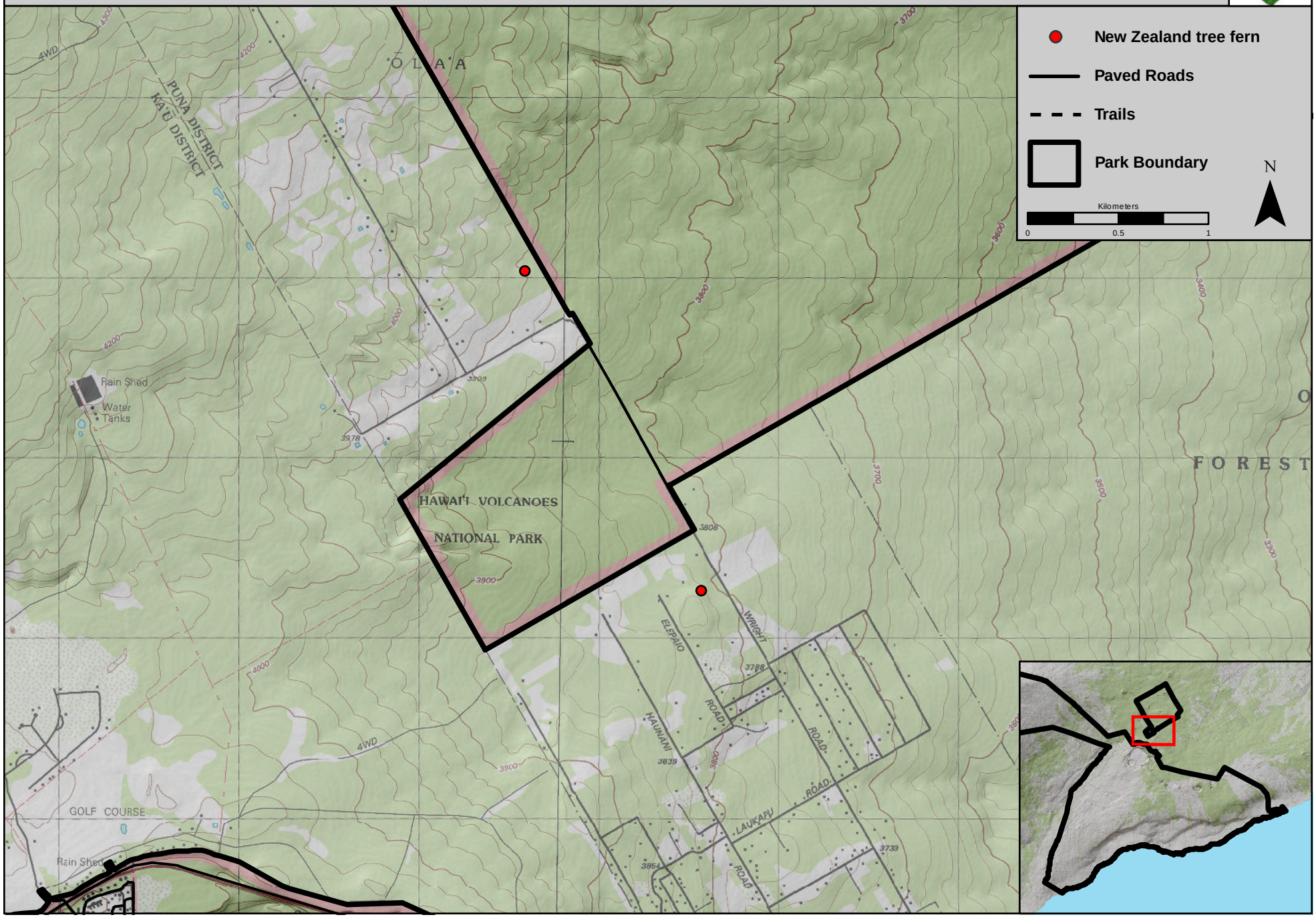
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

New Zealand flax (*Phormium tenax*)



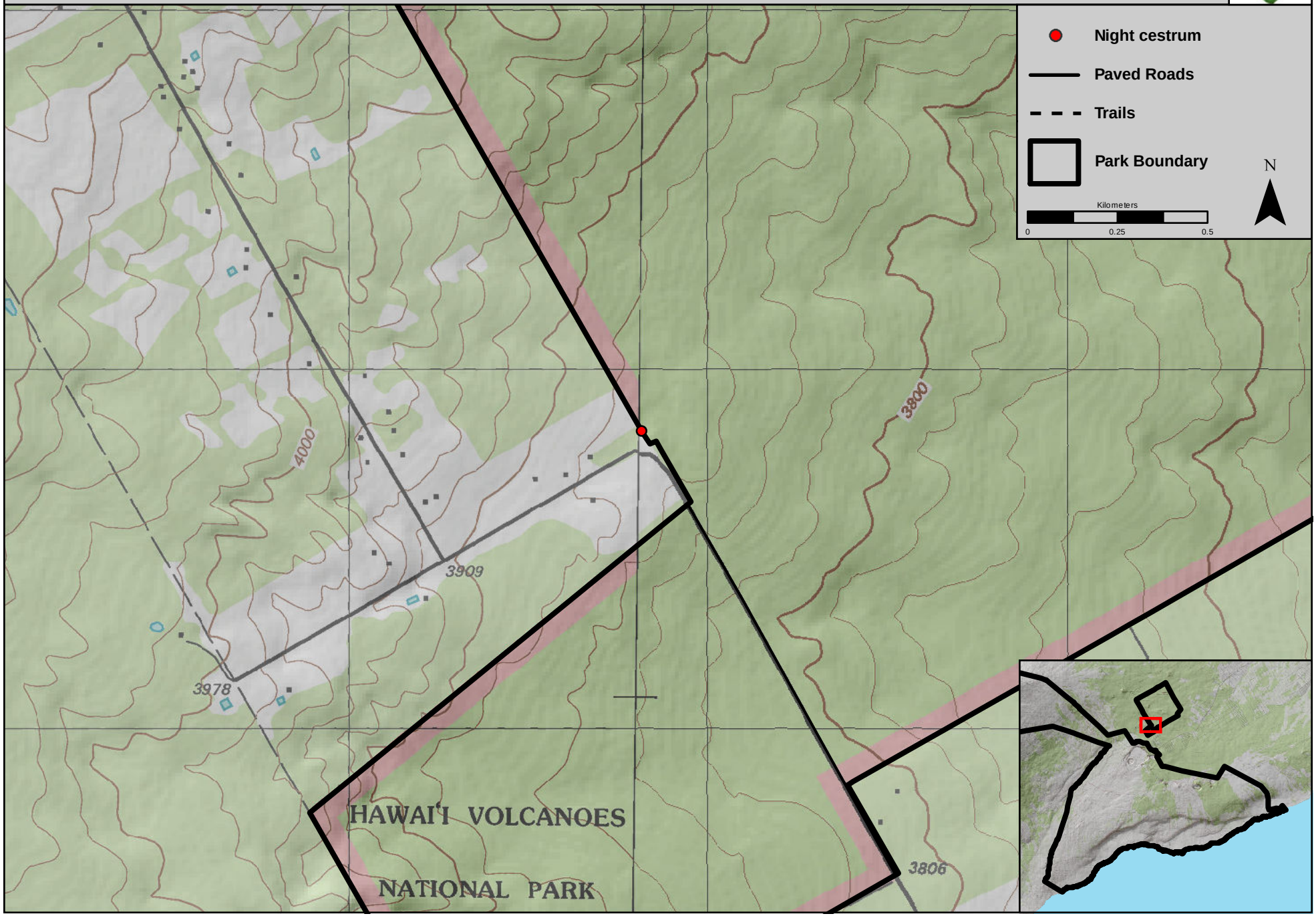
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

New Zealand tree fern (*Dicksonia fibrosa*)



Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Night cestrum (*Cestrum nocturnum*)



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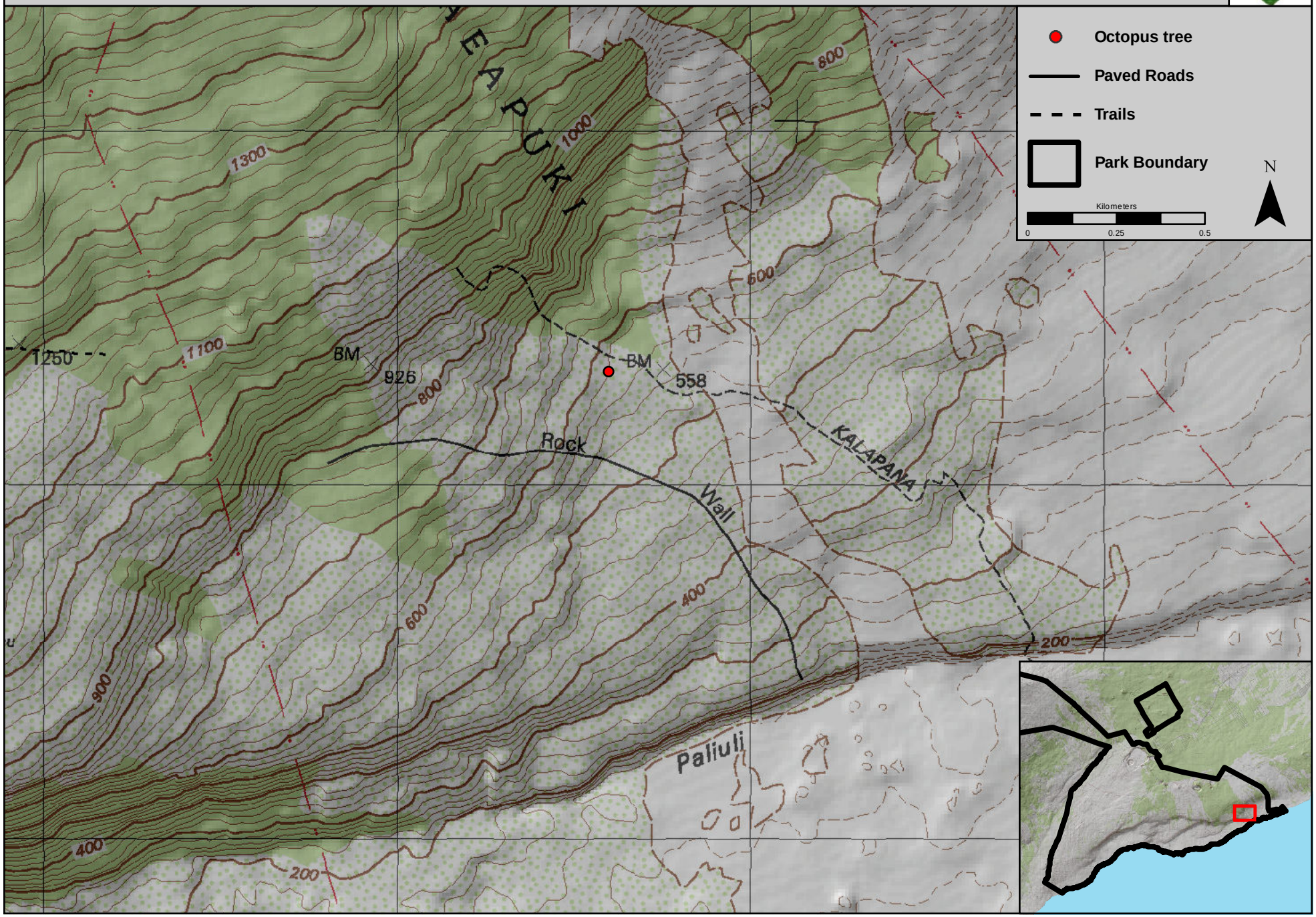
Octopus tree (*Schefflera actinophylla*)



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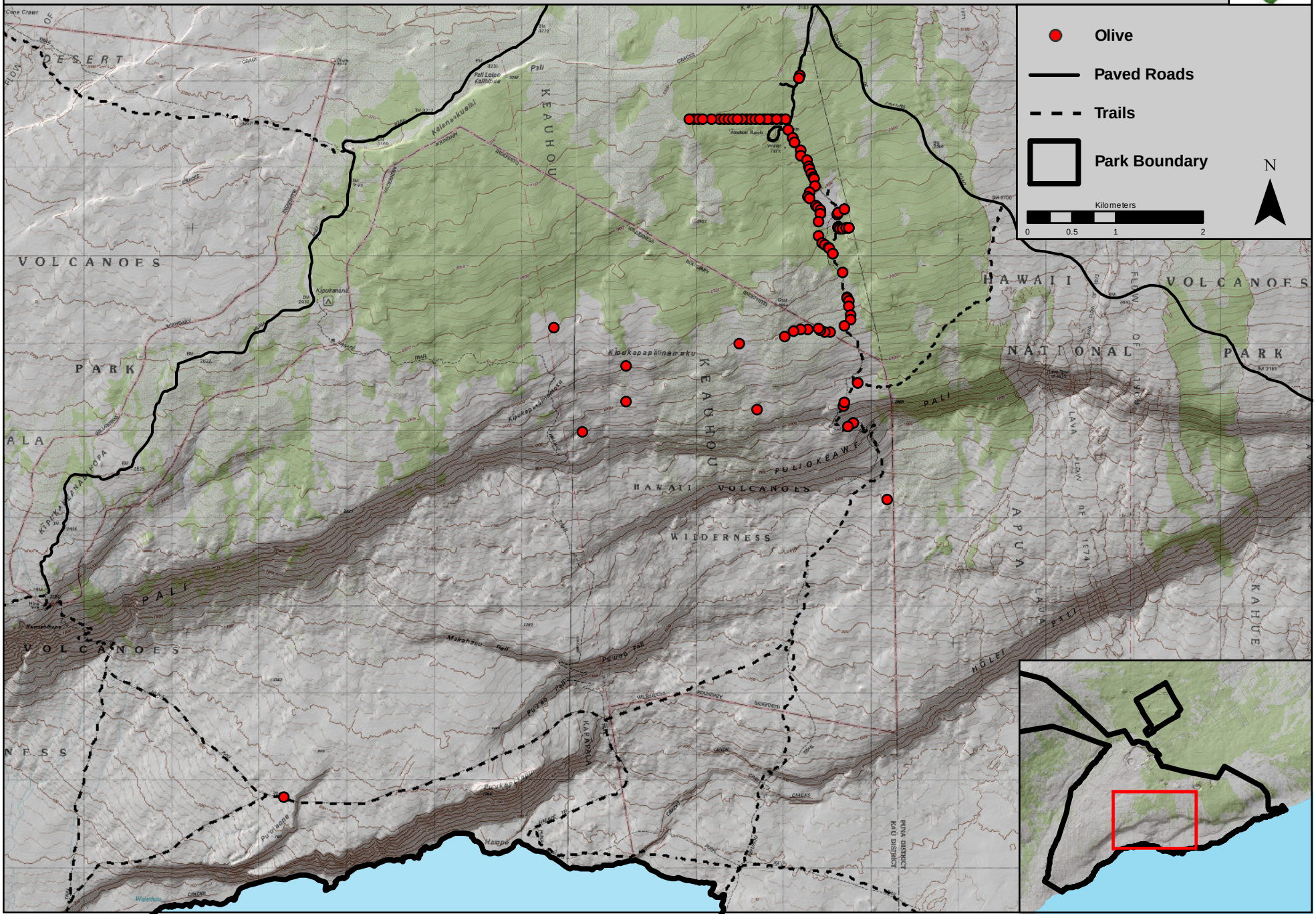
Olive (*Olea europaea*)



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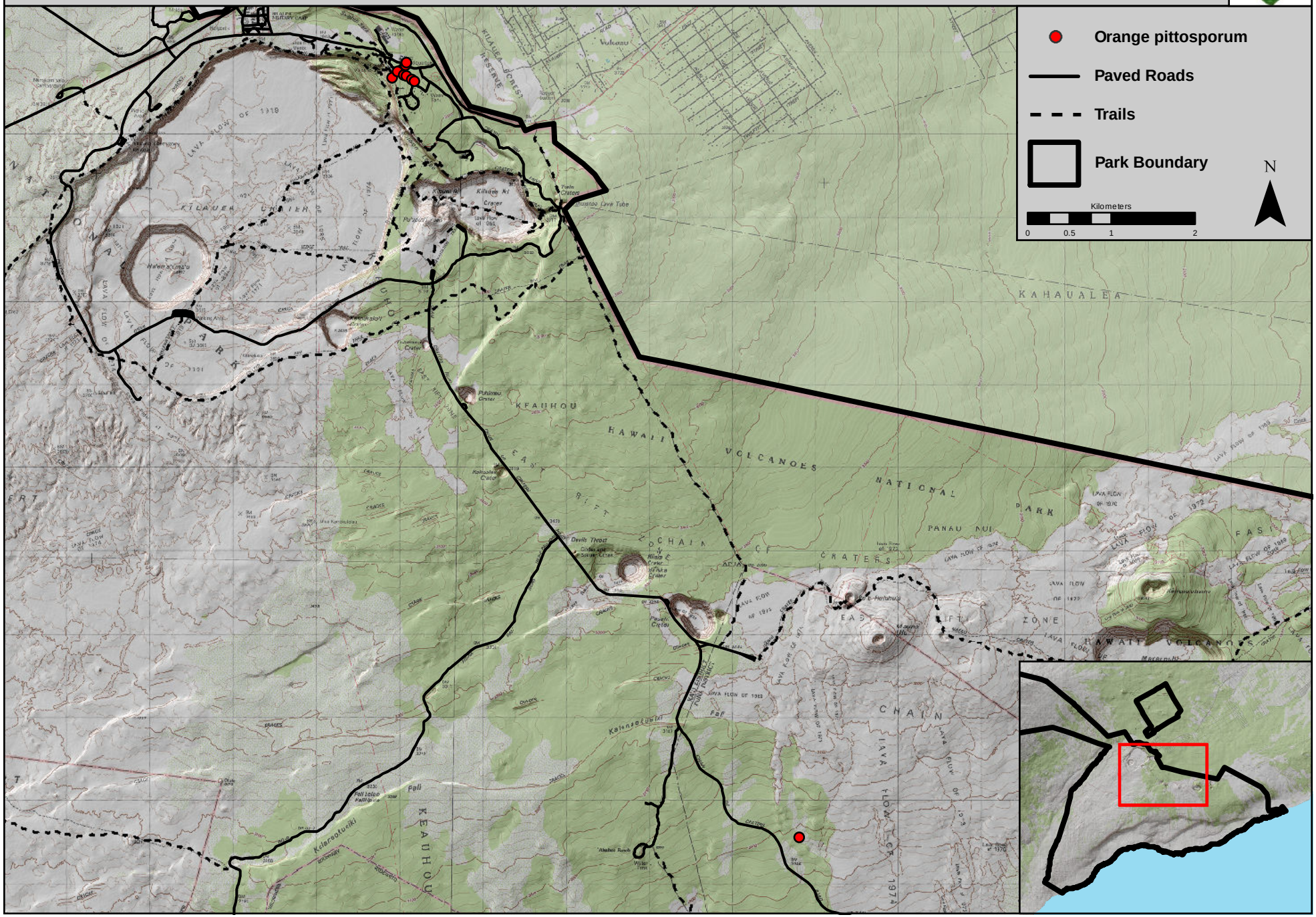
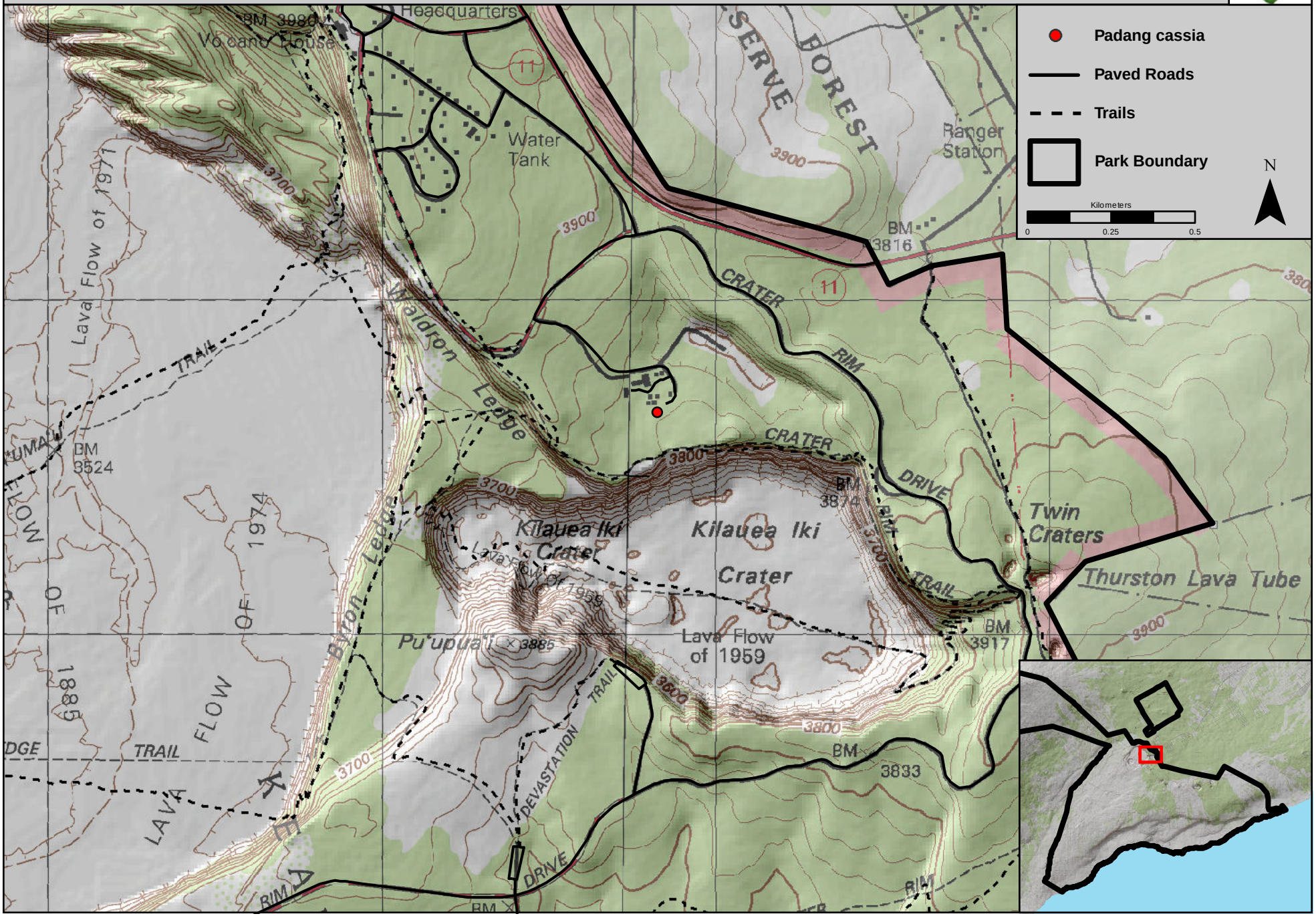
Orange pittosporum (*Pittosporum undulatum*)



Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Padang cassia (*Cinnamomum burmanii*)



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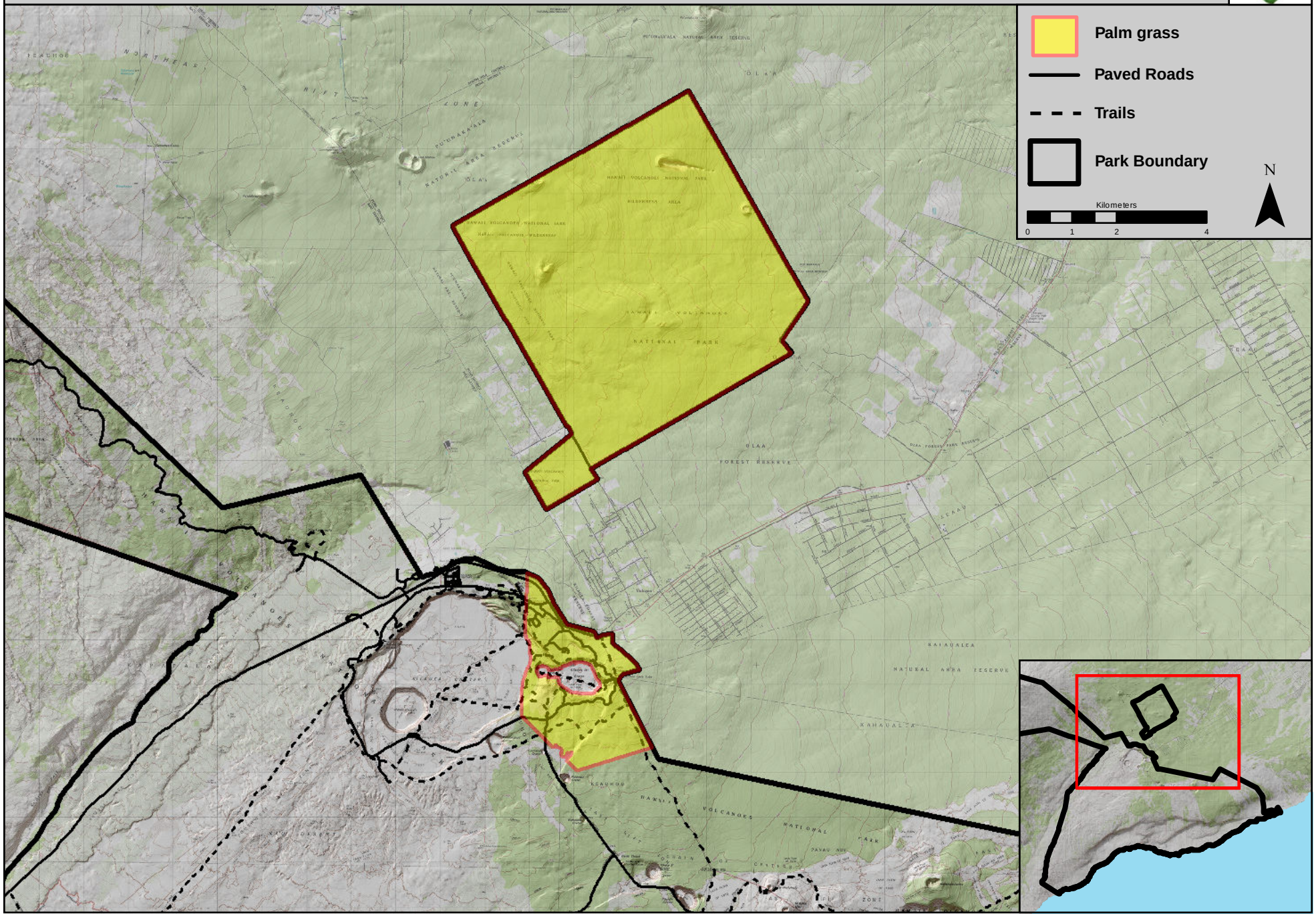
Palm grass (*Setaria palmaefolia*)



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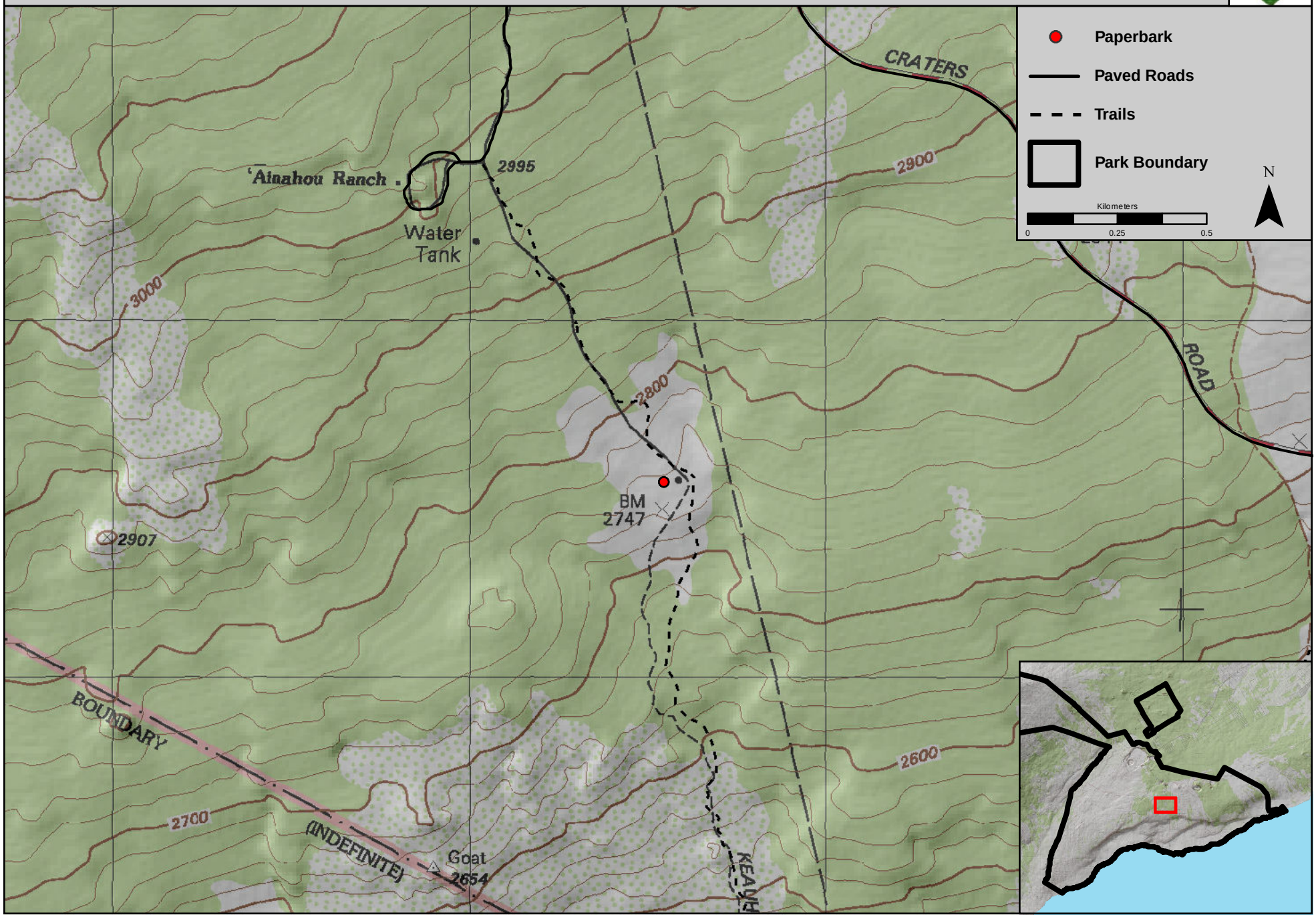
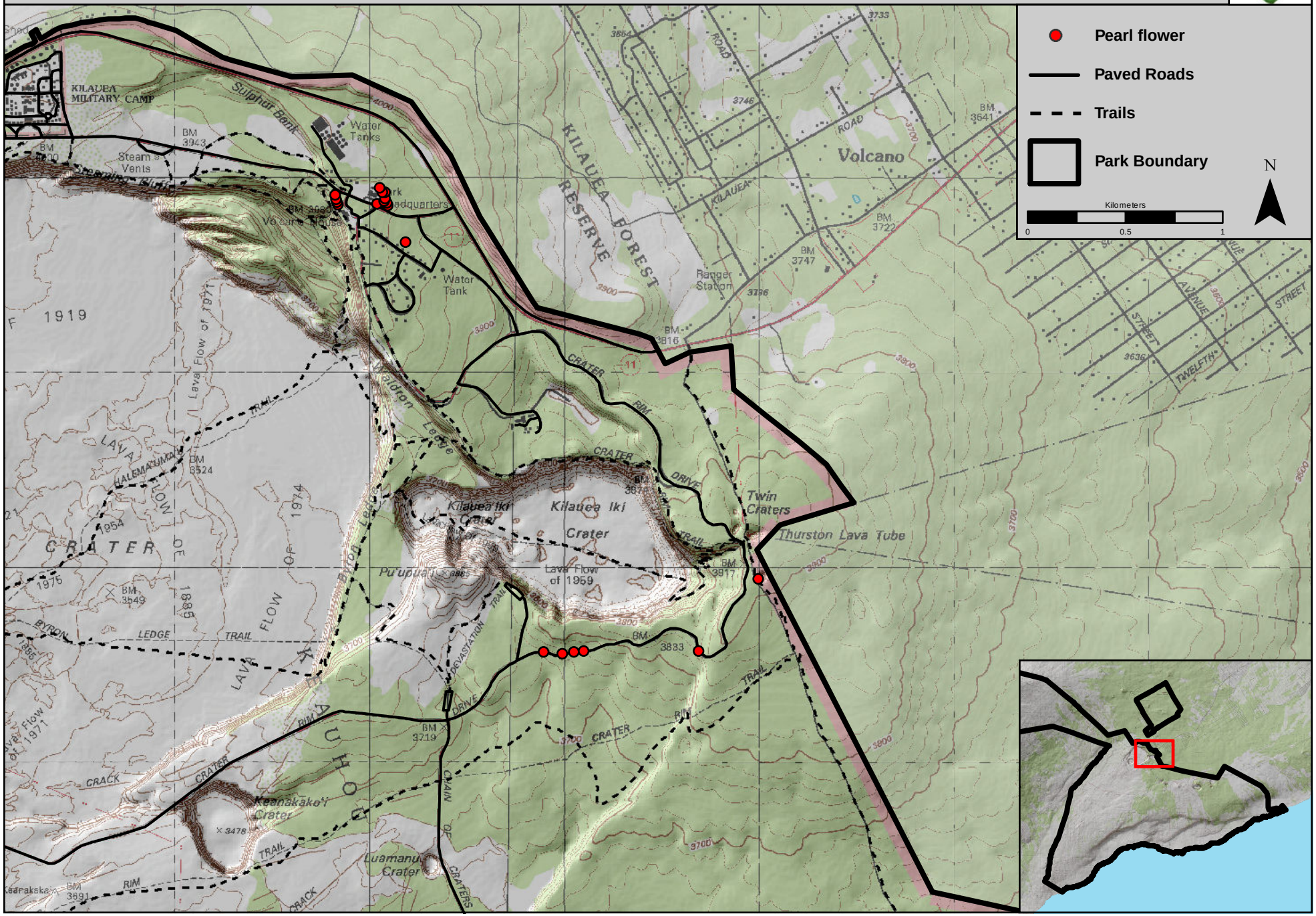
Paperbark (*Melaleuca quinquenervia*)



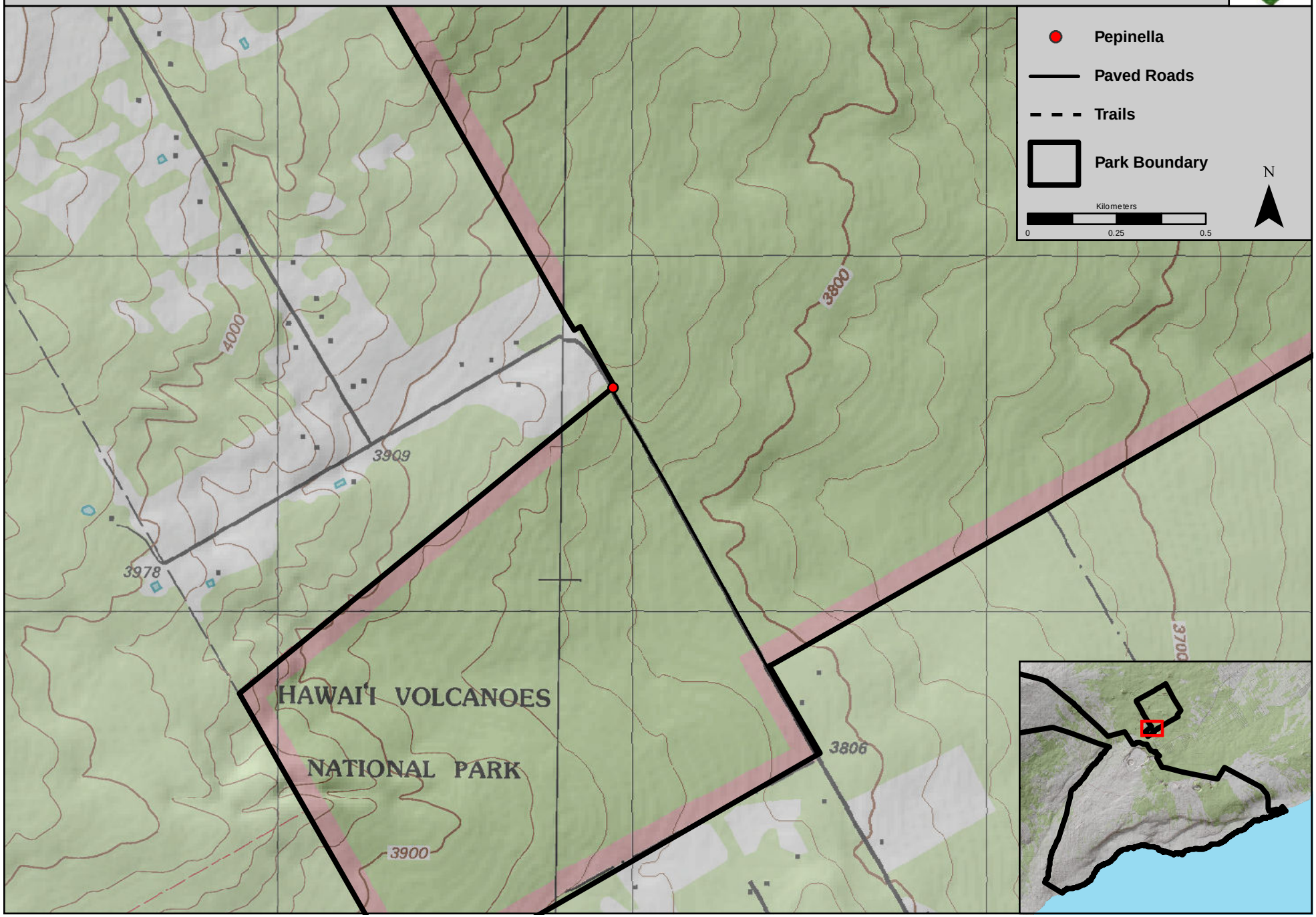
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Pearl flower (*Heterocentron subtriplinerveum*)



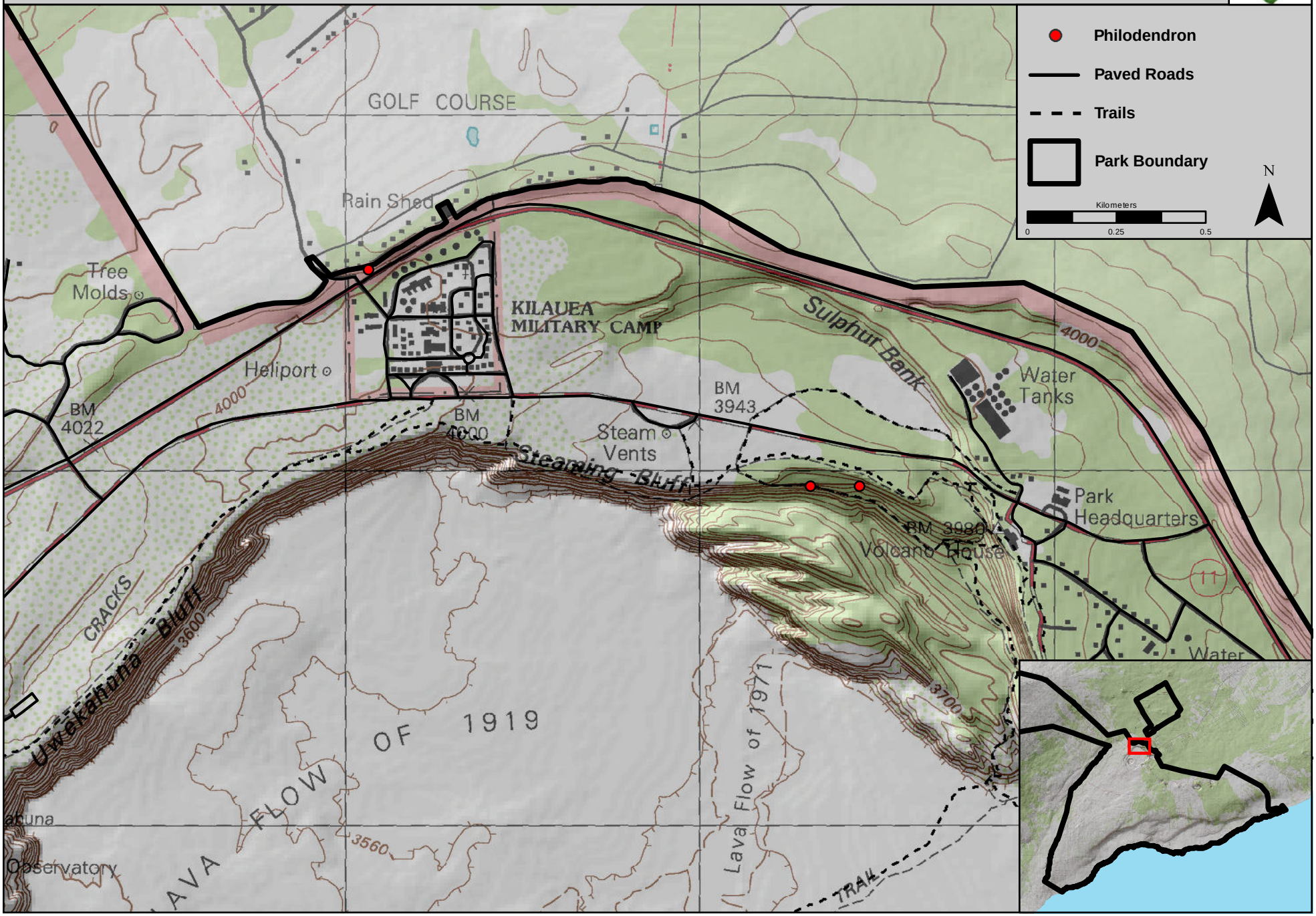
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/13/2011

Pepinella (*Sechium edule*)



Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Philodendron (*Philodendron* sp.)



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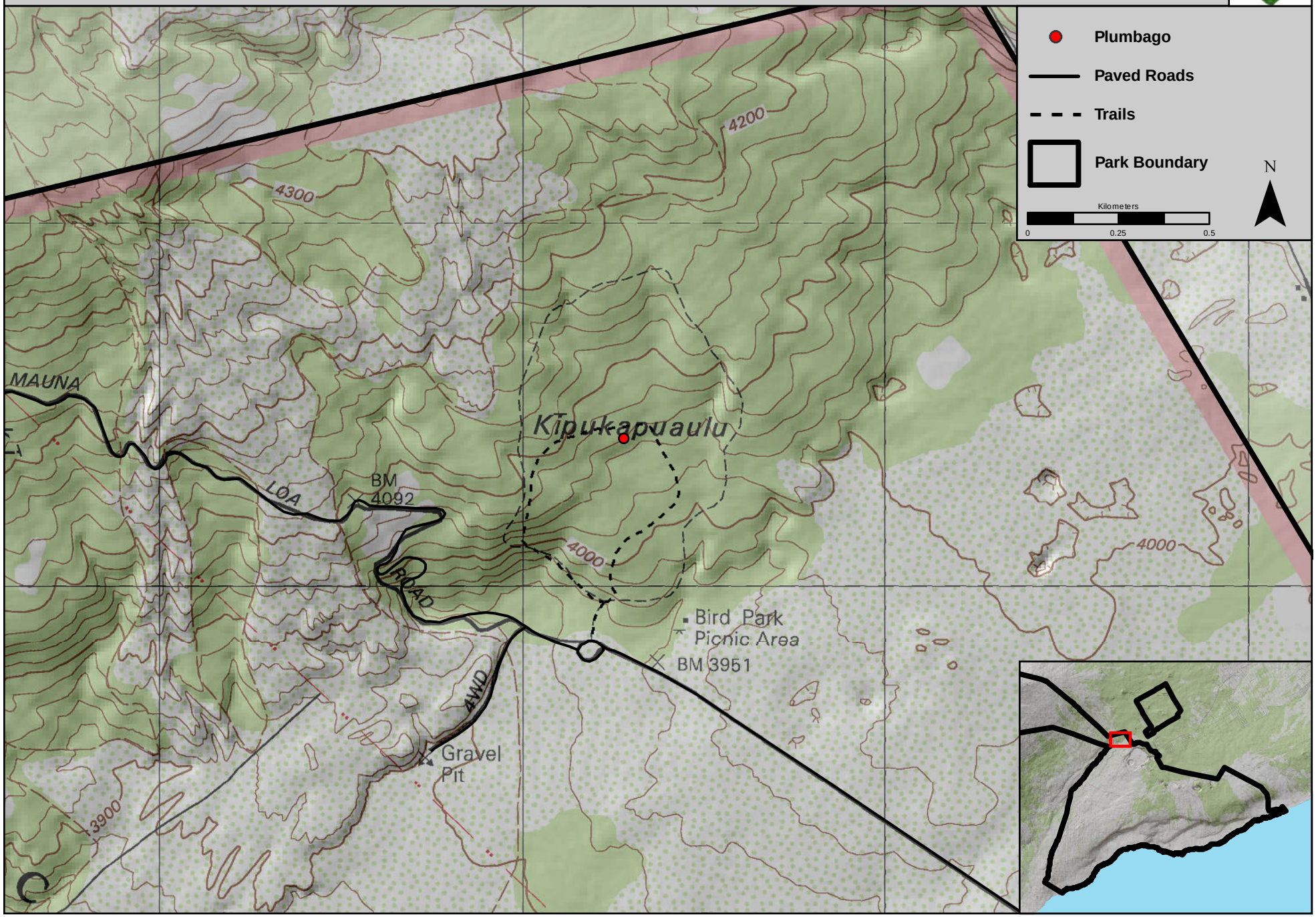
Plumbago (*Plumbago auriculata*)



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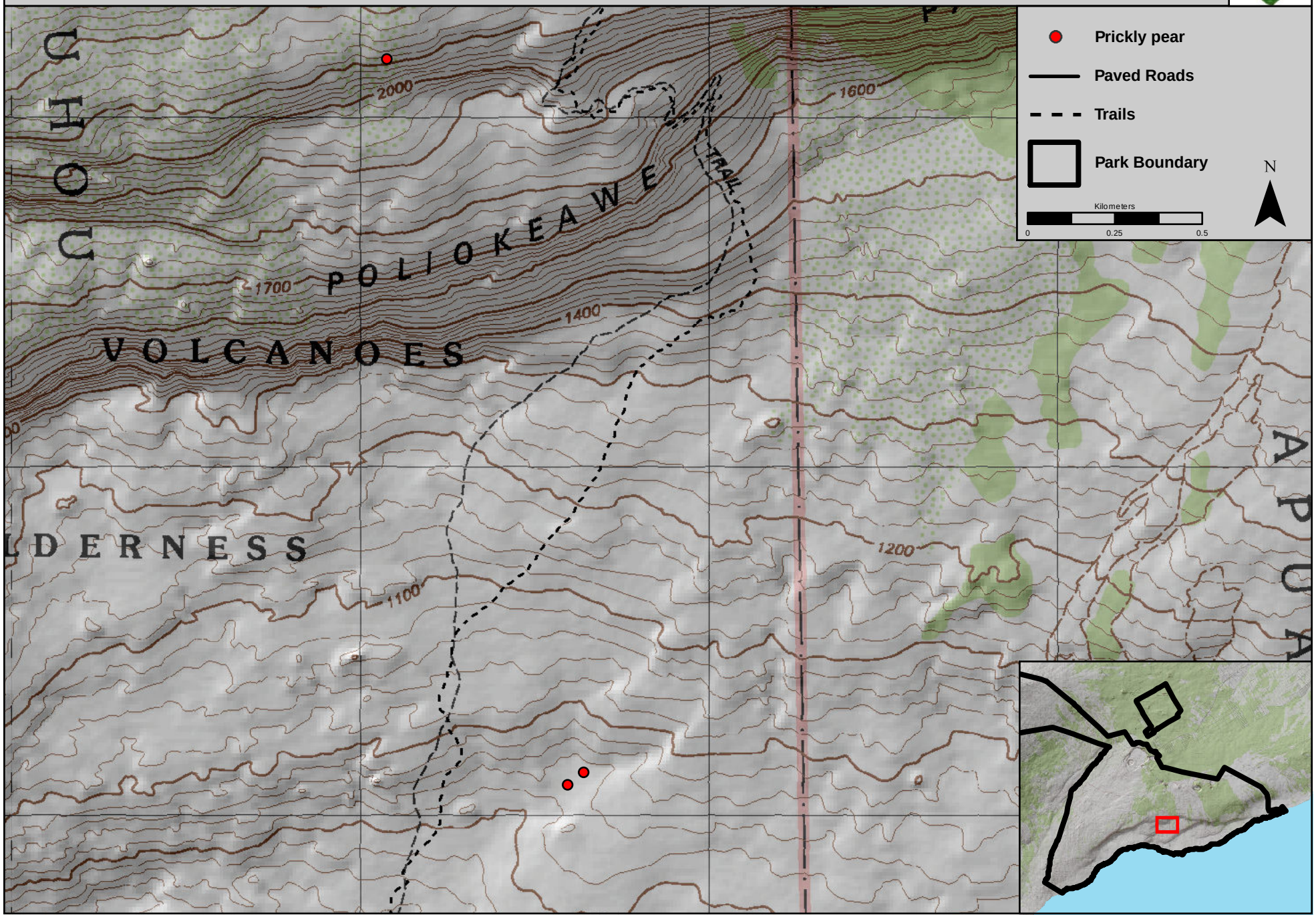
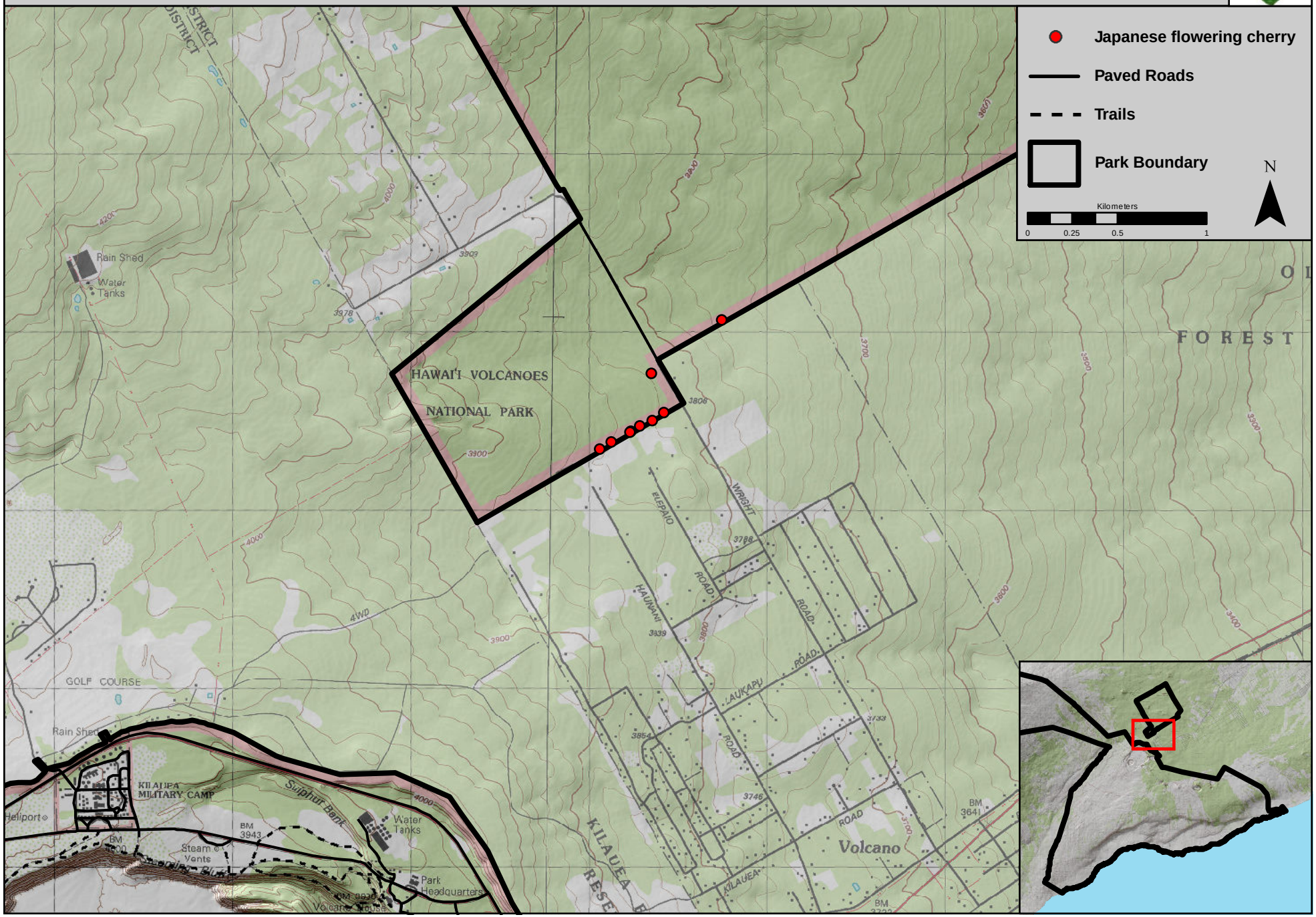
Prickly pear (*Opuntia ficus-indica*)



Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Japanese flowering cherry (*Prunus serrulata*)



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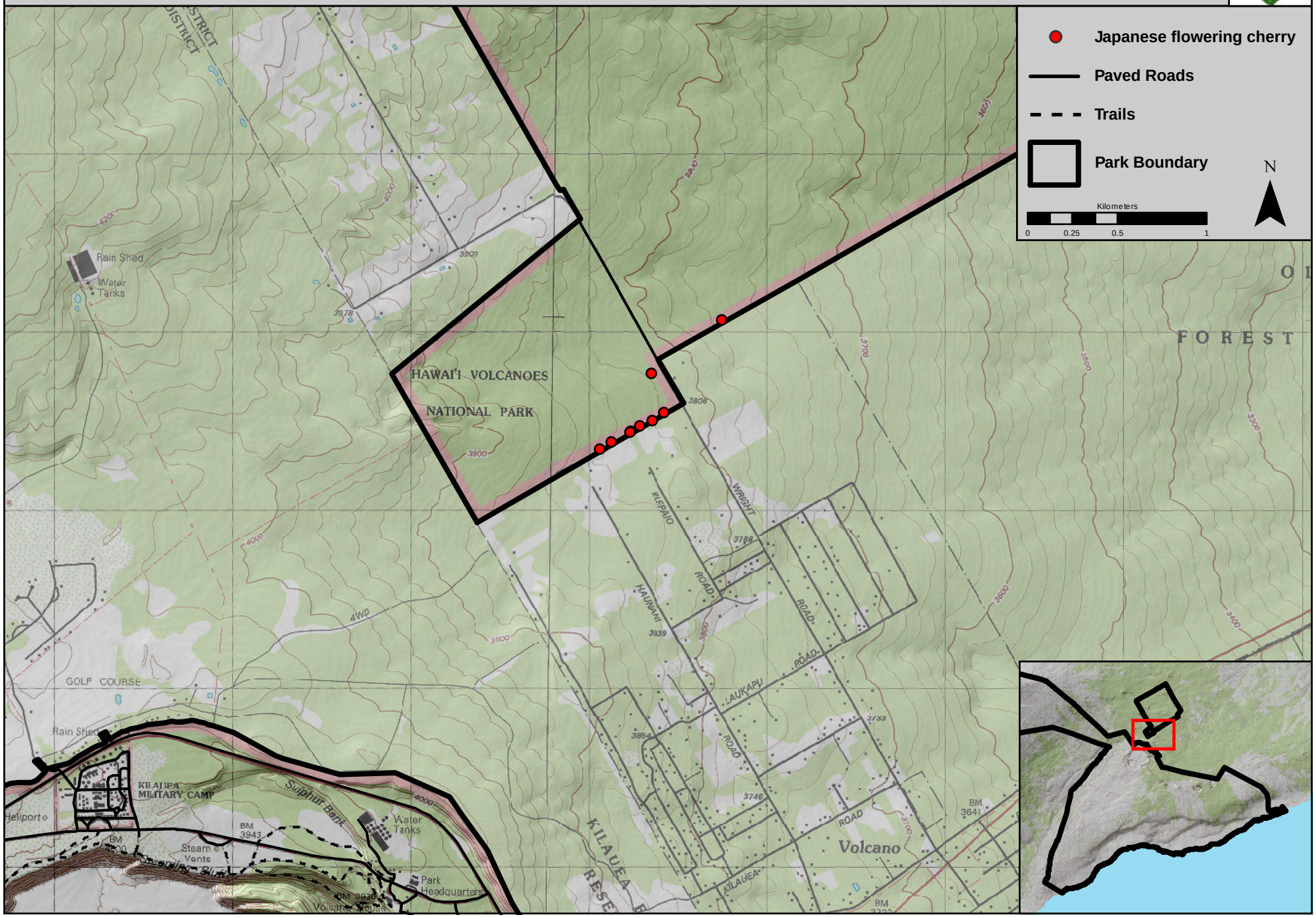
Japanese flowering cherry (*Prunus serrulata*)



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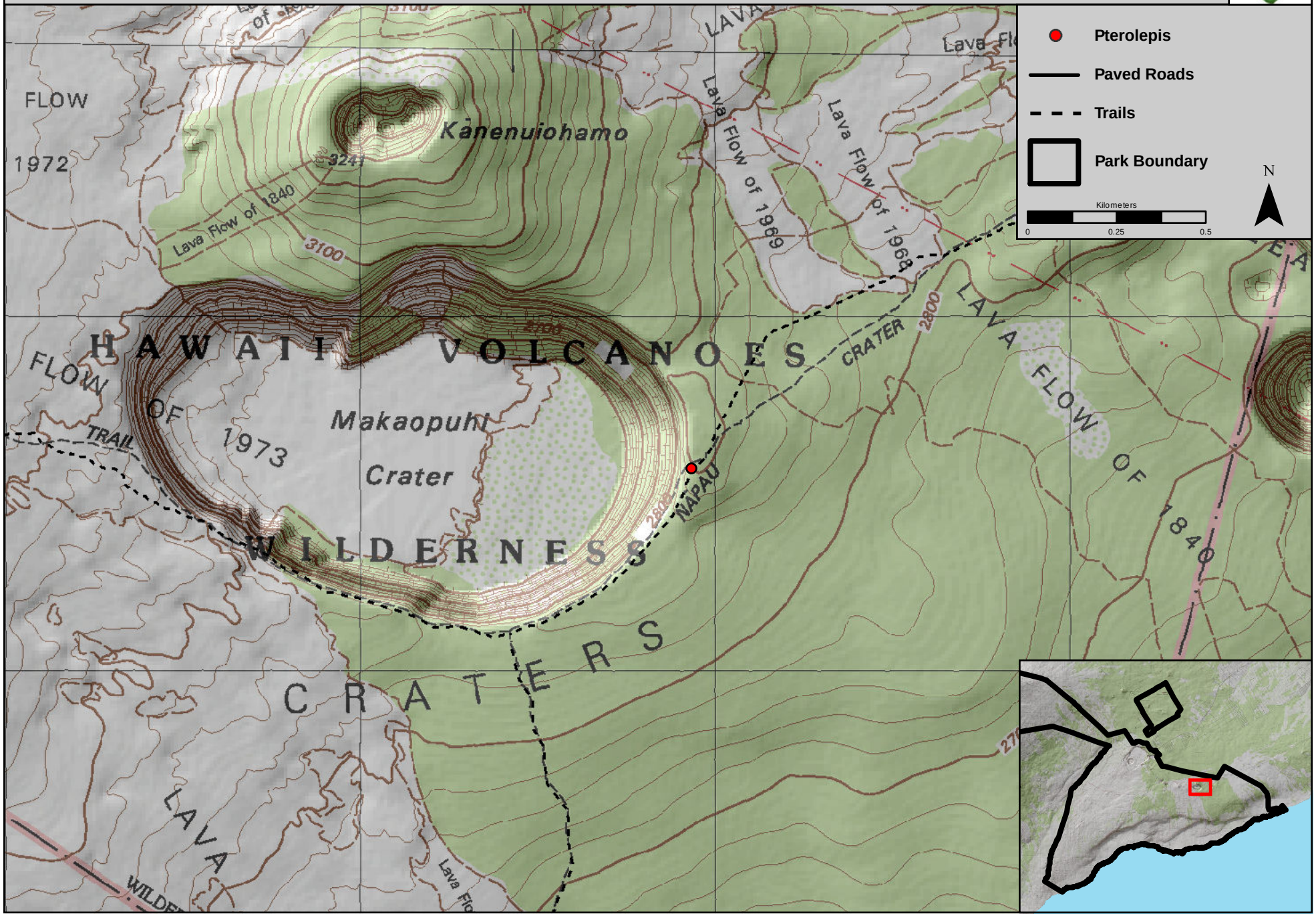
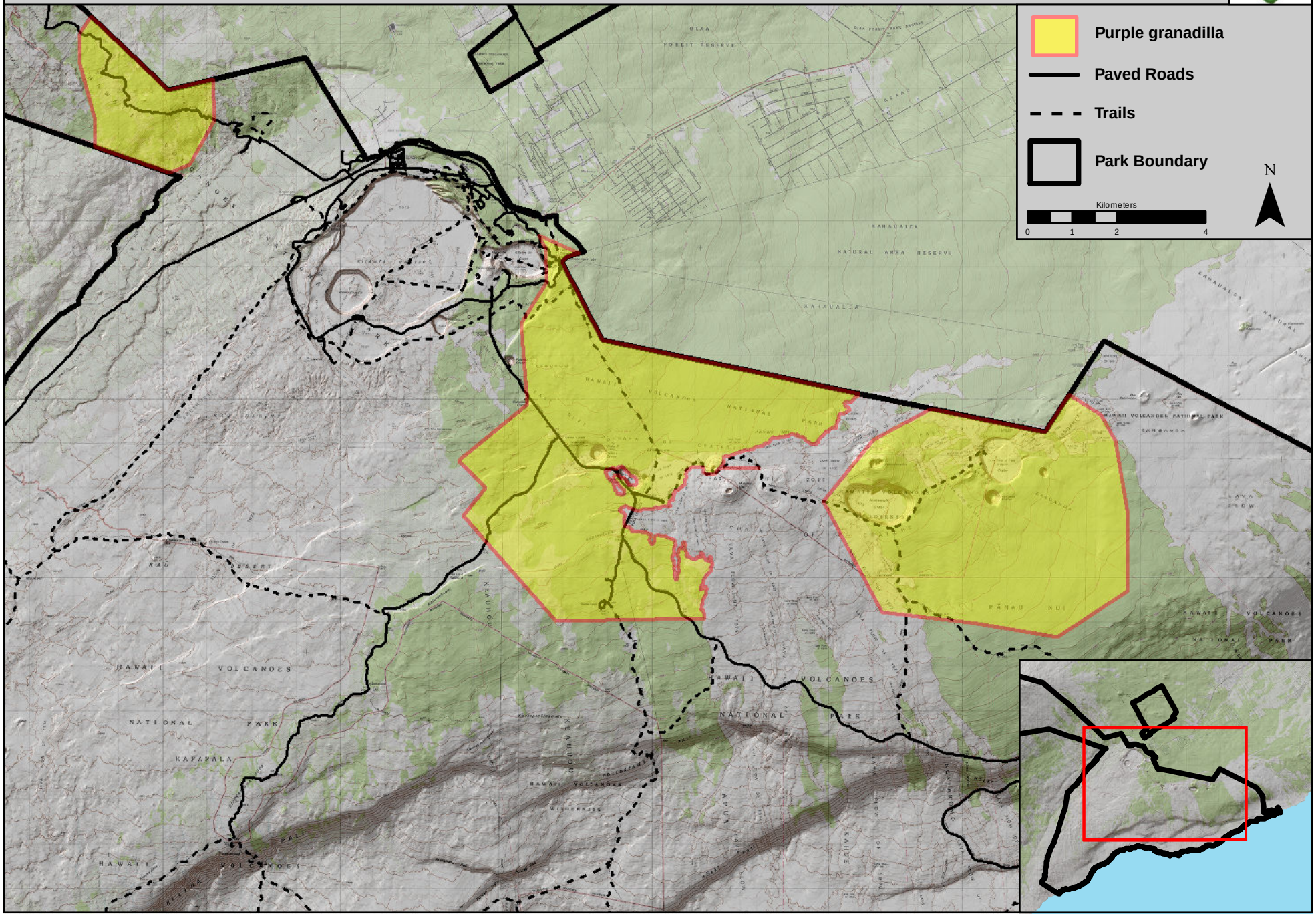
Pterolepis (*Pterolepis glomerata*)



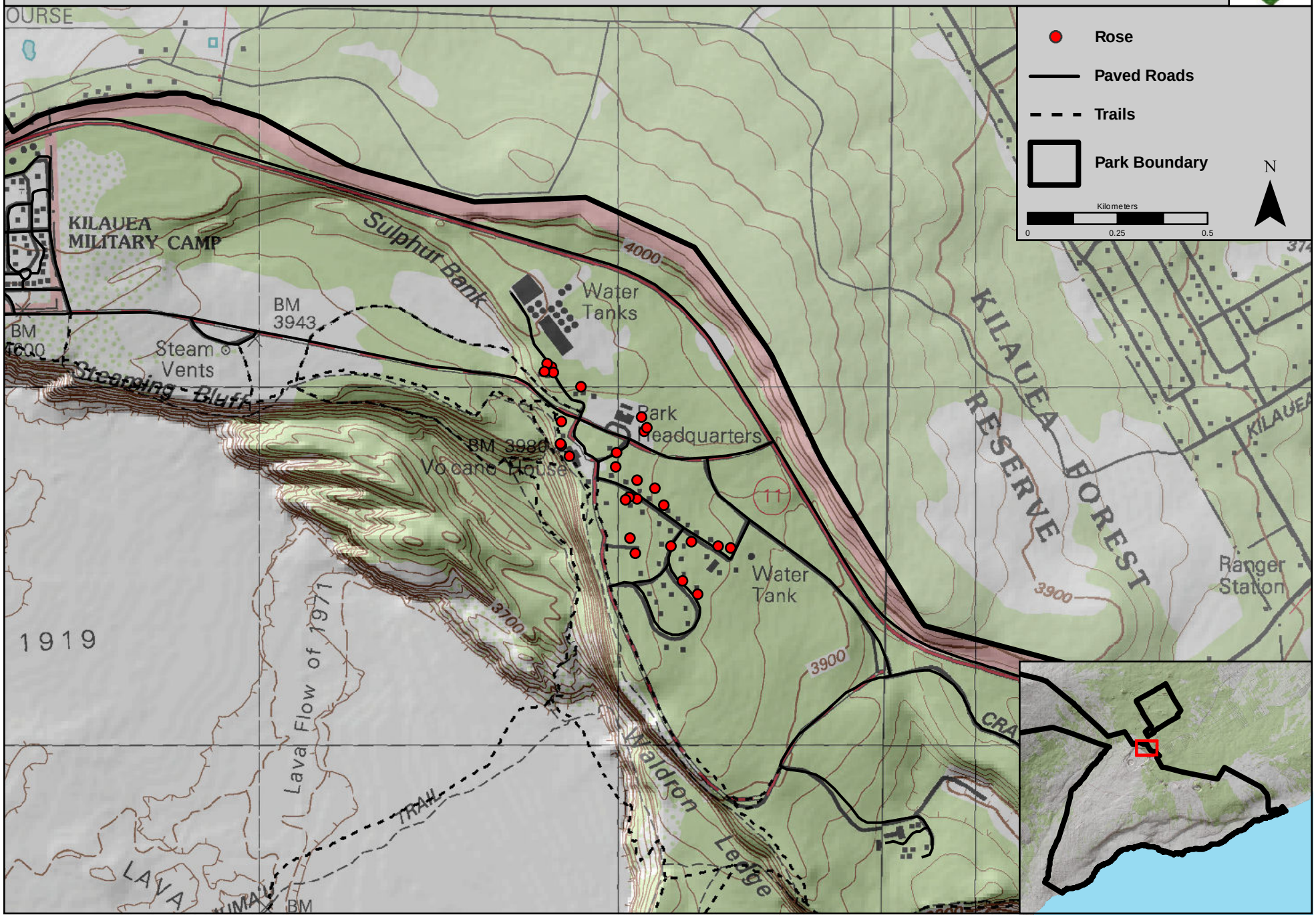
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Purple granadilla (*Passiflora edulis*)



Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/22/2011

Rose (*Rosa* spp.)



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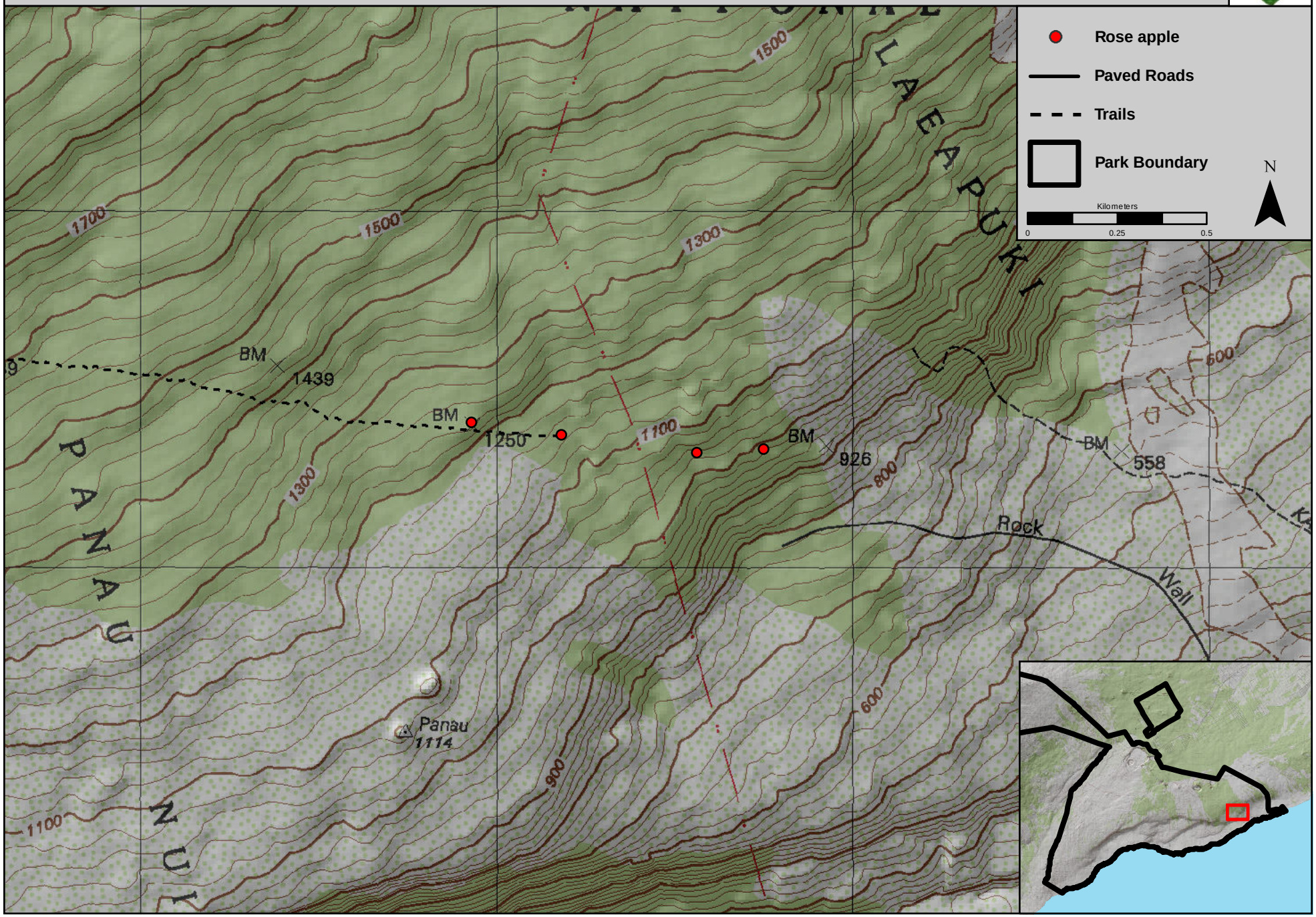
Rose apple (*Syzygium jambos*)



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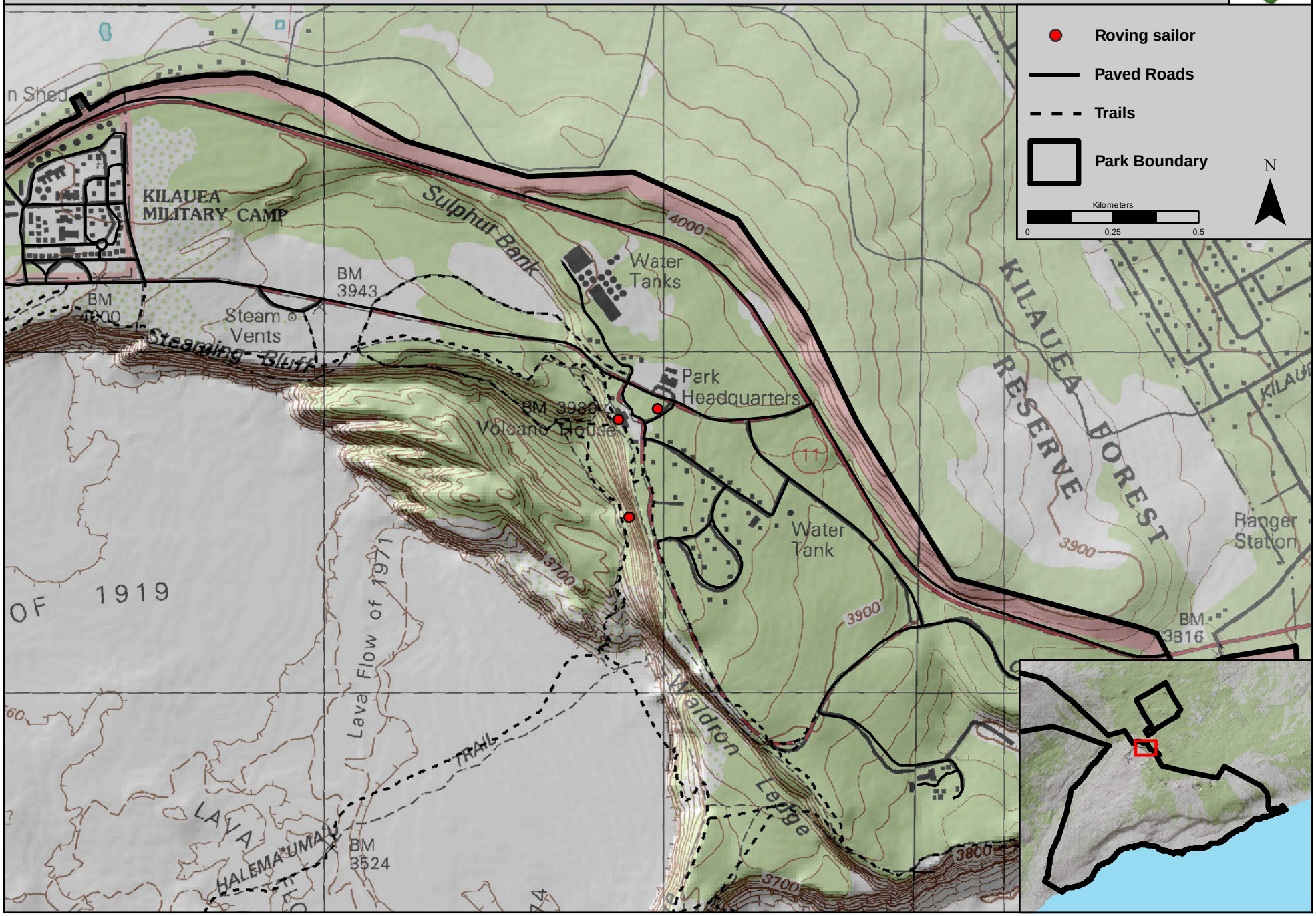
Roving sailor (*Lophospermum erubescens*)



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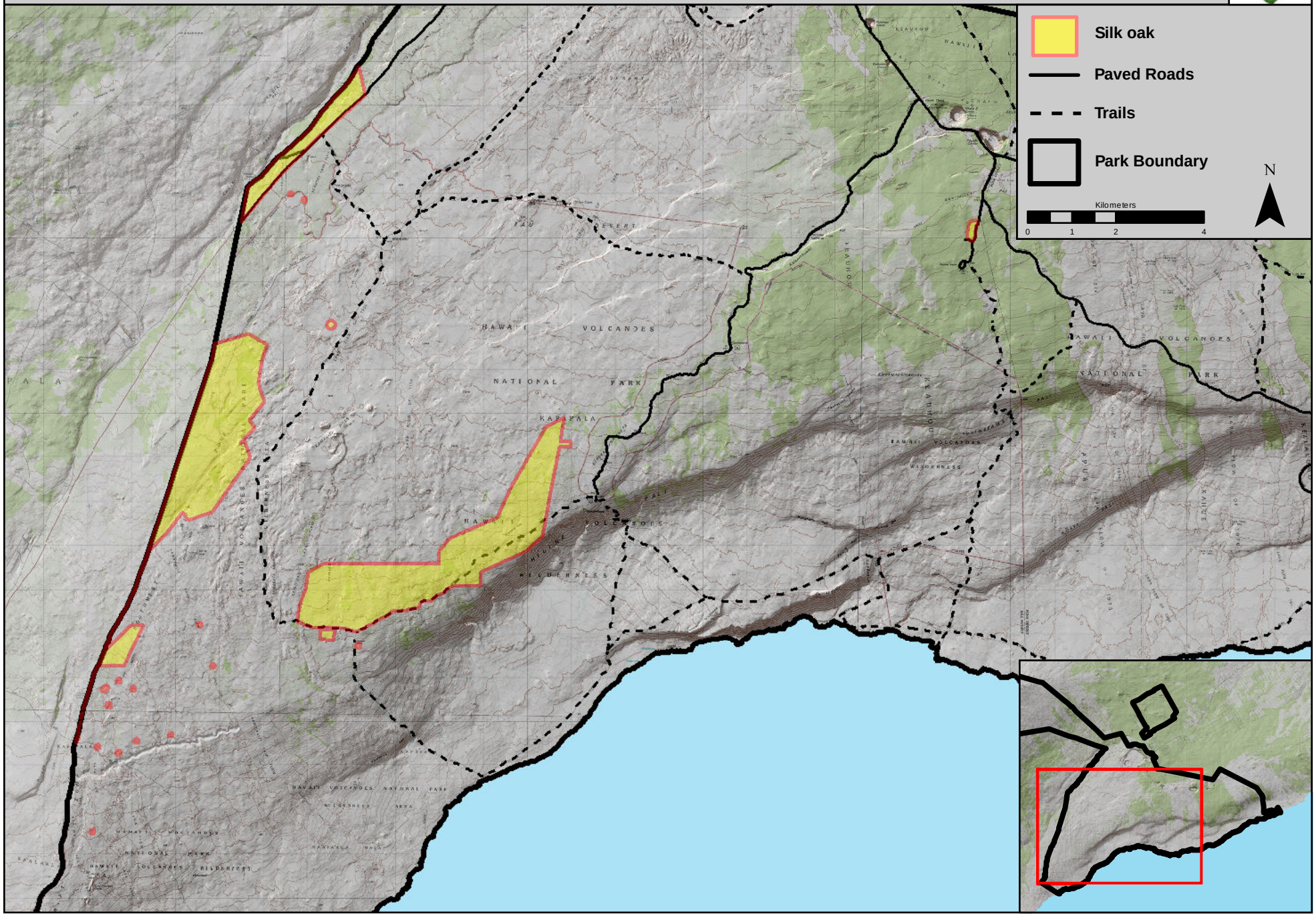
Silk oak (*Grevillea robusta*)



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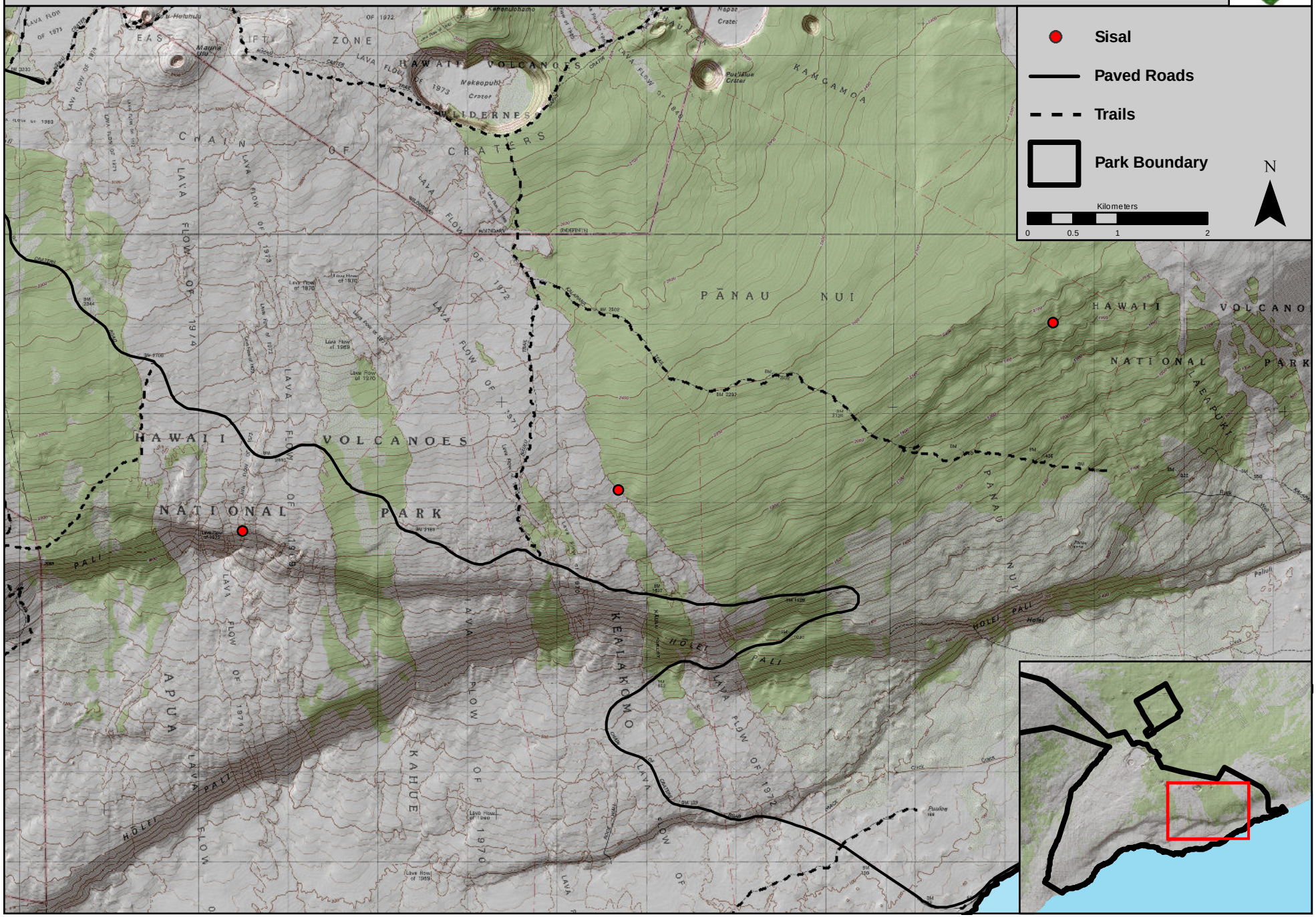
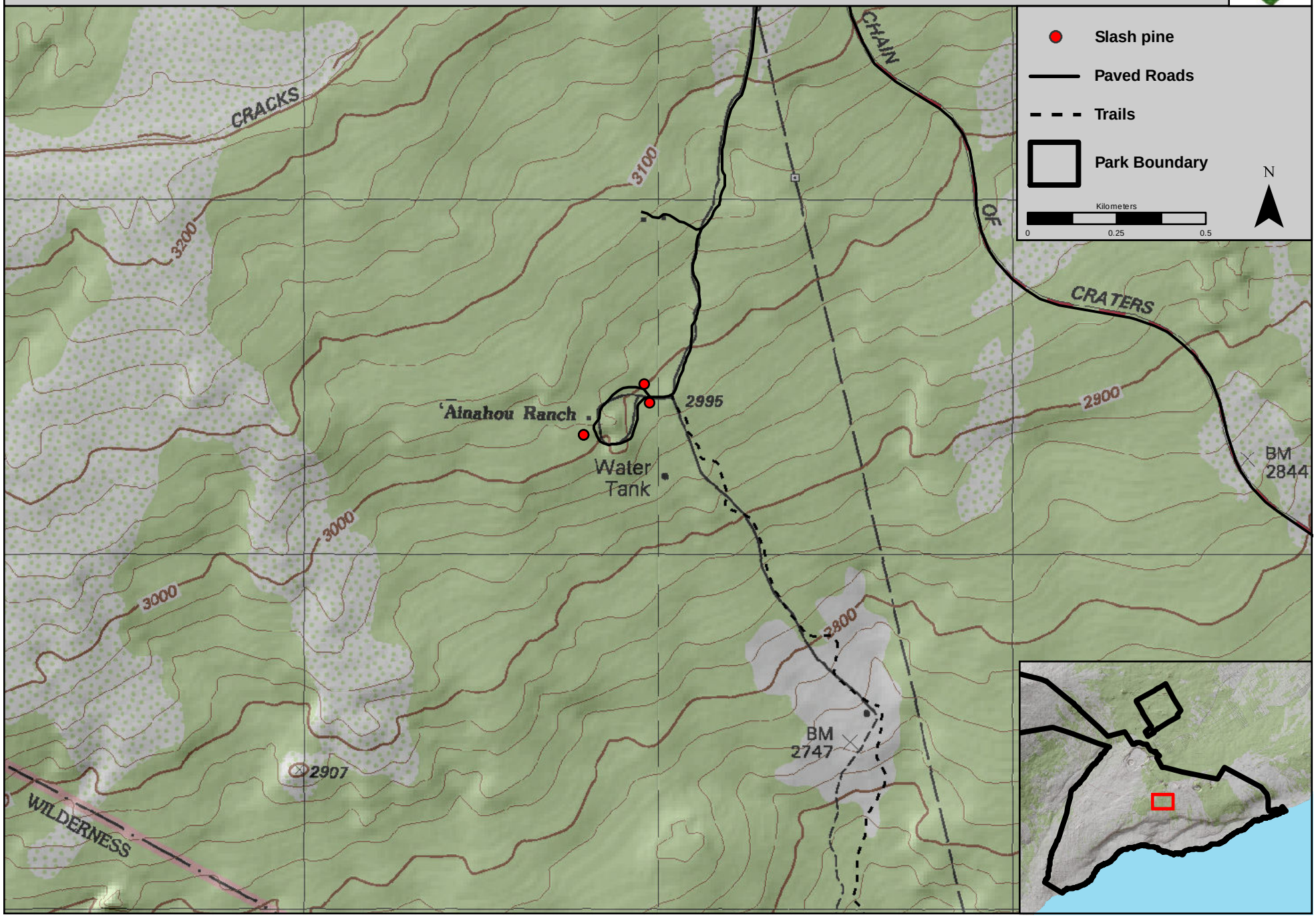
Sisal (*Agave sisalana*)



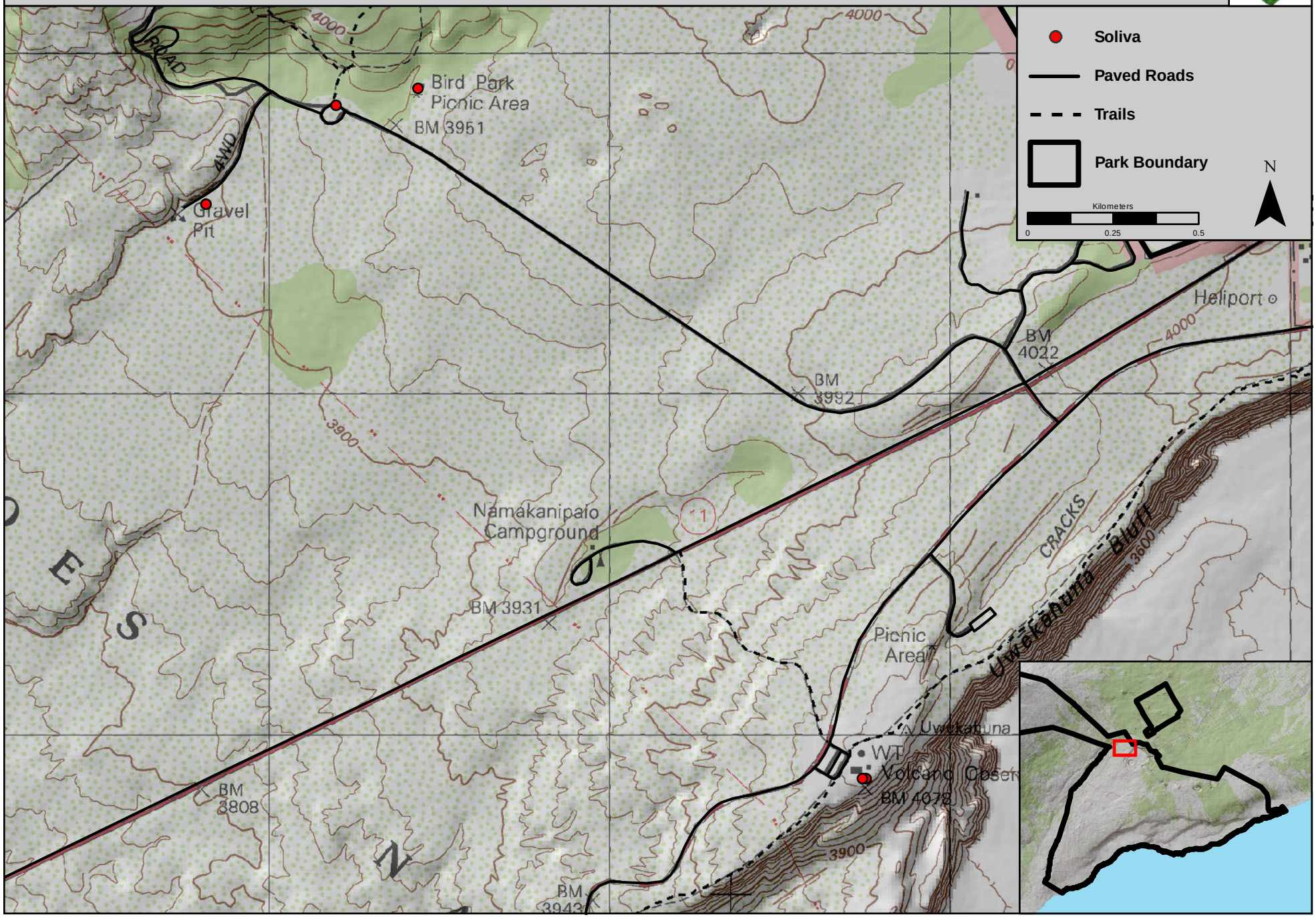
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Slash pine (*Pinus caribaea*)



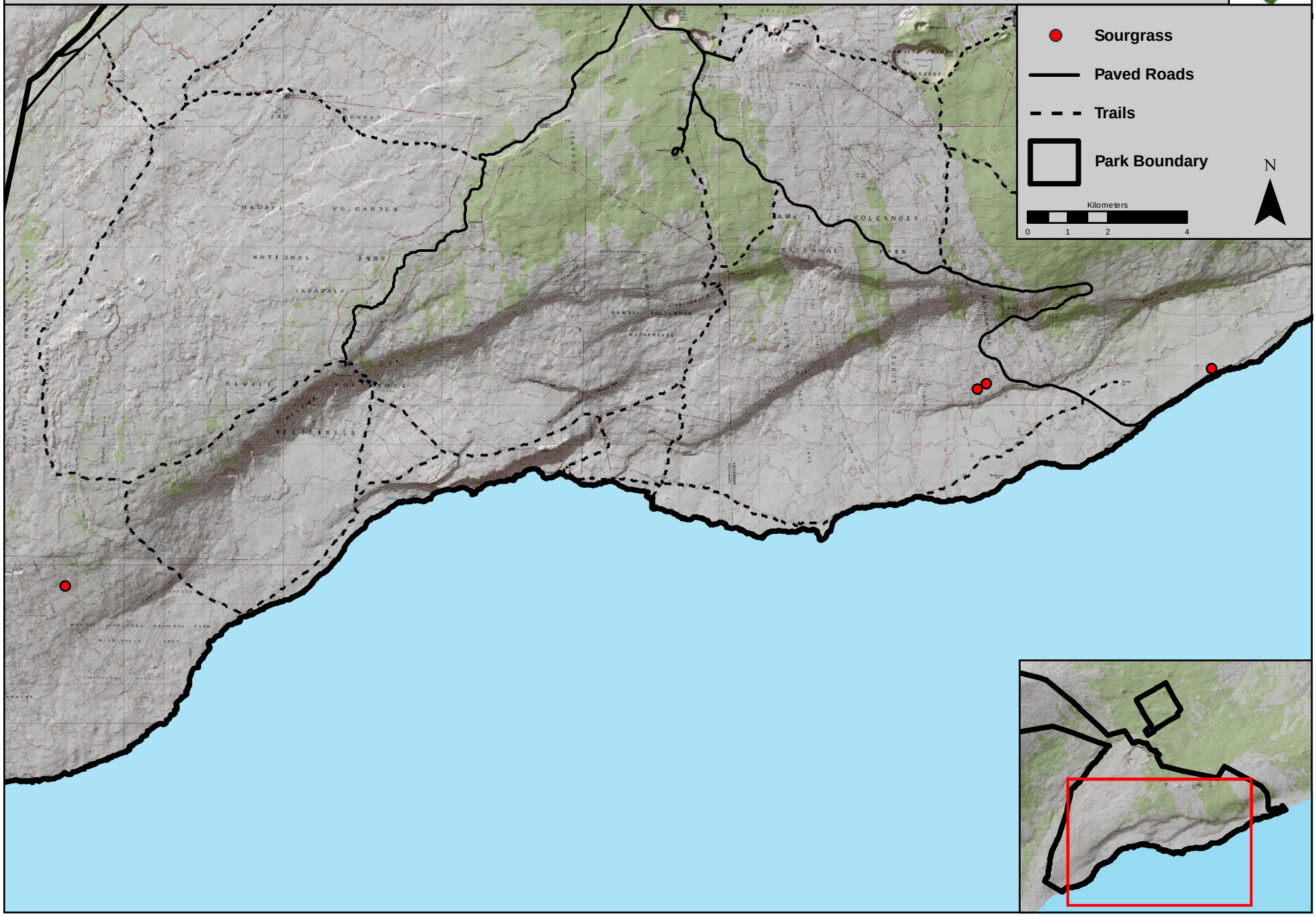
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Soliva (*Soliva sessilis*)



Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Sourgrass (*Digitaria insularis*)



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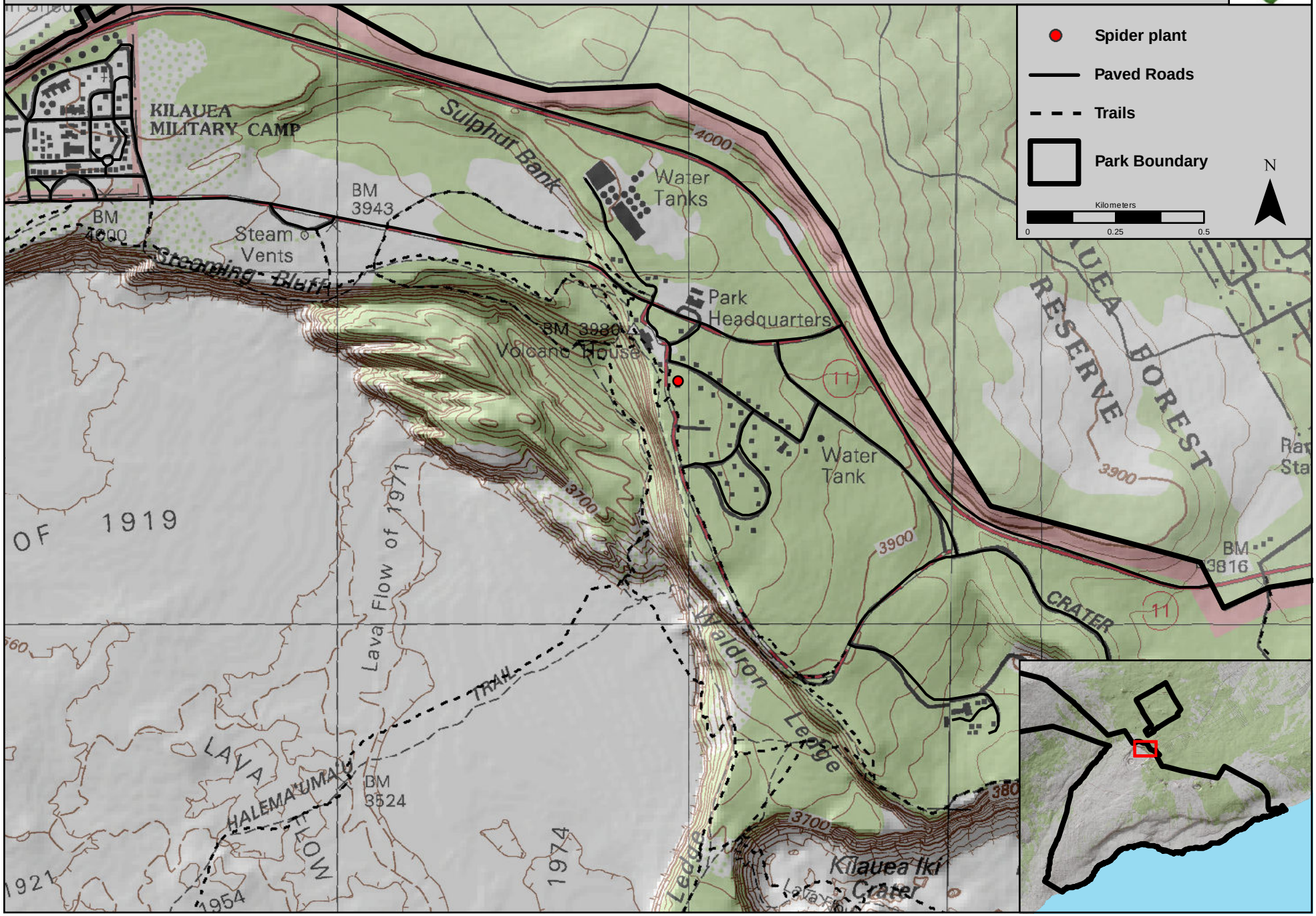
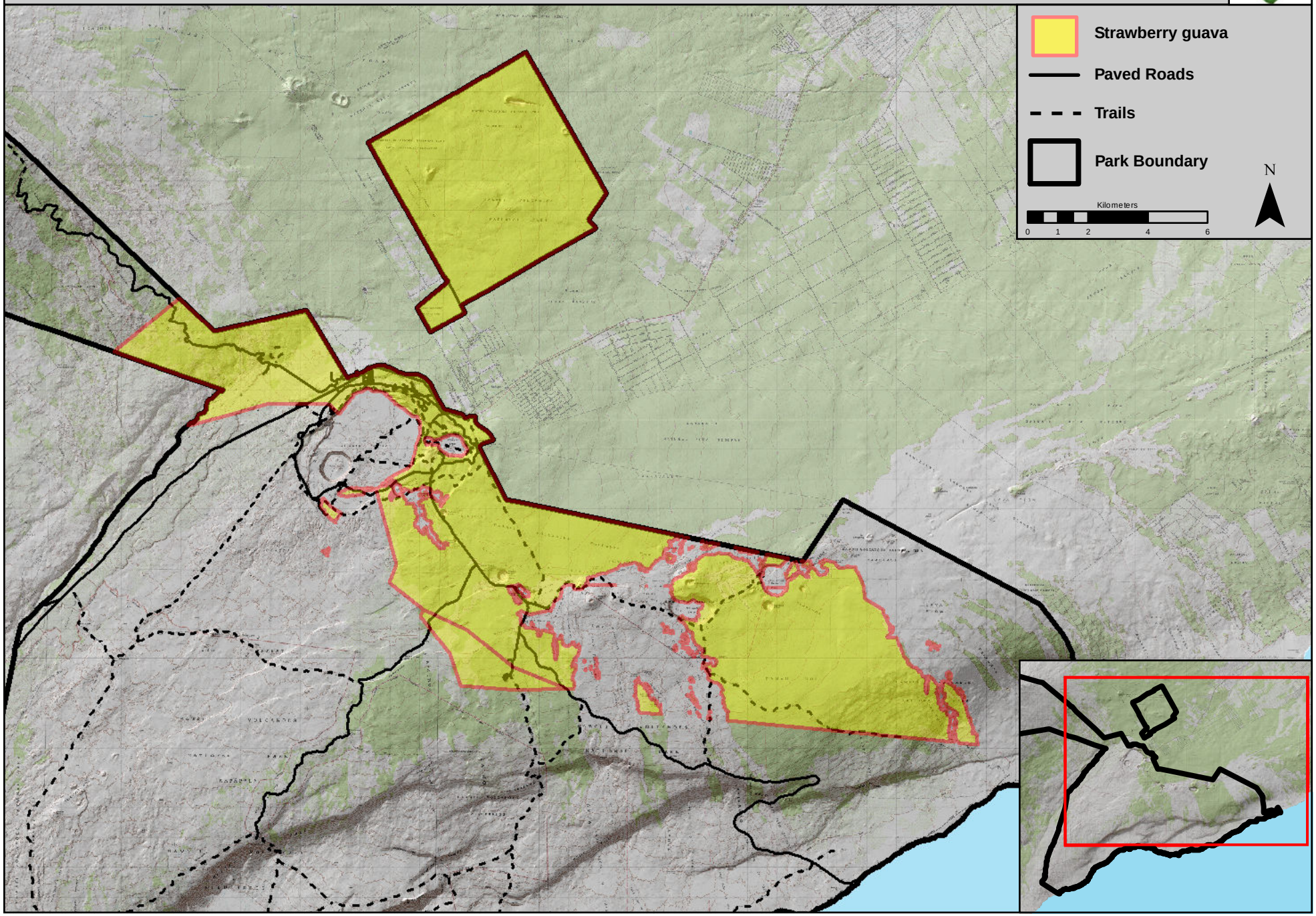
Spider plant (*Chlorophytum comosum*)



Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Strawberry guava (*Psidium cattleianum*)



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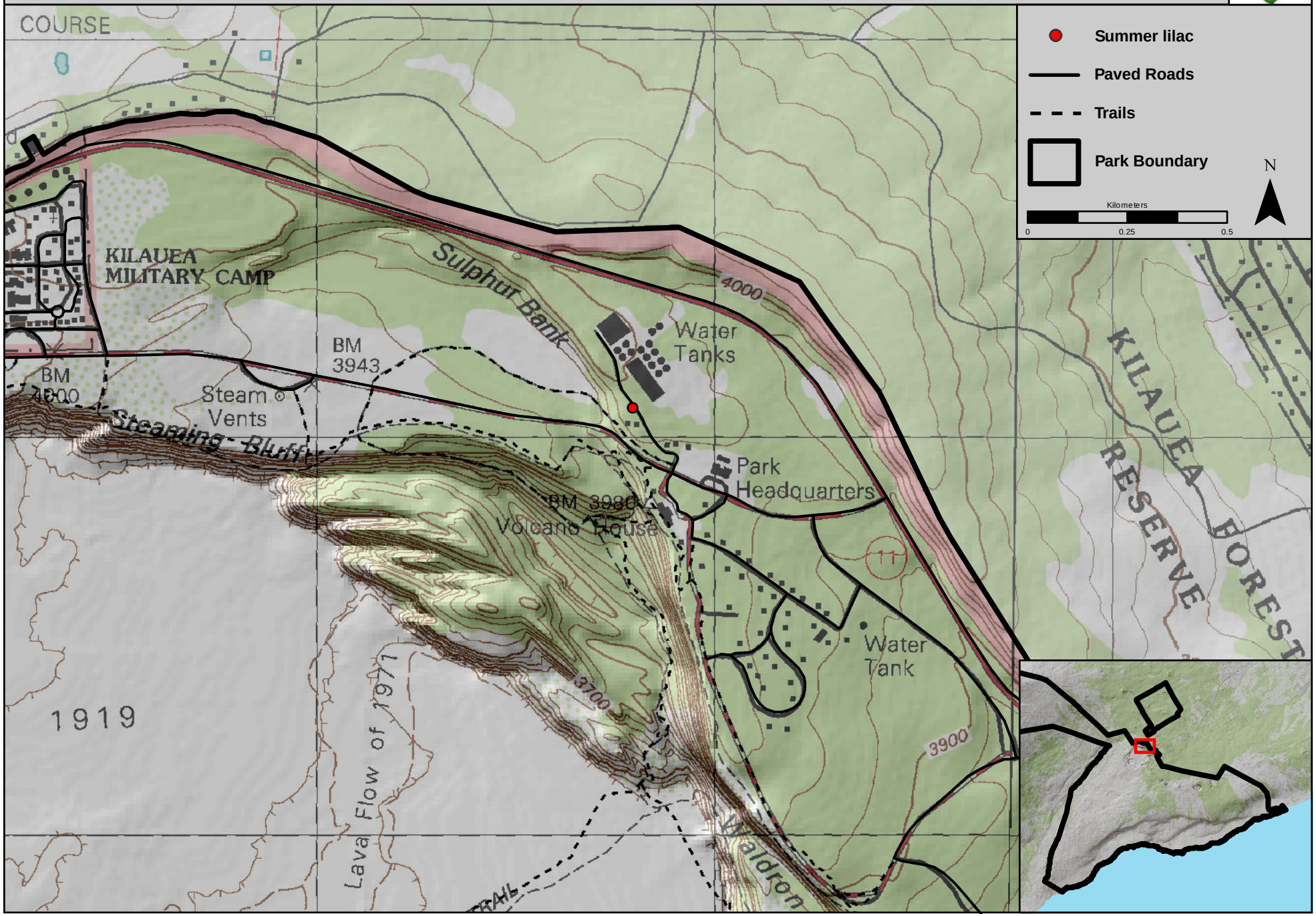
Summer lilac (*Buddleia davidii*)



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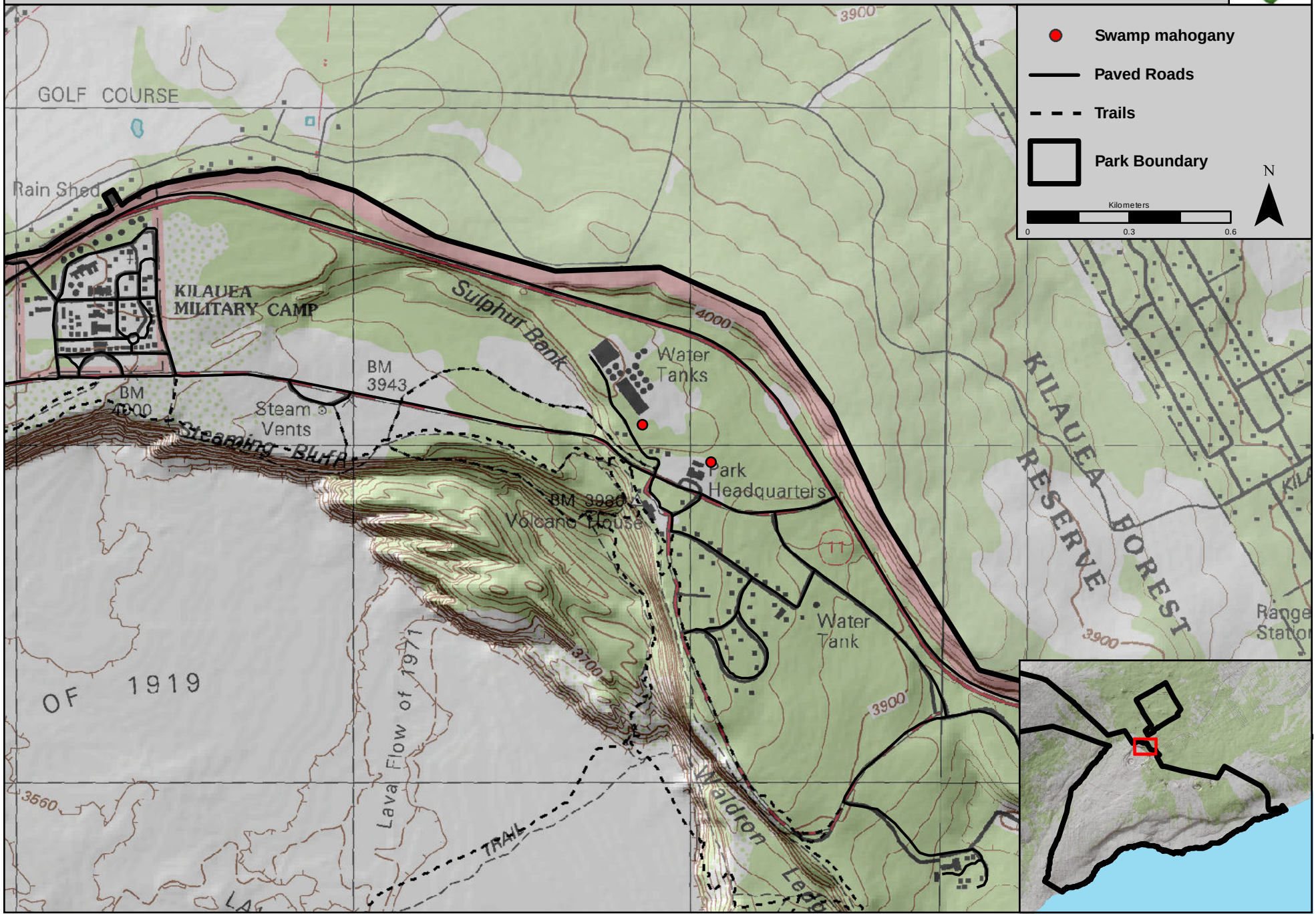
Swamp mahogany (*Eucalyptus robusta*)



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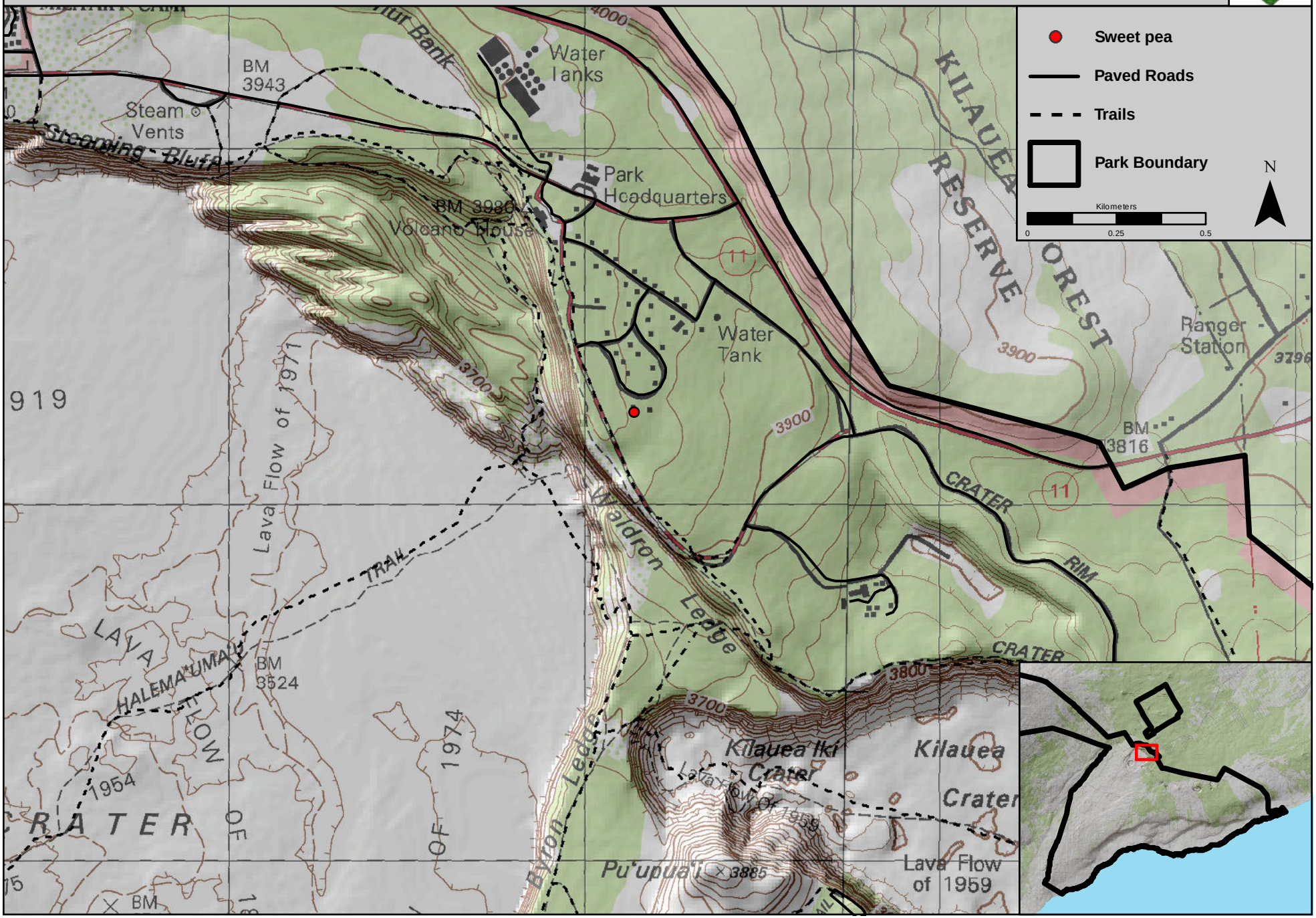
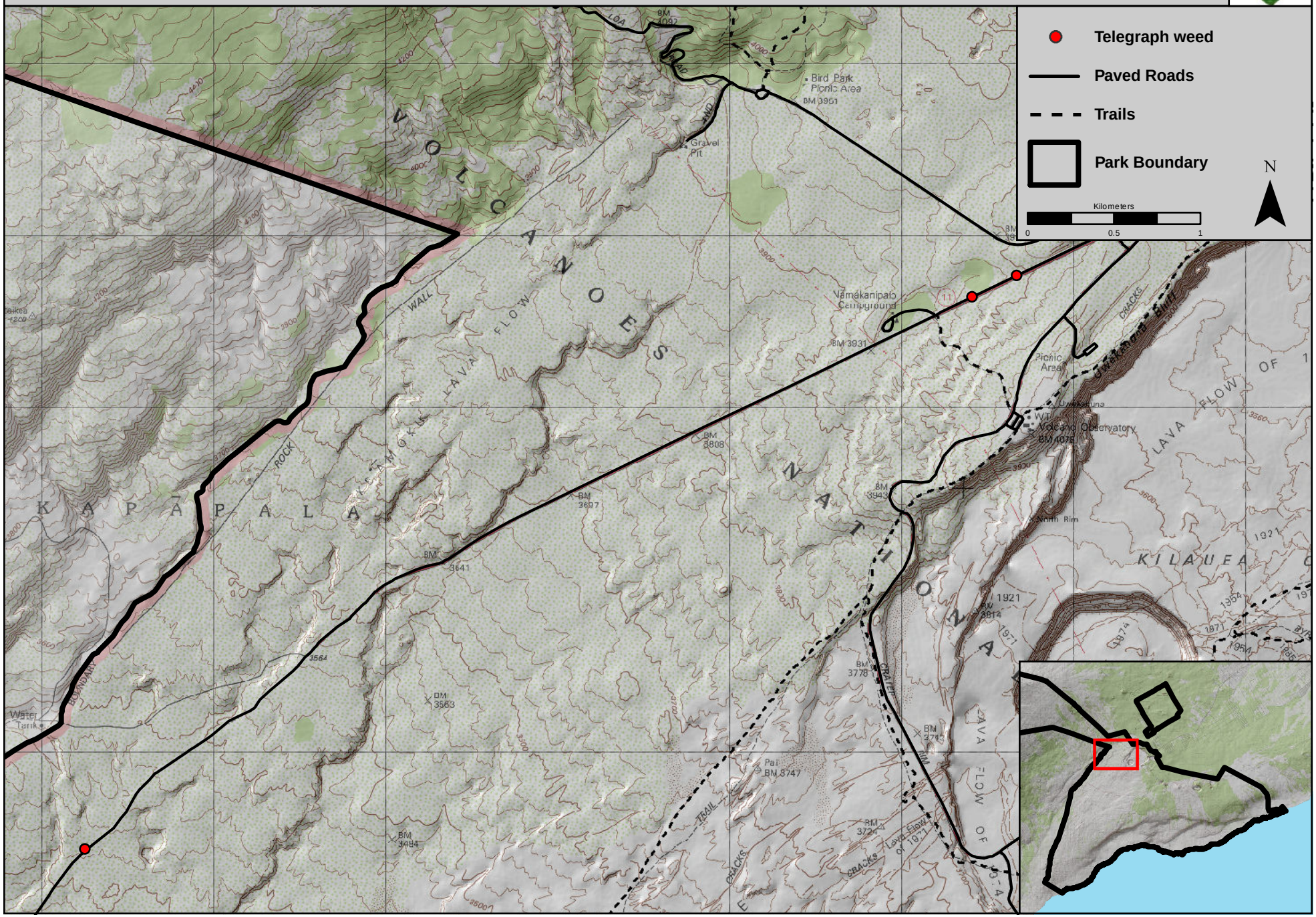
Sweet pea (*Lathyrus odoratus*)



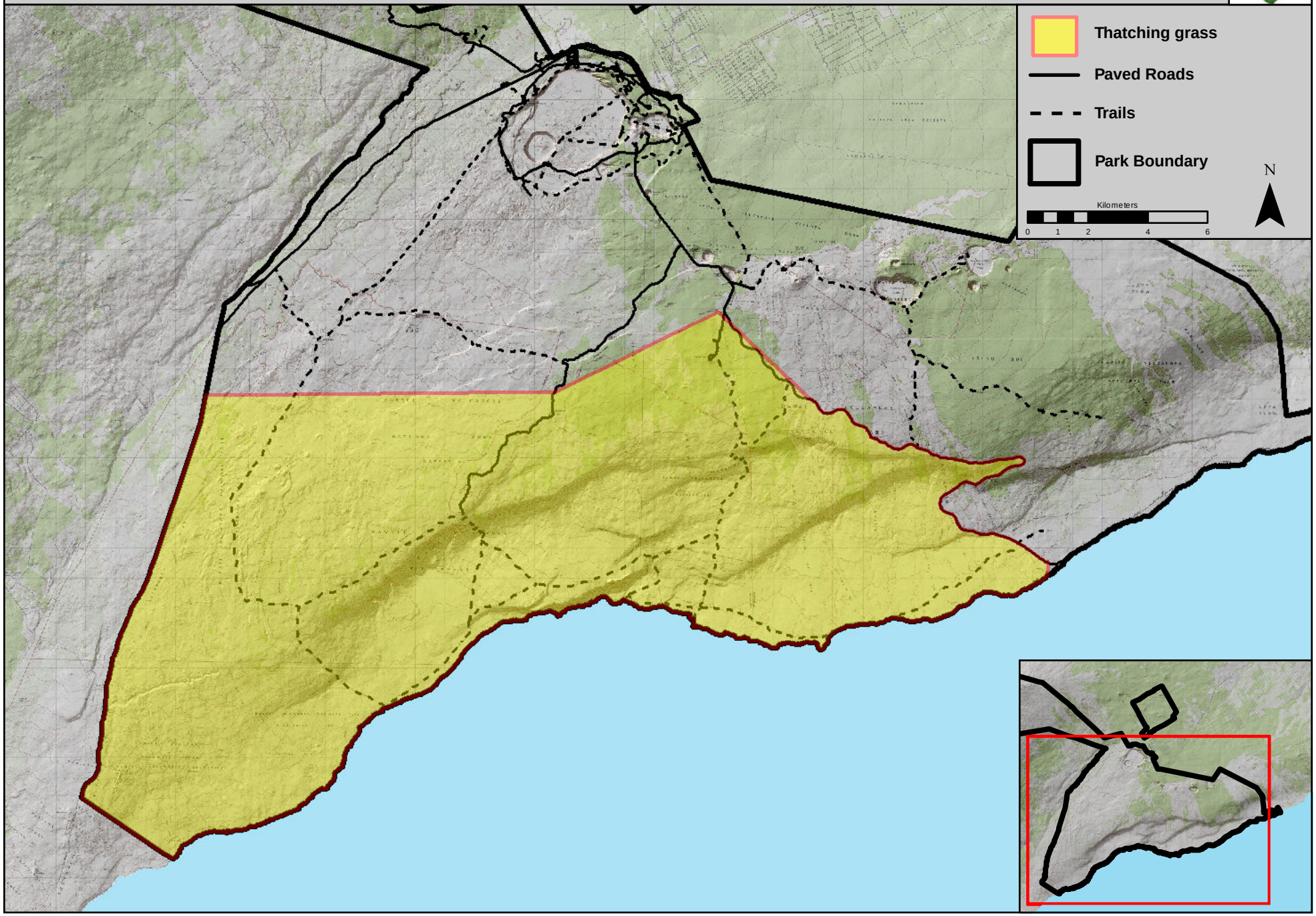
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/15/2011

Telegraph weed (*Heterotheca grandiflora*)



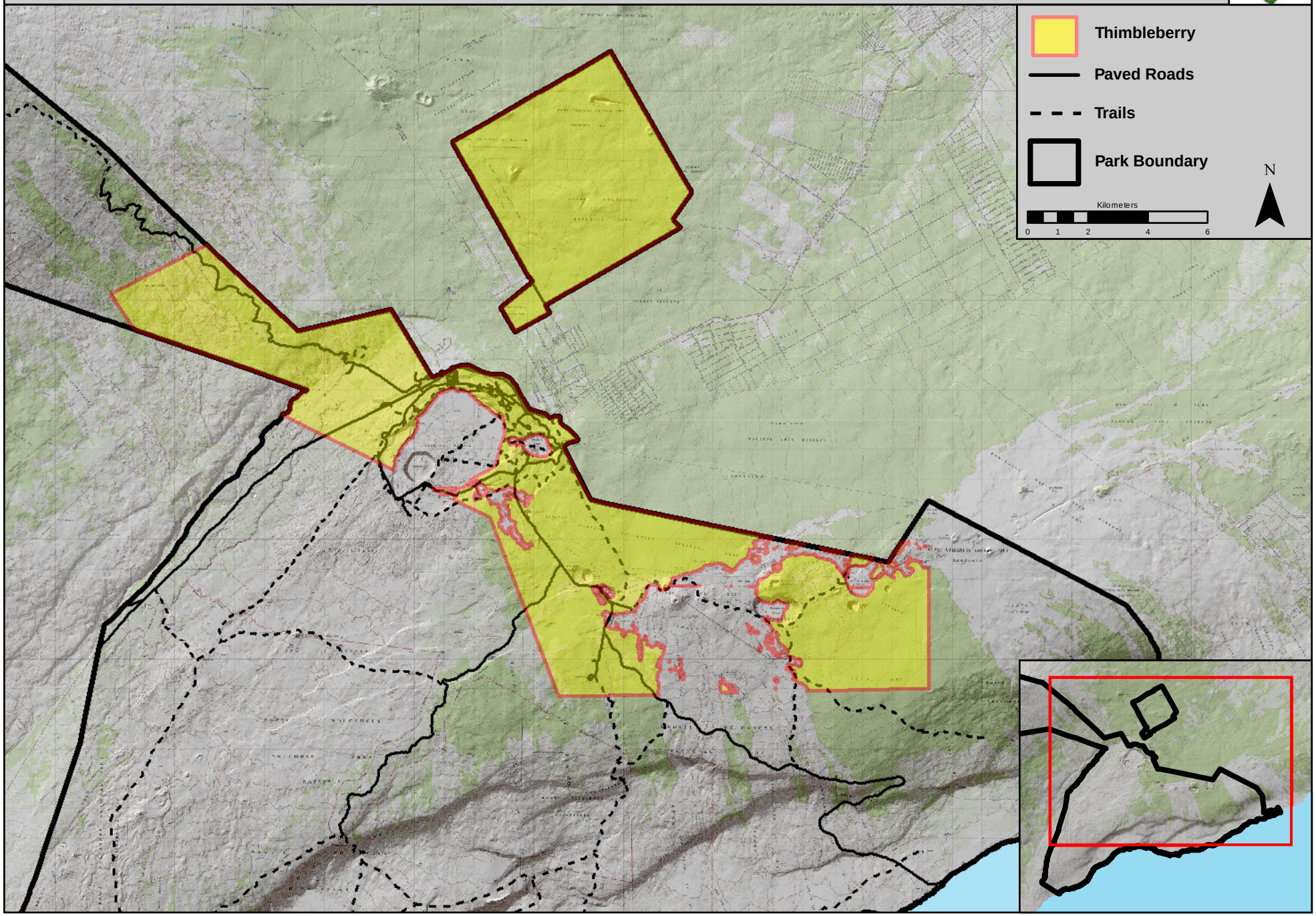
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/14/2011

Thatching grass (*Hyparrhenia rufa*)



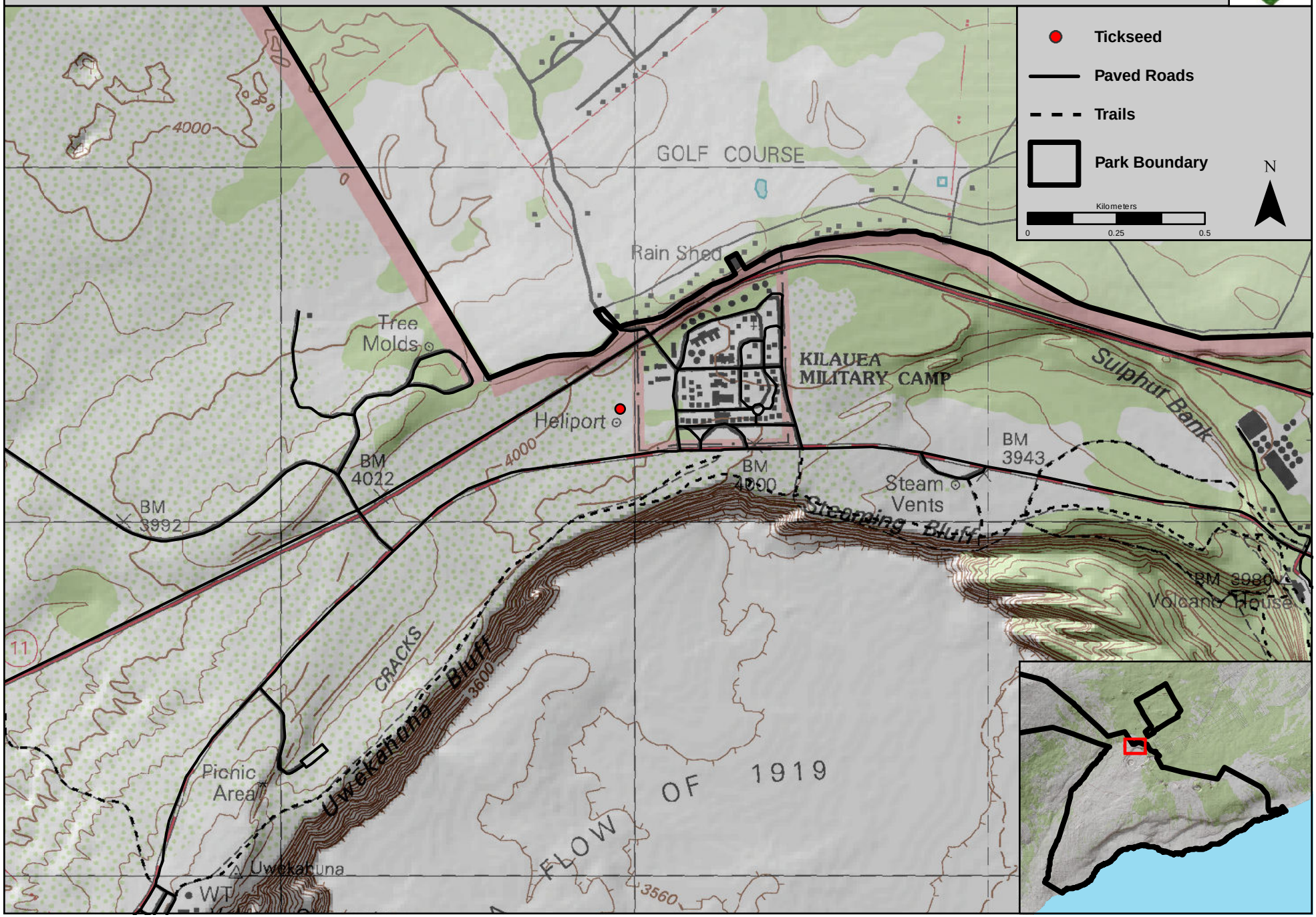
Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/22/2011

Thimbleberry (*Rubus rosifolius*)



Source: The Distribution of Invasive Plant Species of Concern in the Kilauea and Mauna Loa Strip Areas of Hawai'i Volcanoes National Park, 2000-2010. Benitez et al. 2011. Map Created by Matt Casali 6/22/2011

Tickseed (*Coreopsis lanceolata*)



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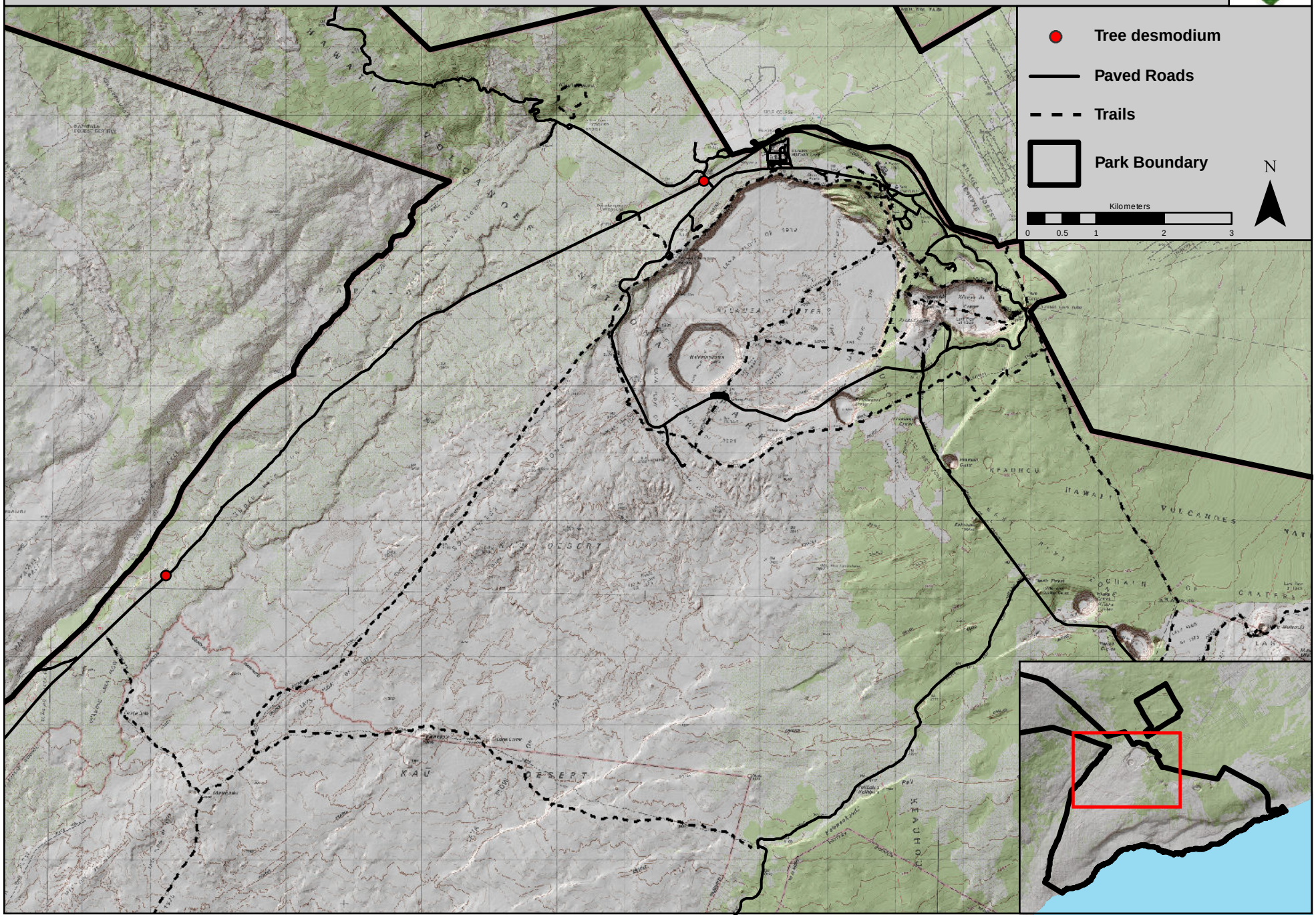
Tree desmodium (*Desmodium cajanifolium*)



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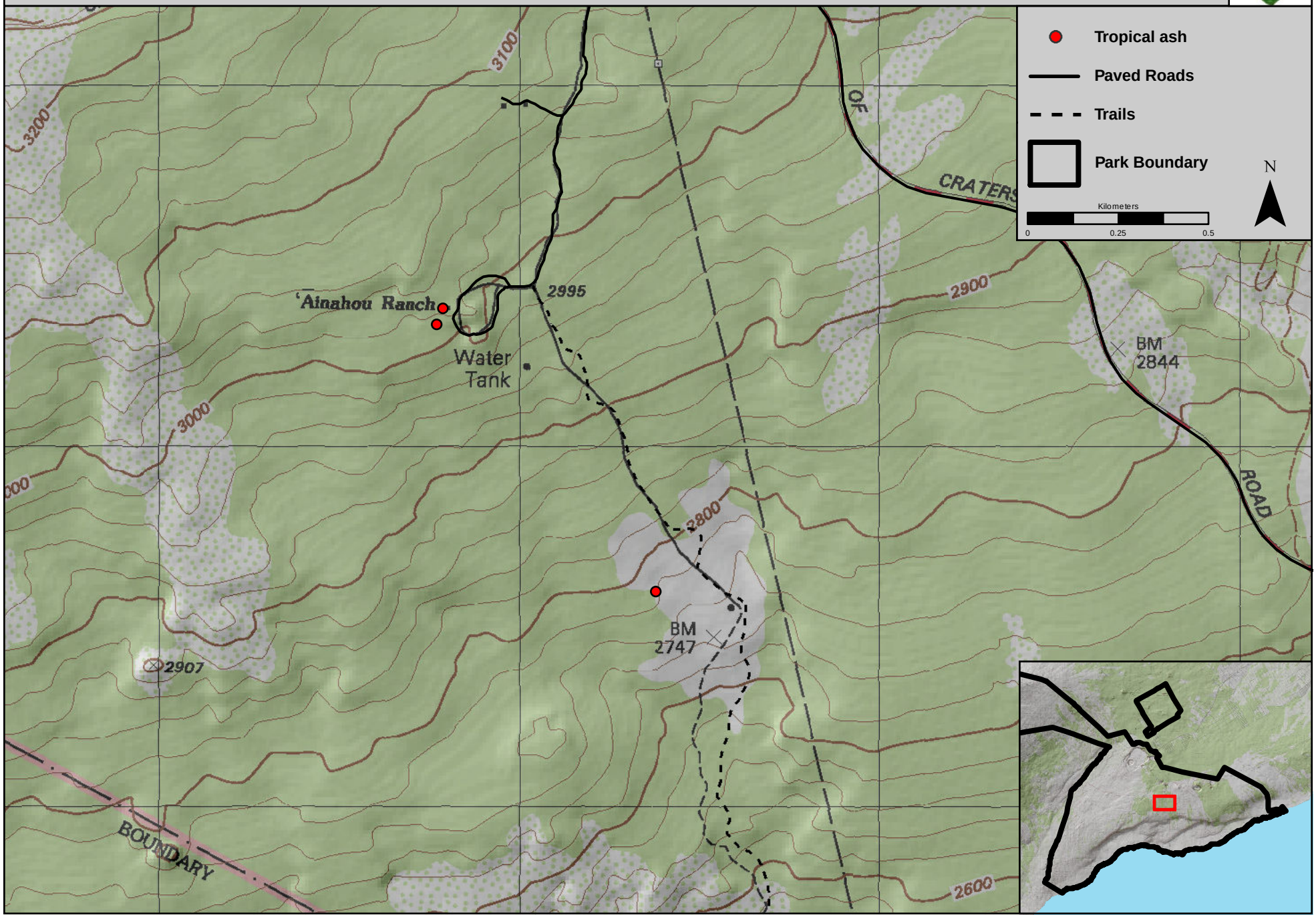
Tropical ash (*Fraxinus uhdei*)



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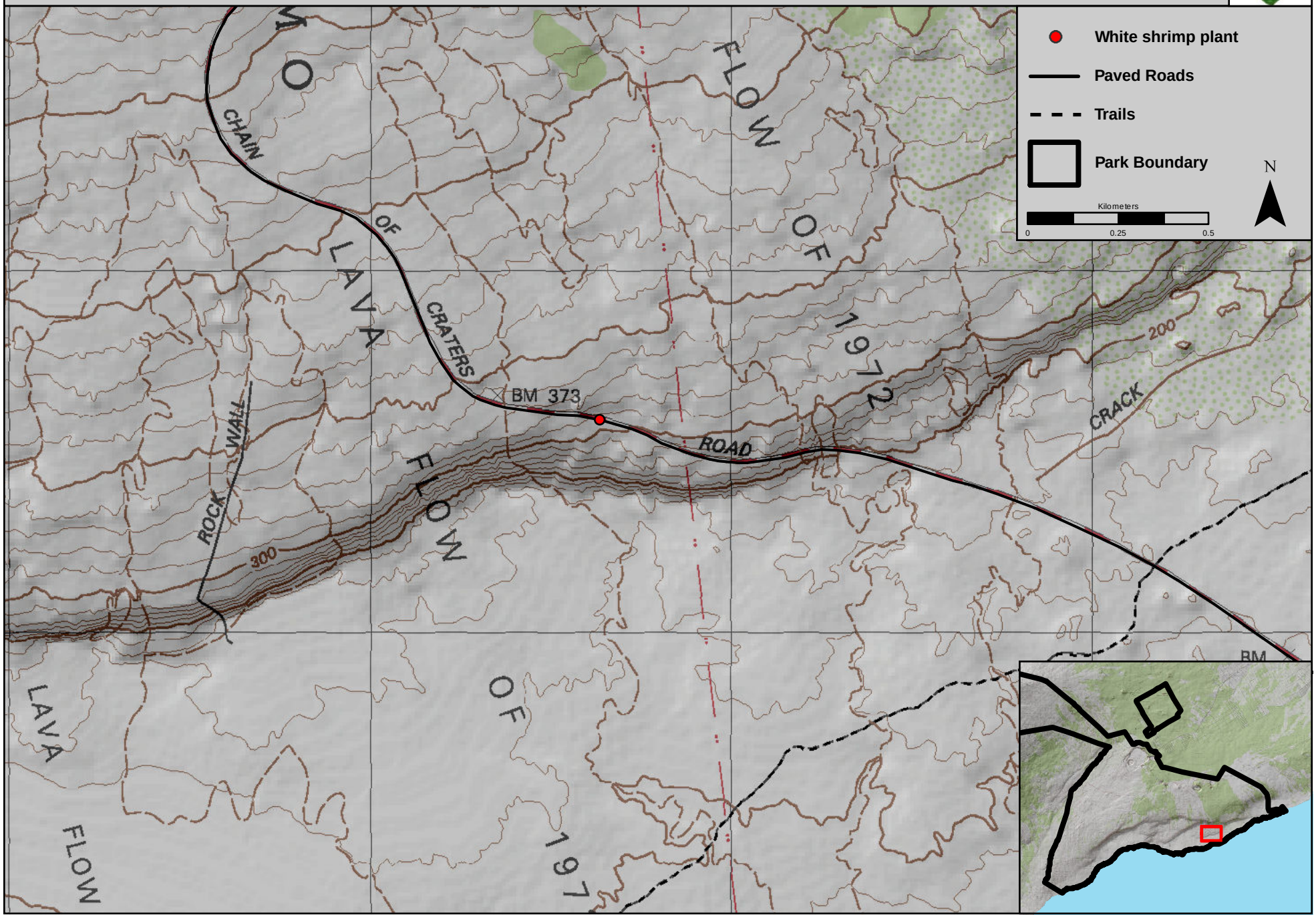
White shrimp plant (*Justicia betonica*)



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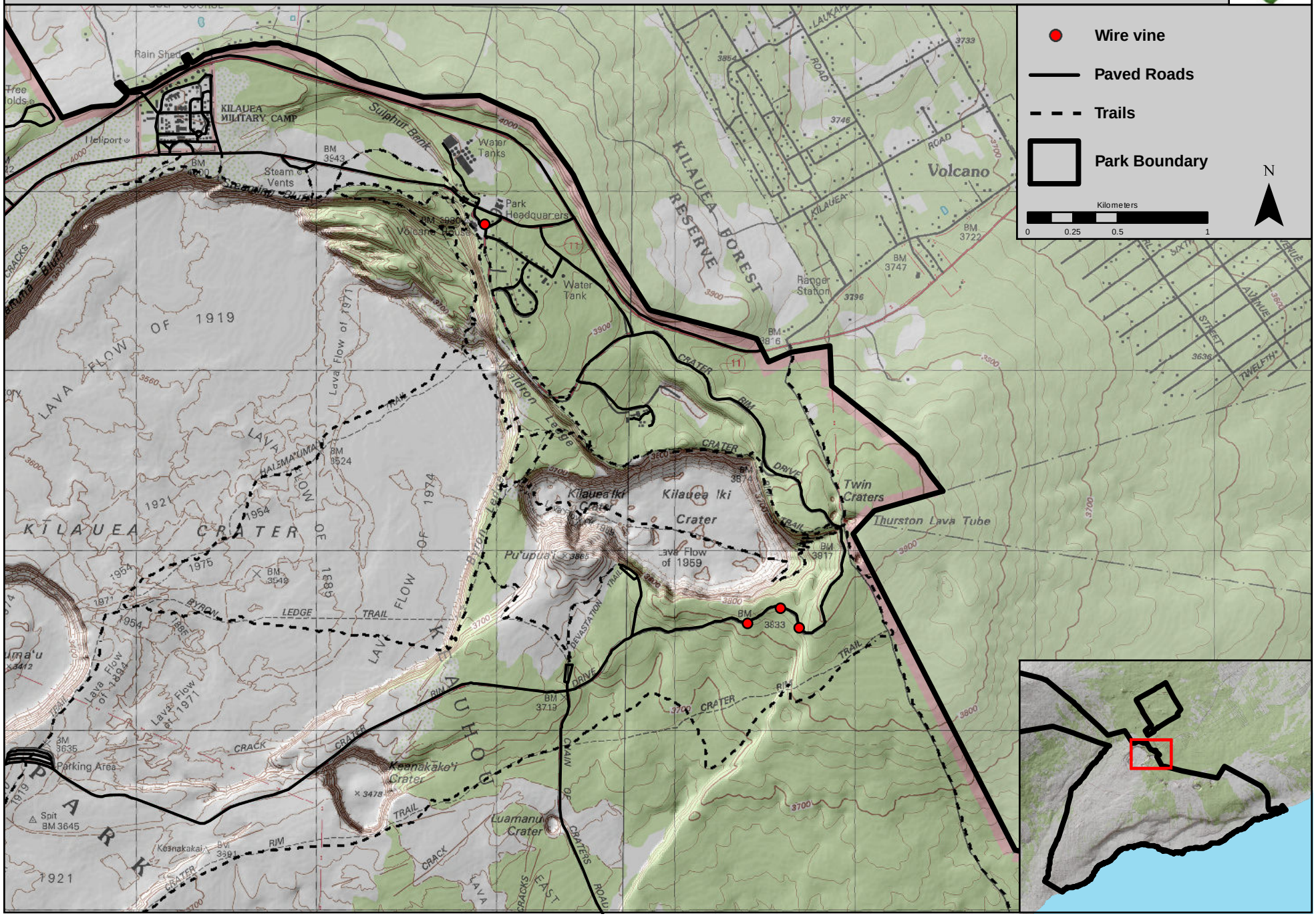
Wire vine (*Muehlenbeckia complexa*)



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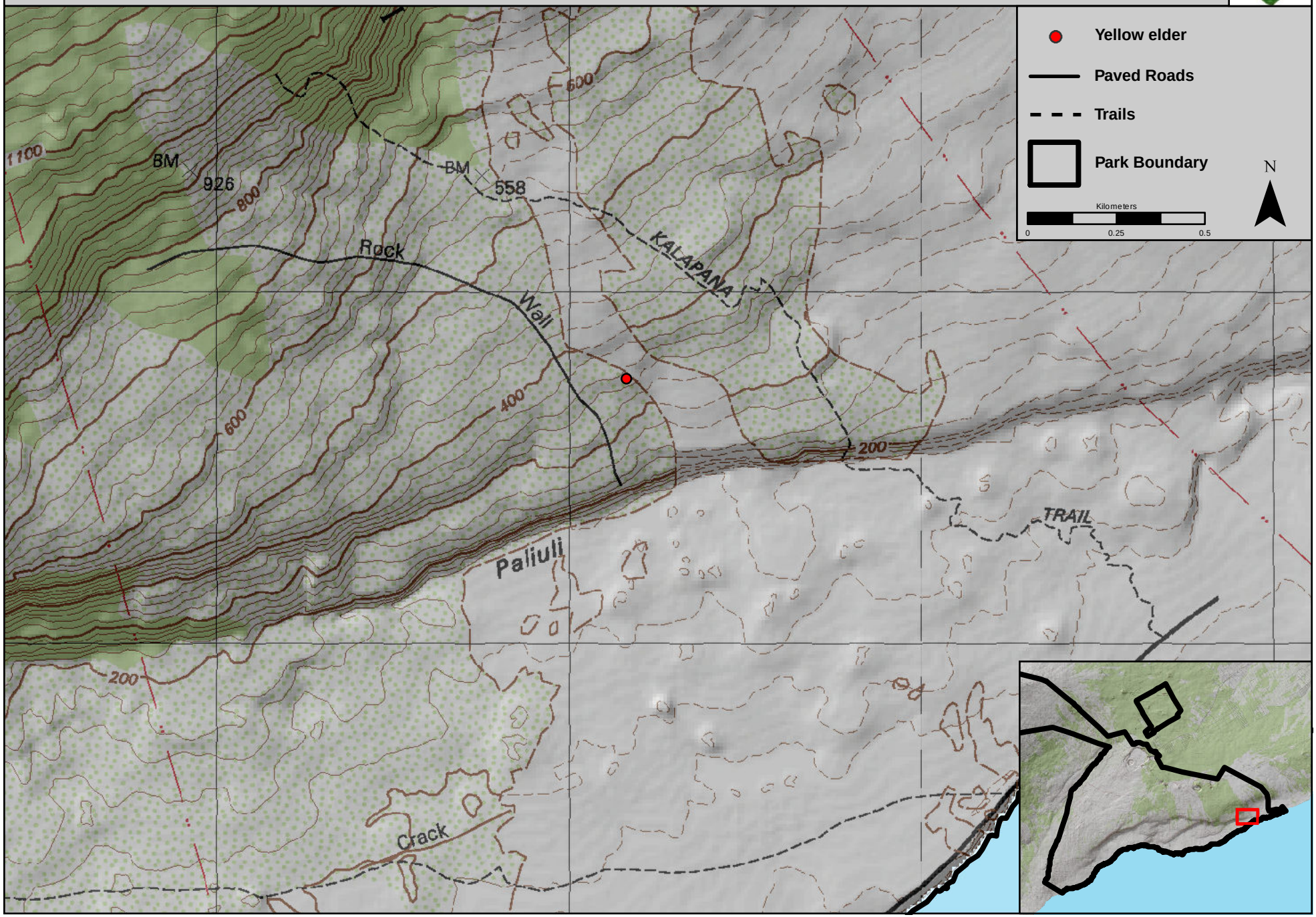
Yellow elder (*Tecoma stans*)



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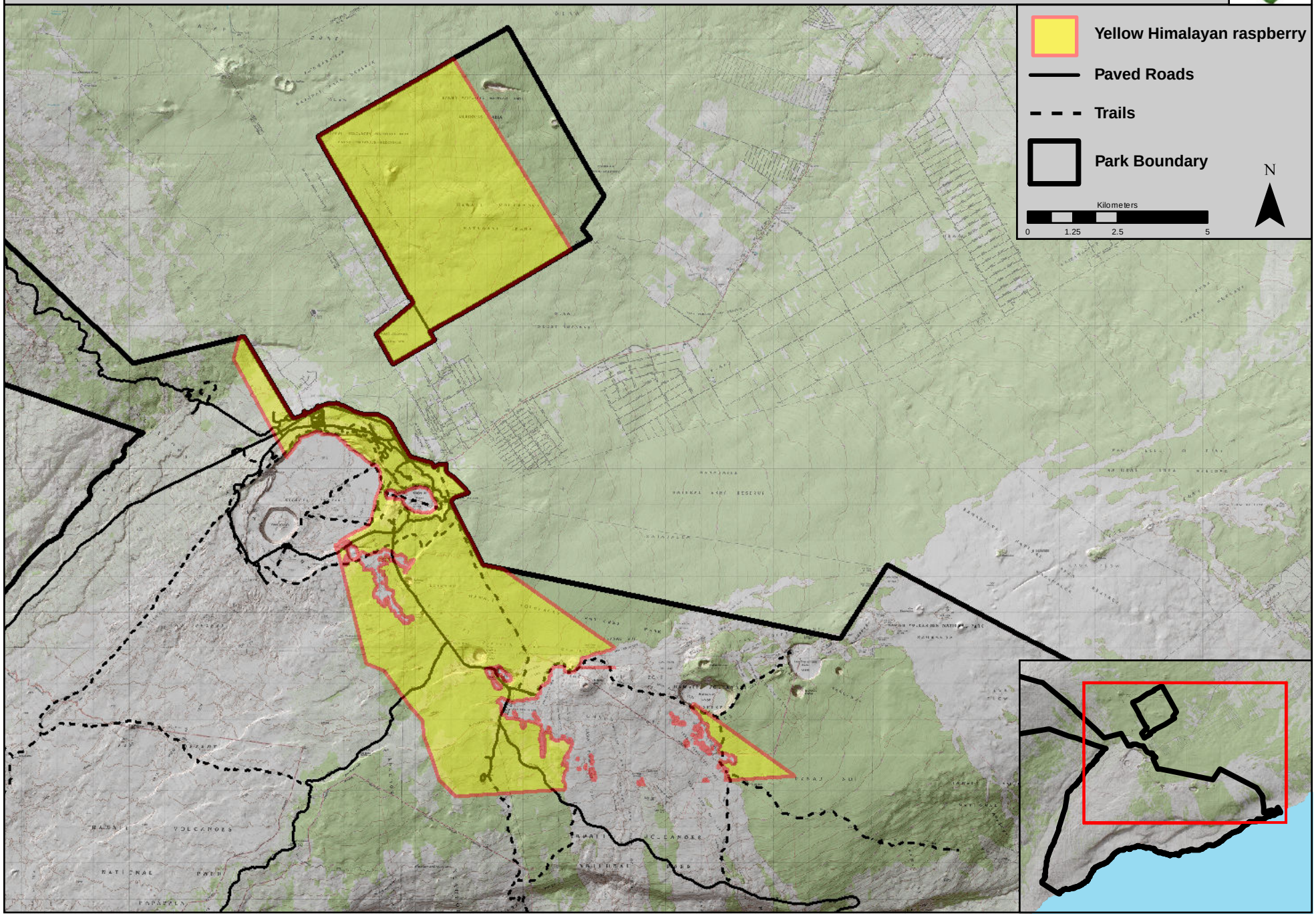
Yellow Himalayan raspberry (*Rubus ellipticus*)



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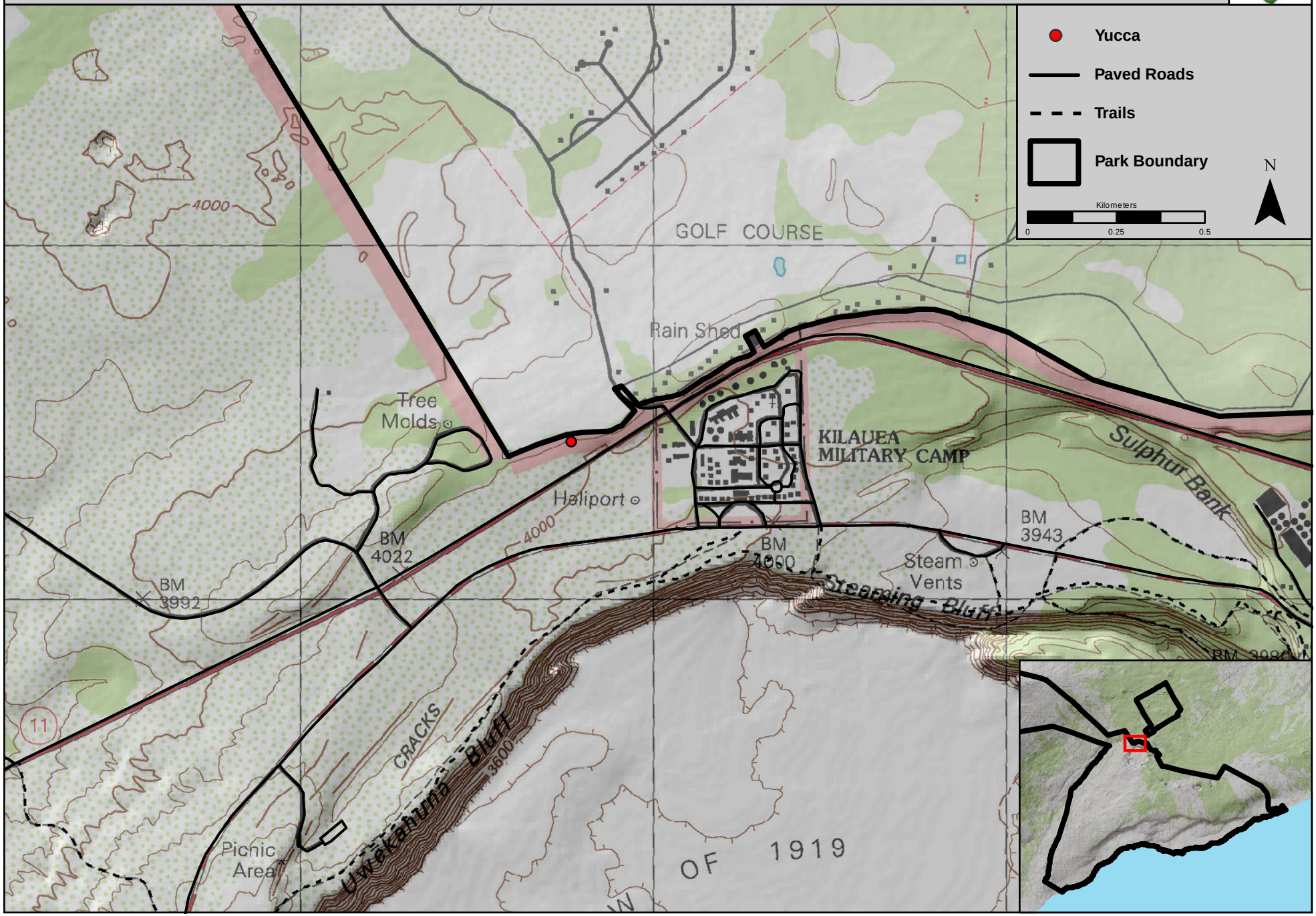
Yucca (*Yucca filamentosa*)



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