Botanical Baseline Survey (2011) of the University of Hawaii's Managed Lands On Mauna Kea

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OMKM
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Author's Note Regarding Written Reports for the Mauna Kea Botanical Baseline Survey.

Fieldwork for the Mauna Kea Botanical Baseline Survey was conducted during the summer of 2011. During the intervening time, the data have been analyzed, reports written and extensively revised. Small amounts of new data were received at various times and incorporated into the reports, requiring various levels of revision. This effort has produced two major final reports:

1) *Botanical Survey of the Astronomy Precinct and 500-meter Buffer Zones on Mauna Kea.* March 15, 2012. Grant Gerrish; and

2) the present report: *Botanical Baseline Survey (2011) of the University of Hawaii's Managed Lands on Mauna Kea.* August 26, 2013. Grant Gerrish.

The first of these is based on the same data-set as the second and they both contain the same findings and many of the same analyses. The first contains some more detailed analyses concerning the Astronomy Precinct than the second. There are minor differences between the reports that are based on their different completion dates, late-arriving information and minor revisions.

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1 INTRODUCTION

1.1 Purpose of This Study

This botanical baseline survey is guided by Section 4.1.4.6.2, “Baseline Inventory” in the Natural Resources Management Plan (MKNRMP 2009), a sub-plan of the Comprehensive Management Plan (Ho’akea LLC 2009) that was approved by the Board of Land and Natural Resources. The need for a baseline inventory was stated, noting that there has never been a comprehensive quantitative study of the plant communities of the UH-Management Areas on Mauna Kea.

The goal of this baseline study is to provide a scientific understanding of botanical resources to assist planning and management. In addition to identifying and enumerating the plants and plant resources of the UH-Management Area, the study includes observation and correlation of plant distributions with environmental factors such as elevation, substrate type, and disturbance level. Observable ecosystem dynamics are analyzed to identify trends, vulnerabilities and potential adverse impacts from the use of the UH-Management Areas on Mauna Kea.

1.2 Study area for this survey

The botanical survey reported in this document is part of a baseline study of the UH-Management Area on Mauna Kea. Other components of the baseline study include surveys of human artifacts, geological features and animal life. The study area is all of the lands on Mauna Kea administered by the University of Hawaii at Hilo (UHH) (Figure 1). In this report, this entire study area will be called the “UH-Management Area.”

The UH-Management Area has been divided into four management units (see Section 2.12, below) defined by University of Hawaii and State of Hawaii Department of Land and Natural Resources (DLNR). This UH-Management Area extends through several recognized ecological units identified as the Subalpine Ecosystem and the Alpine Ecosystem, that have been treated as comprised of four subunits identified as plant communities. The ecosystems and communities do not always correspond to the management units.

This report is organized at the basic level by management unit to facilitate planning and management. At the same time, an effort has been made to keep the data in an ecological context by using the ecological units as a second level of organization. Extensive cross-referencing of ecological data between management units maintains the scientific integrity of the report. Place names used are as represented on the 1982 version of U.S. Geological Survey topographical maps for Mauna Kea.

1.3 Organisms Covered: Vascular Plants and Lichens

This botanical survey is directed towards vascular plants and lichens. Mosses, algae or other protists are not covered here.

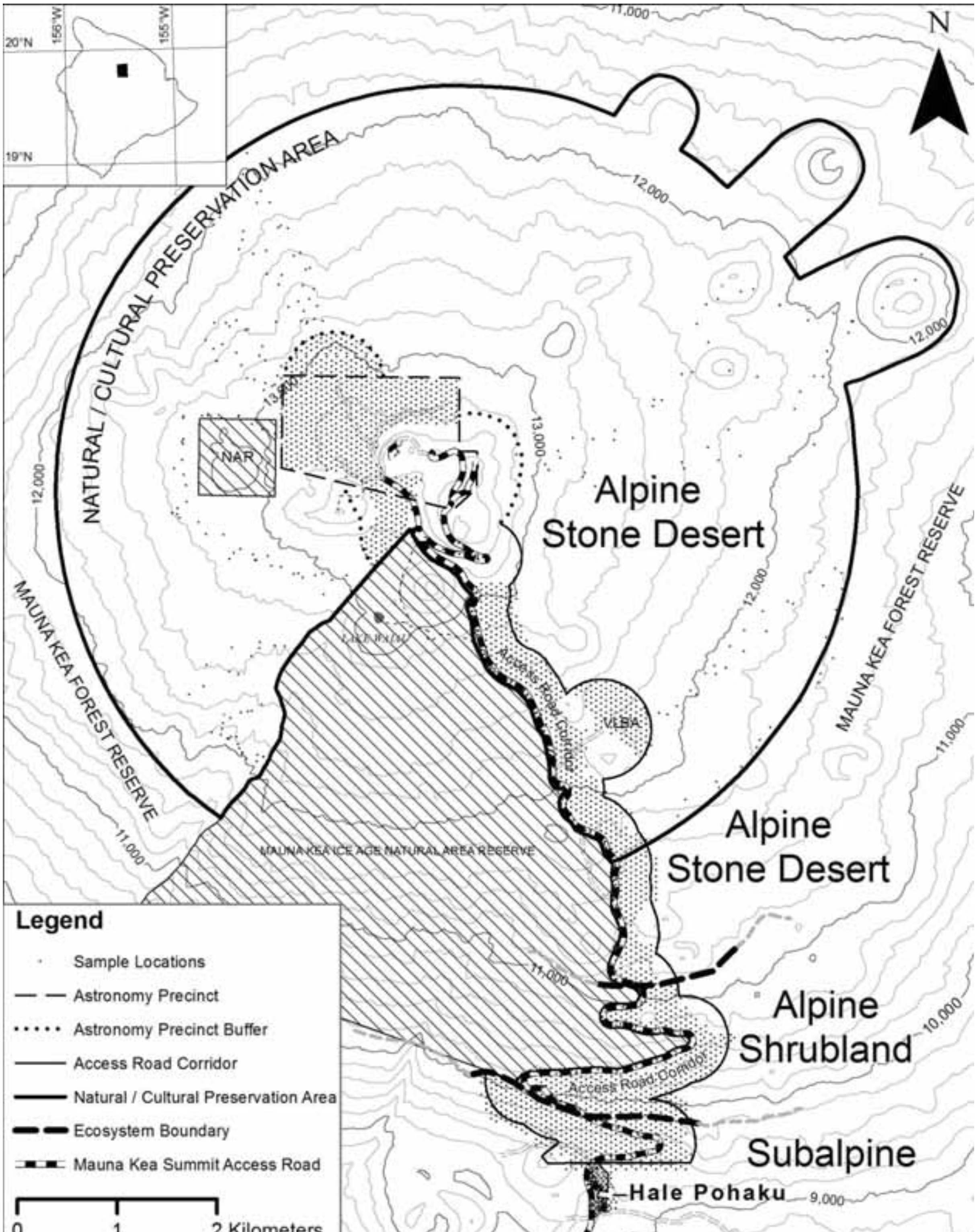


Figure 1. The University of Hawaii's Managed Lands on Mauna Kea: the study area for this botanical baseline survey ("UH-Management Area").

1.4 Companion Documents from the Botanical Baseline Survey

All of the quantitative data from the 2011 Botanical Baseline Survey are archived in an Excel spreadsheet file, “MK Bot Baseline Data.xlsx,” held by OMKM. Documentation, or meta-data, for this data-file is contained in a document, “Data Description,” appended to the present document.

A separate report, ”Botanical Survey of the Astronomy Precinct and 500-meter Buffer Zones on Mauna Kea” (Gerrish 2012), presents all the data from the Astronomy Precinct from the 2011 baseline survey. The Astronomy Precinct report and the present Botanical Baseline Survey report are based on the same data and contain most of the same analyses. The Astronomy Precinct Report is somewhat more detailed. Minor differences exist between the present study and the Astronomy Precinct report because of updates and revision of some data, especially with regards to the naming of lichens.

2 STUDY AREA AND METHODS

2.1 Study Area

2.1.1 Brief Description of Environmental Conditions of the UH-Management Area (Study Area)

The physical environment of the UH-Management Area, including geology, surface features and soil, hydrology and climate are described in detail in section 2.1.4 of the MKNRMP (2009); the biological resources are described by taxonomic group in section 2.2 of the MKNRMP (2009). Environmental conditions of the UH-Management Area are very briefly summarized, below.

Mauna Kea, a dormant volcano, is the highest mountain on the Island of Hawaii and in the Hawaiian Archipelago. The peak, located at 19° 49’ 34” north latitude, 155° 8’ 06” west longitude, is 13,796 ft./ 4206 m high.

Most of the surface is covered with alkalic lava flows and tephra from the Laupahoehoe Volcanics, erupted 65,000 to 14,000 years ago. A small part of the surface displays older lava flows from the Hamakua Volcanics. Large p*u’u* (cinder cones) cover much of the surface. These features are typical of the post-shield-building stage. The surface geology has been strongly influenced by the presence of glaciers at several times during the past 180,000 years, most recently during the Pleistocene, ending about 13,000 years ago. Eruptions sometimes occurred under the ice where the presence of ice and water affected the cooling and, thus, the mineralogy of the erupted material. The movement of glaciers scraped and smoothed the surface of pre-existing flows, leaving them with a “bull-dozed” or even a polished appearance today (MKNRMP 2009).

All of the UH-Management Area is well above the trade-wind inversion layer which tends to limit the rise of moist air; therefore, precipitation of rain and snow is low. Rainfall records from locations at or near the summit are of short duration and prone to errors associated with evaluating snowfall. Existing data indicate that mean annual precipitation is less than 250 mm/10 inches (Giambelluca et al. 2011). Mean monthly temperatures at the summit vary by about 4° C/7.5° F with the mean minimum temperature during the winter months 0.28°C/32.5°F) and the mean monthly maximum temperatures during the summer 4.4°C/40°F (da Silva 2006). Relative humidity is fairly constant in all months of the year, averaging 36% (MKNRMP 2009). The prevailing winds are from the west 80% of the time, averaging 5 to 10 meters per second /11 to 23 miles per hour (MKNRMP 2009).

Biologically, the UH-Management Area extends through several recognized ecological units identified as the Subalpine Ecosystem and the Alpine Ecosystem, together comprised of four subunits identified as plant communities (Gagne and Cuddihy 1990, Mueller-Dombois and Fosberg 1998, Juvik and Juvik 1998, MKNRMP 2009).

2.1.2 Units of the UH-Management Area

2.1.2.1 Management Units

The management units of the UH-Management Area are “Hale Pohaku”, the “Mauna Kea Access Road Management Corridor”, and the “Mauna Kea Science Reserve” (Figure 1). The Science Reserve is further subdivided into the “Astronomy Precinct” and the “Natural and Cultural Preservation Area”. The UH-Management Area is surrounded by the State of Hawaii Mauna Kea Forest Reserve, administered by DLNR. The Mauna Kea Ice Age Natural Area Reserve, a component of the Mauna Kea Forest Reserve, adjoins the Science Reserve and borders a large portion of the Mauna Kea Access Road Management Corridor.

Although the management units named above are precisely defined in the legal documents that establish UHH jurisdiction, some operational modifications are made here, such as adding a buffer zone around the Astronomy Precinct in order to more extensively monitor possible impacts of human activities. This section details how this study defines the management units and how they are integrated with the ecological units of the UH-Management Area.

The largest unit of the UH-Management Area includes all of Mauna Kea above approximately 11,500 ft./3,500 m above sea level. This unit, called the Mauna Kea Science Reserve (11,288 acres/4,568 ha), is subdivided into the Astronomy Precinct (525 acres/212 ha) and the Natural and Cultural Preservation Area (10,763 acres/4,356 ha). The Astronomy Precinct includes the summit of Mauna Kea and the surrounding area where observatories have been built and are proposed to be built in the future. This 525 acres/212 ha area, contains all of the existing and proposed facilities at or near the summit (MKNRMP 2009). We projected a 500-m buffer zone around the facilities and roads that were built near the Precinct's boundary to better evaluate the environment and possible environmental effects of these facilities (Figure 1). Our study defines the Astronomy Precinct as including the 500-m buffer zone anywhere it extends beyond the Astronomy Precinct boundaries. The Astronomy Precinct with this 500-m buffer is approximately 900 acres/364 ha in size.

The Mauna Kea Access Road connects the summit with the mid-elevation facilities at Hale Pohaku. UHH administers a 400 yard-wide (not meters) "management corridor" along the Access Road between Hale Pohaku and the Science Reserve. From the boundary of the Science Reserve to the summit, the Access Road traverses the University-administered Science Reserve. Although a management corridor is not administratively identified within the Science Reserve, in this study, we designate the "Access Road Corridor" as a study unit following the road from Hale Pohaku to the lower boundary of the Astronomy Precinct, incorporating the management corridor and a strip of land within the Science Reserve. We define the "Access Road Corridor" as 400 m from the road along the entire east side of the Access Road from Hale Pohaku to the Astronomy Precinct. On the west side, it extends 30 m from the road where the Access Road borders the Mauna Kea Ice Age Natural Area Reserve and 400 m where it does not. (Figure 1).

"Hale Pohaku" is a 19.3 acre/7.8 ha parcel that includes the Mauna Kea Visitor Center and the buildings and other facilities that make-up the Hale Pohaku Mid-level Support Facilities.

2.1.2.2 Ecological Zones and Plant Communities

Four ecological units have been recognized in the UH-Management Area (MKNRMP 2009) based on treatments of the vegetation on all of Mauna Kea (Gagne and Cuddihy 1990; Mueller-Dombois and Fosberg 1988). According to these treatments, the subalpine ecosystem extends up to the elevation where temperatures drop below freezing every night of the year, approximately 9,500 ft./2,900 m elevation. The Alpine Ecosystem is above this line and is made up of three community types:

- Alpine Shrubland from 9,500 ft./2,900m to 11,150 ft./3400 m
- Alpine Grassland 11,150 t./3,400 m to 12,800 ft./3,900 m
- Alpine Stone Desert 12,800 ft./3,900 m to summit.

The MKNRMP further states, "Very few good stands of alpine grassland currently exist due to overgrazing by feral and domestic sheep and goats." Mueller-Dombois and Krajina (1968) used the name, "Alpine Grass Desert," instead of "Alpine Grassland." "Grass Desert" better describes the sparseness of the vegetation, in my opinion.

These four ecological communities do not conform to the boundaries of the management units described above. This report will present findings organized both by management and ecological units. Data from the present study will be used to characterize the makeup and extent of plant communities that actually occur within the University Lands.

2.2 Vascular Plant Field Methods

2.2.0 Introduction: Subprojects of the Botanical Baseline Survey

We surveyed the entire UH-Management Area with appropriate field methods and levels of intensity. The botanical baseline survey includes the following sub-projects. The field methods for each subproject are described below (Sections 2.2.1 to 2.2.10), in the order listed. Additional documentation of the field methods and data structure are in Appendix B: Data Description.

1. Transect survey of the Astronomy Precinct and Buffer Zone
2. Transect survey of the Access Road Corridor
3. Transect Survey of Hale Pohaku
4. Hale Pohaku Random Point Survey
5. Roadside Survey of the Access Road Corridor
6. Roadside Survey of the Astronomy Precinct and Buffer Zone
7. Astronomy Precinct Facilities Perimeter Survey
8. Astronomy Precinct *Pu'u* Survey
9. Hale Pohaku Facilities Perimeter Survey
10. Natural/Cultural Preserve Area Excursions

2.2.1 Transect Survey of the Astronomy Precinct and Buffer Zone

The same transect survey method was used in the Astronomy Precinct and Buffer Zone, the Access Road Corridor and, with minor modification, at Hale Pohaku.

The locations of transect lines were determined using the Global Positioning System (GPS), a satellite-based navigation and guidance system. All transects follow UTM coordinate lines running east and west. UTM coordinates refer to a systematic grid of north-south and east-west (imaginary) lines that are more easily used than the traditional lines of latitude and longitude marked in degrees. We followed these UTM transects with hand-held GPS units (Garmin 62s). Our GPS units can display UTM coordinates with estimated 3 to 10 meter accuracy. We did not mark the transects or sample points on the ground with any physical markers, such as flagging tape, paint or stakes at any time during this botanical survey.

We established UTM transects along UTM "northings," i.e. east-west running coordinates (Figure 2). Every UTM transect is identified by the UTM northing. The transects were spaced 30 m apart, with the exception of the transects at UTM N 2195080, N 2195115 and N 2195150 that were 35 m apart. The beginning and ending point, as well as the sample points along the transect are identified by the UTM eastings. We centered 30 m-wide "belt-transects" over each transect line. These adjacent belt-transect cover 100% of the surface of the Astronomy Precinct and Buffer Zone, the Access Road Corridor and at Hale Pohaku.

Names for the transects are derived from the transect northing. All transects in the Astronomy Precinct and Buffer Zone begin with the prefix "S" followed by the last five digits of the northing. For example, transects at 2195080, 2195115 and 2195150 are named S-95080, S-95115, and S-95150, respectively. The sample points are identified by the transect names and sequential two-digit numbers, beginning at the western end of each transect. Thus, the first three sample points at the western end of transect S-95080 are named S-95080-01, S-95080-02 and S-95080-03. Thus, each UTM transect and sample point is globally, uniquely identified with these coordinates.

Our sample points were spaced 100 meters apart along the UTM transects. The sample points were established at predetermined UTM eastings. Transects with even numbered northings, when divided by ten, had sample points at eastings evenly divisible by 100 and transects with odd numbered northings, when divided by ten, had sample points at eastings evenly divisible by 50 but not by 100 (Figure 2).

At each sample point we recorded all vascular plant species present within a two-meter diameter ("2-m plot") and a six-meter diameter ("6-m plot") circular plot centered on the sample point. A 3-meter long pole (PVC pipe) marked at one meter intervals was used to determine the boundaries of the circular plots. These circular plots are small enough to permit an accurate record of all species present within them. We also recorded the presence of all vascular plants within the 100 meters between these sample points ("100-m segments"). We attempted to view as much of the terrain as feasible within the 30 meter-wide transect segment by walking a wandering path and intentionally walking to topographic features, such as outcrops, overhangs and depressions, that might harbor plants and lichens. However, because of the large size of the belt transect and the ruggedness of the terrain, we could not be certain that we were observing all the plants present within these 100-m segments.

Within the Astronomy Precinct and Buffer Zone we established a total of 78 transects between UTM Northings of 2193010 and 2195360. The transects are of various lengths due to the irregular shape of the survey area. The number of sample points on transects ranged between 2 and 18 sample points. A total of 682 points along approximately 70,000 meters of transect were sampled within the Astronomy Precinct and Buffer Zone. Field technicians walking the transects were responsible for surveying a belt 30 meters wide centered on the UTM transect line, i.e. they surveyed 15 meters on either side of the line. We did not establish transects and sample points over the p*u'u* because of their cultural sensitivity and because we determined that very few plants grow on the loose material that comprises them. The p*u'u* were observed from their margins, established trails and roads, and other unobtrusive places (see "Astronomy Precinct *Pu'u* Survey" Subproject: Sections 2.28 and 3.2.1.4).

At most sample points within the astronomy precinct (522 out of 682 points) we took a standardized photograph with a digital camera (Gerrish 2012). We placed the 3-meter measuring pole on the ground with one end at the exact sample point and the other pointing north. We then stood at the southern edge of the plot, 3 meters from the center of the 6-m plot , and focused the camera's view on the measuring pole.

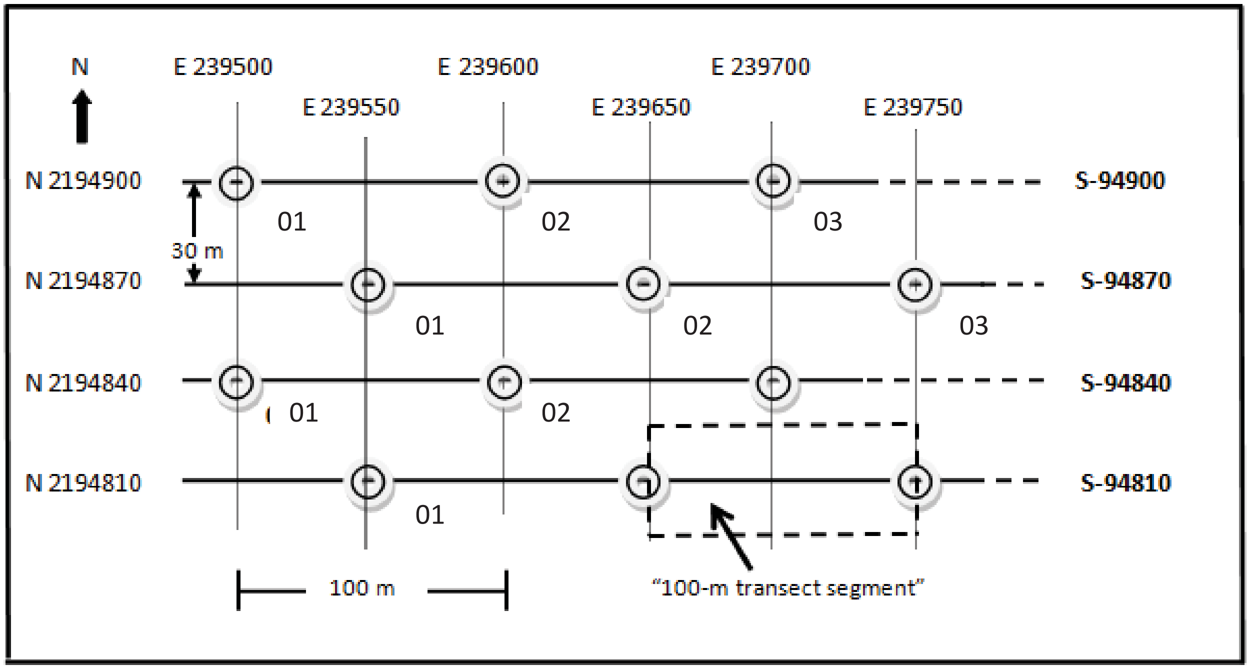


Figure 2. Illustration of the layout of four transects and first three sample points at the northwest corner of the astronomy precinct. Transects (heavy horizontal lines) are named (shown far right side) for the UTM northing coordinate (shown far left side). Transects are 30 meters apart. Sample points (black circles numbered one to three) are positioned at UTM eastings (shown across the top). Sample points on transects that are even-numbered when divided by ten (e.g. Transects S-94900 and S-94840) are at eastings divisible by 100 (e.g. E 239500, E239600, E239700); sample points on transects that are odd-numbered when divided by ten (e.g. S-94870 and S-94810) are at eastings that end in 50 (e.g. E 239550, E 239650, E 239750). Dashed rectangle indicates an example of a "100-m segment" sample unit that is identified as sample point S-94810-02.

2.2.2 Transect survey of the Access Road Corridor

The transect survey of the Access Road Corridor used the same methods as described in the previous section for the Astronomy Precinct. One hundred ninety-six transects were established on the east side of Access Road between northings 2186970 and 2192840 with 1065 sample points. These transects are spaced every 30 m from the upper boundary of Hale Pohaku to the lower boundary of the Astronomy Precinct Buffer Zone. The Access Road Corridor is 400 m-wide along the entire east side of Access Road. Transects were not established on the slopes of *pu'u* where they extended into the Corridor. Sample Points were numbered from west to east, beginning approximately ten meters east of the road, beyond visible physical disturbance associated with road construction.

The west side of the Access Road corridor is determined by the Mauna Kea Ice Age Natural Area Preserve. The UH-Management Area extends only 30 m west of the Access Road where it is contiguous with the Natural Area Preserve. No transects were established between the Access Road and the Natural Area Preserve. The 30 m-wide strip on the west side was surveyed as part of the "Roadside Survey of the Access Road Corridor" (Section 3.2.5). Below the lower boundary of the Natural Area Preserve, the Access Road Corridor extends 400 m west of the Access Road, just as it does on the east side of the road. Thirty transects with 235 sample points were established on the west side of Access Road between northings 2186970 and 2187870, corresponding to the upper boundary of Hale Pohaku to the lower boundary of the Natural Area Preserve. Sample Points were numbered from east to west, beginning approximately ten meters east of the road, beyond visible physical disturbance associated with road construction. Locations of sample points were determined in the same way as described in Section 2.211

The same sample units (2- and 6-m diameter plots and 100-m segments) were used and the same data were recorded as in the Astronomy Precinct (Section 2.2.1). Sample points were not photographed in the Access Road Corridor.

2.2.3 Transect Survey of Hale Pohaku

The transect survey of Hale Pohaku used a modification of the transect methods described in the above sections for the Astronomy Precinct and the Access Road Corridor. Sample points were established at 50 m, rather than 100 m, intervals to increase the number of sample points within the small, but culturally significant, area of Hale Pohaku. Thirteen transects with 67 sample points were established on the east side of Access Road traversing Hale Pohaku. 2-m and 6-m concentric circular plots were sampled at each point, and 50 m-long transect segments extended between the sample points. The west side of the road was surveyed as part of the "Roadside Survey of the Access Road Corridor."

Sample Points were numbered from east to west, beginning approximately ten meters east of the road, beyond visible physical disturbance associated with road construction. Locations of sample points were determined in the same way as described in Section 2.2.1, with the modification in spacing noted above. Sample points were not photographed at Hale Pohaku.

The small number of sample points at Hale Pohaku is augmented by data from the "Hale Pohaku Random Point Survey," described in the next section.

2.2.4 Hale Pohaku Random Point Survey

We identified two areas within Hale Pohaku with the least amount of visible physical disturbance to the substrate and vegetation where intensive, random point surveys were conducted. Forty-nine sample points, identified with the code "NI," are within the "North Intensive" area between UTM 242600 and 242720 Eastings and between UTM 2186760 and 2186850 Northings. Forty-eight sample points, coded as "SI," are within the "South Intensive" area between UTM 242620 and 242790 Eastings and UTM 2186550 and 2186680 Northings. These 97 sample points were established by drawing random coordinates (defined as integer meters) within these two areas. We used 2- and 6-m diameter circular plots to sample presence and absence of vascular plant species at these points. Data from these sample points is compatible with the data from the corresponding circular plots used in the transect surveys. This random point study does not include sample units corresponding to 100- or 50-m segments.

2.2.5 Roadside Survey of the Access Road Corridor

We conducted an intensive survey along the Mauna Kea Access Road from the lower boundary of Hale Pohaku to the point where the Access Road enters the Astronomy Precinct Buffer Zone. Survey of the roadside within the Astronomy Precinct is described in the following section (Section 2.2.6).

This special roadside survey used transects on both sides of Access Road through the UH-Management Area. The transect on the west side is identified with the code, "RW," and the transect on the east side is identified as "RE." We defined these roadside transects as a 3 m-wide strip extending away from the road, beginning at the outer edge of the drive-able roadway or shoulder. This 3 m-wide transect contains most of the physically-disturbed substrate associated with road construction, use and maintenance. We used transect segments of two different lengths during the survey. Initially 50-m long segments were used, but then changed to 100-m long segments to reduce the amount of time required to complete the survey.

An additional roadside transect was used where the Natural Area Preserve borders the Mauna Kea Access Road (Figure 1). Here the UH-Management Area is defined as a 100 ft.-wide strip on the west side of the Access Road. We established transect segments identified by the code "WW" west of the RW transect and extending 30 meters west of the roadway.

The number of segments in each transect and their lengths are:

RE = 144 segments	1 to 39 @ 50 m	40 to 144 @ 100 m
RW = 148 segments	1 to 71 @ 50 m	72 to 148 @ 100 m
WW = 133 segments	1 to 75 @ 50 m	76 to 133 @ 100 m

Since the road is not straight or running along a cardinal direction, the length of each segment was determined by GPS. The starting point of each segment is 50 (or 100) meters from the end point of the preceding segment. A technician walked through each segment and recorded the presence of all vascular plant species observed, using the following index of abundance:

a = species observed only once in transect segment
b = observed ≥2 and < 10 times in transect segment
c = observed ≥ 10 times in transect segment

2.2.6. Roadside Survey of the Astronomy Precinct and Buffer Zone

The Access Road approaches the summit and enters the Astronomy Precinct Buffer Zone at 13, 260 ft./4,042 m), with three steep switchbacks traversing the lower slopes of *Pu'u Hau Kea* and *Pu'u Wekiu* and the cinder lands in between. The roadway includes retaining walls that stabilize the cinder slopes. We surveyed the paved and unpaved shoulders of the road between the roadway and the base of the retaining wall and a narrow strip on the upper side of the retaining wall where the wall meets the cinder slope. All plant species within 100 m segments were recorded using the abundance scale of a to c, described above in Section 2.2.5. We used GPS to measure the beginning and ending points of the segments. We conducted this survey between 13,260 ft./4,042 m and 13,600 ft./ 4,146 m elevation.

A total of twenty-four 100-m segments were surveyed. Frequency of each species is calculated as the number of segments where the species was present divided by 24.

2.2.7. Astronomy Precinct Facilities Perimeter Survey

A survey was conducted around all the observatories and other constructed facilities within the Astronomy Precinct. The goal of this survey was to find plants that might be growing by the foundations or near any human-made object at the summit. We walked around each observatory and all the out-buildings, retaining walls, and culverts and recorded all vascular plants found near each facility. The area that contains the numerous radio telescopes of the Sub-millimeter Array was covered by the transect survey of the Astronomy Precinct and Buffer Zones.

We examined the perimeters of these facilities:

UHH 0.9-m Telescope	Canada-France-Hawaii Telescope
Block Building	W. M. Keck Observatory I
Public Restrooms	W. M. Keck Observatory II

United Kingdom Infrared Telescope	NASA Infrared Telescope Facility
UH 2.2-m Telescope	James Clerk Maxwell Telescope
Gemini North Telescope	Caltech Sub-millimeter Observatory
Subaru Telescope	Sub-millimeter Array (main building)

2.2.8. Astronomy Precinct *Pu'u* Survey

We did not establish survey transects on the *pu'u* of the summit (or elsewhere). We observed and made notes of plant life from established trails and vantage points, including the trails and roads on *Pu'u Wekiu,* the trail to the summit of *Pu'u Poliahu*, and we could observe much of *Pu'u Hauoki* and *Pu'u* Kea from the roads between the observatories.

2.2.9 Hale Pohaku Facilities Survey

We walked around all 16 buildings at the Hale Pohaku Mid-Elevation Facilities and recorded all vascular plant species near the foundation wall. We surveyed a narrow strip from the foundation out to the "drip-line" of the eaves, awnings or rain gutters.

We surveyed these structures:

Cafeteria	Cabin 1
Building A	Cabin 2
Building B	Cabin 3
Building C	Cabin 4
Building D	Visitor Information Center
Work Shop	Upper Visitor Building
Storage shed near workshop	Lower Visitor Building
Water & Gas Tanks	Old Observatory Dome

2.2.10 Natural/Cultural Preservation Area Excursions

We made ten reconnaissance excursions into the Natural/Cultural Preservation Area (N/CPA) (Figure 1). Our excursions ranged between 11,559 ft./3,524 m and 13,023 ft./3,970 m. These walking surveys explored various parts of the N/CPA and sampled the range of geologic substrates. The general purpose of these excursions was to determine if the plant-life and physical conditions in the N/CPA were comparable to similar elevations along the Access Road or in the Astronomy Precinct and to see if there were plant species not recorded elsewhere.

On each excursion, two or more people walked a generally pre-arranged course observing conditions and plant-life. The team members generally maintained some distance between themselves to maximize spatial coverage. Observations were recorded. We each subjectively chose sample points where we recorded the plant species present and descriptions of the environment.

Observations were recorded with a standard protocol for Excursions 3 through Excursion 10, allowing a numerical analysis of the findings. However, neither the excursion routes nor the samples were randomized and this analysis provides a general overview rather than a quantitative profile.

2.3 Vascular Plant Data Analysis

Transect data were entered into spreadsheet (Microsoft Excel) and GIS (ArcGIS 10) files at the end of each field day. All data entries were double-checked to assure accuracy.

The UTM coordinates of each sample point were recorded in the field by our GPS units; however, the elevations that are used for analysis in this study were derived from a digital elevation model (DEM) used with our GIS system to assign elevation based on location coordinates (USGS 2004). The surface geology at each sample point is based on a digital database (Trusdell, Wolfe and Morris 2005) based on the map of Wolfe and Morris (1996).

All quantitative data from this botanical baseline survey is stored in an Excel spreadsheet format. Inquiries concerning access to this database may be addressed to OMKM. A detailed description and documentation of the data in the database are appended to this report as "Appendix B: Data Description."

2.4 Vascular Plant Names Used in This Report

Identification and nomenclature of flowering plants is primarily according to Wagner, Herbst and Sohmer (1990) with updates from "Flora of the Hawaiian Islands" as posted on the Smithsonian Museum of Natural History website (Smithsonian Institution and the National Tropical Botanical Garden). Fern identification and nomenclature follows Palmer (2003) and lichen taxonomy is based on reports by C. W. Smith and others (Smith, Hoe and Conner 1982; Berryman and Smith 2011)**.** Names used in this report are consistent with the names used in the Natural Resource Management Plan (MKNRMP 2009).

The full scientific names and published common names of all plants encountered in the study area are in Appendix A. Scientific names are used in the text of this report except for native Hawaiian trees and shrubs that have unambiguous, Hawaiian-language names that are widely used, and introduced plants that are widely recognized by their common, English-language names. I use these Hawaiian common names for the plants listed in the table below (Table 1). Both the scientific and the common name of all plants are given at the first occurrence of the name in the report.

Table 1. Plants referenced by common name in this report and their scientific names.

Common Names Used in Report	Botanical Name
'āhinahina	*Argyroxiphium sandwicense*
'ūlei	*Osteomeles anthyllidifolia*
'a'ali'i	*Dodonaea viscosa*
'āweoweo	*Chenopodium oahuense*
hinahina	*Geranium cuneatum*
māmane	*Sophora chrysophylla*
na'ena'e	*Dubautia ciliolata*
ohelo	*Vaccinium reticulatum*
pūkiawe	*Leptecophylla tameiameiae*

2.5 Lichen Study Methods

Independent Lichen studies were conducted in two different parts of the UH-Management Area, in the Astronomy Precinct and Buffer Zone, and at Hale Pohaku and the Access Road Corridor. Further, two separate lichen studies with different methodologies were conducted in the Astronomy Precinct and Buffer Zone by two separate teams.

2.5.1 Lichen Study of Astronomy Precinct by Berryman and Smith (2011)

Field work for a subcontracted lichen study was conducted in the summer of 2011 (Berryman and Smith 2011; see Appendix D1) to be included in a survey of the proposed site for the Thirty Meter Telescope (TMT) (Pacific Analytics 2012). The second author, C. W. Smith, has led or participated in several lichen and botanical studies of the summit of Mauna Kea, beginning in 1982 (Smith, Hoe and O'Conner 1982).

Berryman and Smith (2011) established twenty-nine 3 m by 3 m sample plots within designated lichen habitat (MKNRMP 2009) at the summit within the proposed footprint of the TMT and within an extensive buffer area expected to contain any direct impacts of the proposed construction of the TMT. Eighteen of these sample plots were established as random points within a spatial stratification of this study area; 6 plots were subjectively placed in areas of observed high density and diversity of lichens; and an additional 5 plots were located within the proposed footprint of the TMT observatory building, itself.

All lichen species present within each plot were recorded. "Abundance" was calculated as the frequency with which each species occurred in the total 29 plots. The substrate affinities of each species was observed and noted and community groupings of lichen species were also noted.

2.5.2 Lichen study of Astronomy Precinct by Baseline Botanical Survey Technicians

The same team of field botanists and botanical technicians that performed the survey of vascular plants also recorded lichen species that we could identify within the 2-m and 6-m plots. We used a photo guides to recognize nine of the more frequent species of lichens found in the summit area after being briefly trained by specialists (B. Perry: mycologist, University of Hawaii at Hilo Biology Department; and C. W. Smith) to identify these species. Several of the lichen species are distinct and easy to positively identify. Others are very small and often lack fruiting bodies or other distinctive features. Many specimen appear to be depauperate (small and lacking usual features) because of the extreme environmental conditions of the summit (C. W. Smith Unpublished; see Appendix D-3). Data showing lichen species present at a sample point can be taken as a positive indication that those species are present; however, data showing a species as absent should not be taken as a positive determination that that species does not occur at the site.

2.5.3 Lichen Study on Elevation Gradient at Hale Pohaku and Access road Corridor

A team led by C. W. Smith and B. Perry recorded the species of lichens present and collected unidentified specimen at 7 sites along the Access Road corridor. The survey sites were located at intervals of approximately 200 m elevation. Sites were not marked nor were the surveys constrained to a specific area. At each site the team looked for habitats with lichens, usually rock outcrops. All lichen species that could be identified were recorded. Collections were made from lichen populations that could not be identified in the field.

3 RESULTS

3.0 Plant Communities and Ecological Zonation

We used the distribution of dominant species to determine the identity and extent of plant communities within the UH-Management Area on Mauna Kea. Our findings differ somewhat from the zonation described in the Management Plan. This is in part due to our findings being specific to the University Lands rather than based on a treatment of Mauna Kea as a whole.

The following zonation is supported by our data:

Subalpine Ecosystem

- *Māmane (Sophora)* Woodland 9,100 ft. /2,775 m to 9,800-10,100 ft./(3,000/3,080 m (variable)

Alpine Ecosystem

- *Pūkiawe* (*Leptechophylla*) Shrubland 9,800 ft./3,000 m to 11,150 ft./3,400 m

- Alpine Stone Desert w/widely scattered grasses and ferns 11,150 ft./3,400 m to 13,796 ft./4,206 m
  With subzones coinciding with management units:
    - Access Road Corridor above 11,150 ft./3,400 m to 13,000 ft./4,000 m
    - Astronomy Precinct and Buffer 13,000 ft./4,000 m to summit)

Māmane (*Sophora*) Woodland is the prevalent community within the subalpine ecological zone. "Tree-line," on Mauna Kea is usually defined by the upper extent of *māmane* (*Sophora chrysophylla*). This tree-line is visually distinct on the slopes above Hale Pohaku. We marked the upper limit of this community and the Subalpine Ecosystem to follow the area of more or less continuous presence of *māmane* in our 100-m segments (Figure 3). *Māmane* Woodland extends from the lowest part of the UH-Management Area at Hale Pohaku to the lower boundary of the Natural Area Reserve on the west side of Access Road at about 10,100 ft./3080 m and generally follows the switchback of Access Road down to 9,800 ft./3000 m and from there extends eastward at this elevation. There are small areas we include in this community that lack *māmane* and are dominated by *pūkiawe* (*Leptechophylla tameiameiae*) or native tussock grasses. This community generally conforms to the Subalpine Ecosystem described in the MKNRMP (2009).

The Alpine Ecosystem extends from the *māmane* tree-line to the summit of Mauna Kea. The first of the alpine communities is the *Pūkiawe* (*Leptechophylla*) Shrubland, a distinct open community above tree-line characterized by a number of native shrub species. We place the upper limit of this community at 11,150 ft./3,400 m which is the limit of more or less contiguous occurrences of *pūkiawe* in our 100 m segments (Figure 3). At this elevation, the frequency and apparent cover of *pūkiawe* and all other plant species is much less than in the lower part of this community.

Our data do not support the recognition of two different plant communities above the *Pūkiawe* Shrubland, as described in the MKNRMP (2009) (see Section 2.1.2.2). Although the plant life is somewhat more sparse at the higher elevations, a comparison of species frequencies above and below

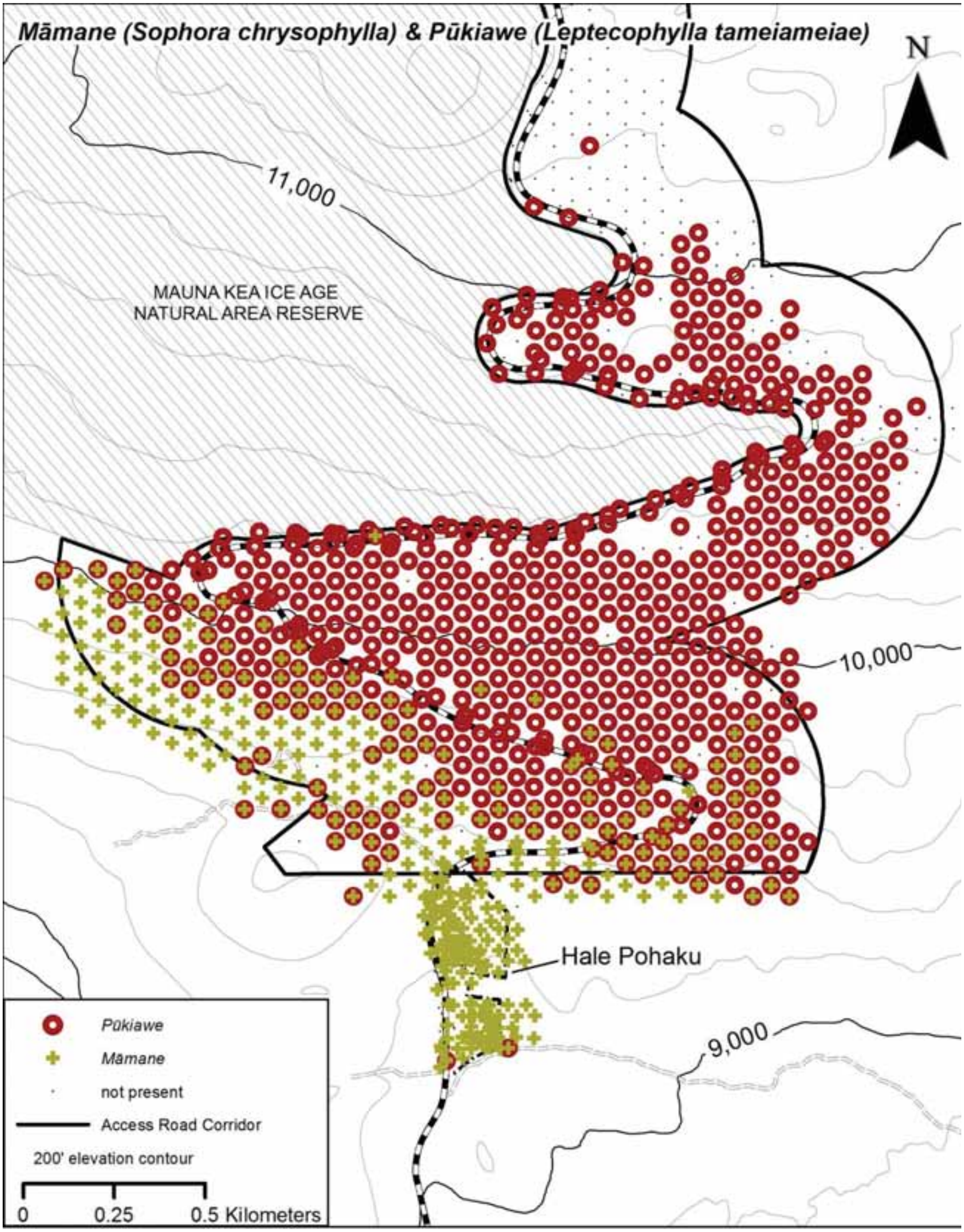


Figure 3. Distribution Boundaries of *Māmane* and *Pūkiawe*

13,000 ft./4,000 m (Table 2, compare Stone Desert Astronomy Precinct to Stone Desert Access Road) shows only small differences. The data show no other important plant distribution properties that support dividing this broad elevation zone into two. Geological differences between these two zones contribute to a difference in the appearance. A larger fraction of the land surface of the Astronomy Precinct is made up of cinder *Pu'u*. In either zone, the *Pu'u* are nearly devoid of vascular plants, but since the Astronomy Precinct is predominantly cinder, it appears more barren.

The land-cover of these high elevations could be called, "Alpine Stone Desert With Widely Scattered Grasses and Ferns" extending from the *Pūkiawe* Shrubland to the summit of Mauna Kea at 13,796 ft./4,206 m and incorporating both the Alpine Grassland and Alpine Stone Desert described in the MKNRMP (2009). The vascular plant life of this zone is inconspicuous, consisting of very widely scattered, low-stature, herbaceous plants. The two native grasses, *Trisetum glomeratum* (*pili uka*) and *Agrostis sandwicensis* (Hawaii bentgrass) are the most frequent species followed by the endemic fern *Asplenium adiantum-nigrum* (*'Iwa 'Iwa*) (Table 2). This ecological zone cannot properly be called a "plant community."

In this report, I identify all of the habitat above the *Pūkiawe* Shrubland as "Alpine Stone Desert." I have subdivided the data from this ecological zone for analysis based on the management units. All the data from the Astronomy Precinct and Buffer (Figure 1) is analyzed separately and identified as "Astronomy Precinct." All the data from the Access Road Corridor below the Astronomy Precinct is analyzed and identified as "Access Road Corridor."

3.1 Flora and Plant Life-Forms of the UH-Management Area

A total of 73 vascular plant species were found in the UH-Management Area, our study area (Table 2) (plant families and full citations given in Appendix A; location maps for all species are in Appendix C.). (Lichens will be discussed later, in Section 3.4.) The greatest diversity of species and plant life forms occurs in the *Māmane* Woodland, the lowest elevation community that we studied (Table 2). Both the number of species and of life forms decreases in each of the alpine communities, with increasing elevation. The Stone Desert at the summit of Mauna Kea supports only a few species of grasses, ferns and herbs, at low frequency. Plant life here is so sparse that it does not form vegetation or a community of interacting plants. The plant life along the Alpine Access Road Corridor is also sparse and in only a few places do grasses form a very open stand that is recognizable as a biological community.

Although only 33 of the 73 species recorded are native to the Hawaiian Islands, the native species are generally much more frequent and predominate in most aspects of these communities (Table 3). Of the introduced plants, only a few of the grasses and herbs are numerous and frequent, and only in the *Māmane* Woodland and, to a lesser extent, in the *Pūkiawe* Shrubland. In some parts of the Mamane Woodland the ground cover is a dense stand of introduced grasses, especially *Nassella cernua* (needlegrass), *Bromus* spp. and *Rytidosperma spp.* Introduced grasses and herbs are present in the Stone Desert, but only at very low frequencies or as incidentals on roadsides, with the exceptions of the herbs, fireweed (*Senecio madagascariensis*) and *Hypochoeris radicata* (gosmore). Native grasses and ferns are the most frequent species in the alpine communities and all of the shrubs of the *Pūkiawe* Shrubland are native.

Table 2. All vascular plant species found in the UH-Management Area and frequency of occurrence (% frequency) within 100-m transects in the subalpine and alpine communities. P indicates species present in community but not found in area covered by transects. Species sorted by life form and by decreasing frequency in lowest elevation community where species occurs, with modifications to show groupings of species with similar distributions. "Spp. Group" indicates membership in Species Groups; see Table 4 for meaning of abbreviations. Native species in bold font, non-native species in regular font.

Spp. Group	Scientific Name	Commmon Name	Subalpine	Alpine Ecosystem		
					Stone Desert	
			Māmane Woodland	*Pūkiawe* Shrubland	Access Road	Astronomy Precinct
			n=397	n=356	n=613	n=682
	Trees					
SA	*Sophora chrysophylla*	***māmane***	**74.6**	**0.56**		
	Coprosma montana	**alpine mirror plant**	**1.76**			
	Malus domestica	apple	0.25			
	Eucalyptus sp.	eucalyptus	0.25			
	Dodonaea viscosa	*a'ali'i*		**0.28**		
	Shrubs					
NS	*Leptecophylla tameiameiae*	***pūkiawe***	**52.6**	**84.8**	**0.16**	
NS	*Tetramolopium humile*	**alpine tetramolopium**	**46.9**	**71.4**	**1.63**	
NS	*Vaccinium reticulatum*	*ohelo*	**26.2**	**60.7**	**1.79**	
NS	*Geranium cuneatum*	*nohoanu*, *hinahina*	**37.0**	**46.1**		
NS	*Dubautia ciliolata*	*na'ena'e*	**6.30**	**8.99**	**P**	
NS	*Silene struthioloides*	**alpine catchfly**	**5.54**	**8.99**		
NS	*Coprosma ernodeoides*	***kūkaenēnē***	**2.02**	**3.37**		
NS	*Rumex giganteus*	***pāwale***	**0.76**	**5.25**		
SA	*Chenopodium oahuense*	***āheahea*, *'āweoweo***	**24.4**			
	Osteomeles anthyllidifolia	***'ūlei***	**0.50**			
	Cytisus palmensis	broom	0.50			
	Dubautia arborea	**Mauna Kea dubautia**		**0.56**		
	Argyroxiphium sandwicense	***'āhinahina*, Mauna Kea silversword**			**0.49**	
	Vines					
SA	*Stenogyne microphylla*	**littleleaf stenogyne**	**14.9**			
SA	*Stenogyne rugosa*	***mā'ohi'ohi***	**3.5**			

Table 2. (Continued) All vascular plant species found in the UH-Management Area and frequency of occurrence (% frequency) within 100-m transects in the subalpine and alpine communities.

Spp. Group	Scientific Name	Commmon Name	Subalpine	Alpine Ecosystem		
					Stone Desert	
			Māmane Woodland	*Pūkiawe* Shrubland	Access Road	Astronomy Precinct
			n=397	n=356	n=613	n=682
	Grasses and Sedges					
UNG	*Trisetum glomeratum*	*pili uka*	**51.6**	**75.0**	**66.7**	**44.6**
UNG	*Agrostis sandwicensis*	**Hawai'i bentgrass**	**30.5**	**28.9**	**56.3**	**59.7**
	Agrostis avenacea	*he'upueo*	**3.02**	**0.76**	**P**	
AGH	*Rhytidosperma semiannulare*	wallaby grass	68.8	54.5	1.31	
AGH	*Bromus catharticus*	rescue grass	45.6	7.87	P	P
AGH	*Anthoxanthum odoratum*	sweet vernalgrass	9.57	2.25	0.65	P
	Holcus lanatus	velvet grass	4.28	0.84	P	
SA	*Deschampsia nubigena*	**alpine hairgrass**	**14.4**	**0.56**		
	Carex macloviana	**St. Malo's sedge**	**4.79**	**5.06**		
	Carex wahuensis	**O'ahu sedge**	**1.01**	**2.25**		
AGH	*Nassella cernua*	needlegrass	70.8	12.9		
AGH	*Vulpia bromoides*	brome fescue	13.1	2.25		
AGH	*Bromus diandrus*	ripgut grass	14.9			
AGH	*Poa pratensis*	Kentucky bluegrass	11.1		P	
	Ehrharta calycina	perennial veldtgrass	0.25	0.56		
	Pennisetum clandestinum	kikuyu grass	1.01	P		
	Dactylis glomerata	orchard grass	0.50			
	Poa annua	annual bluegrass	0.25			
	Pennisetum setaceum	fountain grass	0.25			
	Lolium sp.	rye grass		0.28		
	Luzula hawaiiensis	**wood rush**		**1.97**	**0.49**	
	Ferns					
UNF	*Pellaea ternifolia*	*kalamoho*, *lau-kahi*	**46.6**	**80.3**	**9.46**	**0.29**
UNF	*Asplenium trichomanes*	*'olali'i* , *'owali'i*	**24.2**	**33.2**	**9.62**	**8.80**
UNF	*Asplenium adiantum-nigrum*	*'iwa 'iwa*	**12.1**	**37.9**	**40.0**	**26.8**
	Pteridium aquilinum	**bracken**	**0.50**			
NAF	*Dryopteris wallichiana*	**alpine woodfern**		**P**	**0.16**	**3.23**
NAF	*Cystopteris douglasii*	**Douglas' bladderfern**			**P**	**16.4**

Table 2. (Continued) All vascular plant species found in the UH-Management Area and frequency of occurrence (% frequency) within 100-m transects in the subalpine and alpine communities.

Spp. Group	Scientific Name	Commmon Name	Subalpine	Alpine Ecosystem		
					Stone Desert	
			Māmane Woodland	*Pūkiawe* Shrubland	Access Road	Astronomy Precinct
			n=397	n=356	n=613	n=682
	Herbs					
UAH	*Senecio madagascariensis*	fireweed	96.2	79.2	4.90	9.09
UAH	*Hypochoeris radicata*	gosmore	4.28	18.0	15.1	13.93
UAH	*Taraxacum officinale*	common dandelion	0.50	3.65	0.82	2.20
AGH	*Verbascum thapsus*	mullein	85.6	36.0	0.65	
AGH	*Verbascum virgatum*	wand mullein	16.9	1.12	P	
AGH	*Epilobium billardierianum*	willow herb	15.4	15.7	0.33	
AGH	*Senecio sylvaticus*	woodland ragwort	4.79	0.84	0.16	
	Pseudognaphalium sandwicensium	***'ena 'ena***	**2.52**	**7.87**	**1.31**	
AGH	*Erodium cicutarium*	alfilaria, pin clover	57.7	16.3		0.15
AGH	*Rumex acetosella*	sheep sorrel	61.0	52.0		
AGH	*Heterotheca grandiflora*	telegraph plant	8.82	2.25		
AGH	*Senecio vulgaris*	common groundsel	8.56	0.56		
AGH	*Achillea millefolium*	common yarrow	4.28	1.69		
	Oxalis corniculata	**yellow wood sorell**	**0.76**	**0.28**		
	Argemone glauca	*pua kala*	**1.76**			
AGH	*Trifolium arvense*	lance Clover	6.55			
AGH	*Lepidium sp.*	peppergrass	5.29			
AGH	*Oenothera stricta*	evening primrose	3.78			
AGH	*Mollugo cerviana*	carpetweed	1.51			
	Eschscholzia californica	california poppy	0.76			
	Geranium homeanum	cranesbill	0.50			
	Marrubium vulgare	horehound	0.50			
	Tragopogon porrifolius	salsify	0.50			
	Coreopsis lanceolata	*ko'oko'olau haole*	0.25			
	Melilotus sp.	sweet clover	0.50			
	Verbena litoralis	ōwī		P		

The flora of each community is a subset of the species in the community below it in elevation (Tables 2 and 4). Similarly, the number of life forms represented in each community decreases with elevation. I assigned, subjectively, the more frequent plants to "species groups," each with a similar distribution and other shared properties, such as life-form, and origin (native vs. introduced). With the exception of the "Native Alpine Fern" group, each higher community has a smaller subset of the species groups found in the community below it (Table 4.).

With few exceptions, the plants of the alpine ecosystem are best viewed as plants with distributions centered at lower elevations that can tolerate the alpine environment. The exceptions are three endemic species, the shrubs *ʻāhinahina* (*Argyroxiphium sandwicensis* ssp. *sandwicense*) and *Dubautia arborea* (Mauna Kea dubautia), and *Cystopteris douglasii* (Douglas' bladderfern), a fern that occurs primarily in the high subalpine and alpine ecosystems of Hawaiʻi and Maui.

ʻĀhinahina, the iconic Hawaiian silversword, is a plant of the "alpine cinder deserts" of Maui (*A. sandwicense* subsp. *macrophyllum* (A. Gray) Meyerat) and of Mauna Kea (*A. sandwicense* DC subsp. *sandwicense* (A. Gray) Meyerat), with a reported range of 6,970 to 12,300 ft./2,700 to 3,750 m (Wagner, Herbst and Sohmer 1990). Reportedly, *ʻāhinahina* was once widespread and, perhaps, common on Mauna Kea (Herbst 1986, quoted in Wagner, Herbst and Sohmer 1990). The species is now reduced to two known natural populations, one in the upper Wailuku basin at 9,350 ft./2,850 m in the Mauna Kea Forest Reserve and the other in the Natural and Cultural Resource Preservation Area at 12,000 ft./3,660 m elevation. A few plants have been out-planted in the UH-Management Area and a large number have been re-established nearby in the Mauna Kea Forest Reserve.

Dubautia arborea is a shrub endemic to the subalpine and alpine ecosystems of Mauna Kea from 6,950 to 10,170/2,120 to 3,100 m above sea level, whose distribution and abundance has been much reduced by feral browsers (Wagner, Herbst and Sohmer 1990). We found *D. arborea* at five alpine sites between 10,349 and 10,617 ft./3,155 and 3,235 m.

Cystopteris douglasii is an endemic Hawaiian fern restricted to high elevation sites on Maui and Hawaii island (Palmer 2003). We found *Cystopteris* in the Alpine Stone Desert on Mauna Kea between 12,031 and 13,350 feet (3,368 and 4,070 m).

In our data (Table 2), *Lolium* (rye grass) appears to occur in the alpine *Pūkiawe* Shrubland but not in the Subalpine *Māmane* Woodland. This is clearly an anomaly of the data and does not reflect alpine adaptation. *Pāwale* (*Rumex giganteus*) is a native species with a wide ecological range and is well-known from 2,165 to 10,000 ft./660 to 3,050 m above sea level within the subalpine and lower elevation ecosystems on Hawaiʻi and Maui (Wagner, Herbst and Sohmer 1990). We found p*āwale* at five sites above 10,000 ft./3050 m, the highest at 10,422 (3,177 m). The absence of p*āwale* from our subalpine sample points is, again, a data anomaly. Similarly, the indigenous fern, *Dryopteris wallichiana* (alpine woodfern) appears in our data to be a plant of the high alpine communities; however, this species is common in montane mesic forests and open pastures or lava flows on all the main islands between 2,790-9,000 ft./850-2,740 m (Palmer 2003) and is known historically from Hale Pohaku and the vicinity, perhaps as high as 9,500 ft./2,900 m (Hart and Neal 1940 in MKNRMP 2009). Our finding of *Dryopteris* near the summit at 13,317 ft./4,060 m is a new elevation record for this fern in Hawaii.

Table 3. Summary of species data in Table 2.

Life Form	Entire Study Area		Subalpine		Alpine Ecosystem					
			Māmane Woodland		*Pūkiawe* Shrubland		Stone Desert			
							Access Road		Astronomy Precinct	
	Native	Alien	Native	Alien	Native	Alien	Native	Alien	Native	Alien
Trees	3	2	2	2	2	0	0	0	0	0
Vines	2	0	2	0	0	0	0	0	0	0
Shrubs	12	1	10	1	9	0	5	0	2	0
Grasses	7	14	6	13	7	9	4	5	4	4
Ferns	6	0	4	0	4	0	5	0	5	0
Herbs	3	23	3	23	2	12	1	7	1	4
Subtotal	33	40	27	39	24	21	15	12	12	8
Total	73		66		45		27		20	

Table 4. The distribution of "Species Groups" within the communities of the UH-Management Area. Code" refers to group membership shown in Table 2. Species groups with members conspicuously present in the community are indicated by dark-gray shading. "

Code	Species Group	Subalpine	Alpine Ecosystem		
		Māmane Woodland	*Pūkiawe* Shrubland	Stone Desert	
				Access Road	Astronomy Precinct
SA	Subalpine Group				
NS	Native Shrubs				
UNG	Ubiquitous Native Grasses				
UNF	Ubiquitous Ferns				
UAH	Ubiquitous Alien Herbs				
AGH	Alien Grasses and Herbs				
NAF	High Elevation Ferns				

3.2 Baseline Survey of Management Units

3.2.1 Astronomy Precinct and Buffer Zone

This unit is entirely within the Alpine Stone Desert. Fifteen species of vascular plants were found within the Astronomy Precinct (Table 5). These are 5 species of grasses, 5 species of ferns and 5 species of herbs. No shrubs or other woody plans were found. Seven of the fourteen species are native to Hawaii. The two native grasses, *Agrostis sandwicensis* and *Trisetum glomeratum*, are endemic, as are two of the ferns, *Cystopteris douglasii* and *Asplenium trichomanes*. The remaining three native plants are the indigenous ferns, *Asplenium adiantum-nigrum*, *Dryopteris wallichiana*, and *Pellaea ternifolia*. The eight introduced plant species are five herbs and three grasses.

Table 5. List of all vascular plants found within the Astronomy Precinct and Buffer Zone.

Origin	Scientific Name	Common Name	Life Form
E	*Agrostis sandwicensis* Hillebr.	Hawaii bentgrass	Grass
X	*Anthoxanthum odoratum* L.	sweet vernalgrass	Grass
I	*Asplenium adiantum-nigrum* L.	*iwa 'iwa* , Bird's nest fern	Fern
E	*Asplenium trichomane* s L. subsp. *densum* (Brack) W. H. Wagner	*'olali'i, 'owali'i*	Fern
X	*Bromus catharticus* Vahl	rescue grass	Grass
E	*Cystopteris douglasii* Hook.	Douglas’ bladderfern	Fern
I	*Dryopteris wallichiana* (Spreng.) Hyl.	*‘I’o nui, laukahi* , alpine woodfern	Fern
X	*Erodium cicutarium* (L.) L'Hér.	alfilaria, pin clover	Herb
X	*Hypochoeris radicata* L.	hairy cat's ear, gosmore	Herb
I	*Pellaea ternifolia* (Cav.) Link	*kalamoho, lau-kahi*	Fern
X	*Poa pratensis* L.	Kentucky bluegrass	Grass
X	*Senecio madagascariensi* s Poir.	fireweed	Herb
X	*Senecio* cf. *vulgaris*	cf. common groundsel	Herb
X	*Taraxacum officinale* W. W. Weber *ex* F. H. Wigg	common dandelion, *laulele, lauhele*	Herb
E	*Trisetum glomeratum* (Kunth) Trin.	*pili uka, he'upueo* , mountain pili	Grass

Notes:

1. Origin: E = Endemic, I = Indigenous, X = Introduced.

2. Scientific and common names are generally consistent with names used in the Natural Resources Management Plant (MKNRMP 2009) with minor corrections based on Wagner, Herbst and Sohmer (1990) for flowering plants and Palmer (2003) for ferns.

3.2.1.1 Plants found on transects and their Relative Frequencies

No vascular plants at all were recorded in 22% of the 682 100-m segments. Similarly, 76% of the 6-m sample plots and 95% of the 2-m sample plots were barren of all vascular plants. Of the 24.5% of the 6-m sample plots that were occupied by a plant or plants, 19.4% had only one species, 4.0% had two species, 1.0% had 3 species, and 0.1% (one plot) had 4 species. Five of the fifteen species found within the Astronomy Precinct were encountered only during the roadside survey (Tables 5 and 6) and did not occur on the transects.

Table 6. Frequency of vascular plants found in sample plots (2-m circle and 6-m circle) and 100-m segments, grouped by life form (n=682) in the Astronomy Precinct and Buffer Zone.

Origin	Scientific Name	Life Form	% Frequency		
			2-m Circle	6-m Circle	100-m Transect
E	*Agrostis sandwicensis*	Grass	3.23	15.4	59.68
E	*Trisetum glomeratum*	Grass	1.32	6.89	44.57
I	*Asplenium adiantum-nigrum*	Fern	0.59	3.52	26.83
E	*Cystopteris douglasii*	Fern	0.44	1.61	16.42
E	*Asplenium trichomanes*	Fern	0	0.88	8.8
I	*Dryopteris wallichiana*	Fern	0	0.29	3.23
I	*Pellaea ternifolia*	Fern	0	0	0.29
X	*Hypochoeris radicata*	Herb	0	1.17	13.93
X	*Senecio madagascariensis*	Herb	0.15	0.88	9.09
X	*Taraxacum officinale*	Herb	0	0.29	2.2
X	*Erodium cicutarium*	Herb	0	0	0.15
	Barren Segments and Sample Plots		94.7	75.5	22.3
	Ungulate Dung	Dung	1.1	2.97	18.94

Notes: 1. Origin: E = Endemic, I = Indigenous, X = Introduced.

We found only one individual *Erodium cicutarium* (alfilaria) plant, an introduced herb that is common at lower elevations. The next nearest sample point with this species is at 10,448 ft. (3185 m) elevation in the Alpine Shrubland Community. This species may not be established as a reproducing species at the Mauna Kea summit.

We found the indigenous fern, *Pellaea ternifolia (kalamoho)*, in just two 100-m segments in the Astronomy Precinct. However, unlike *Erodium*, *Pellaea* occurs in 5% of the 100-m transects in the Alpine Access Road Corridor below the Astronomy Precinct (Table 2). *Pellaea* may be sparingly reproducing at the summit.

The other 9 species, both native and introduced, shown in Table 5 are undoubtedly established and reproducing within the Astronomy Precinct. The two native grasses are the most frequent species within this very, very sparse Stone Desert Community, followed by two native ferns, *Asplenium adiantum-nigrum* and *Cystopteris*. Two introduced weeds, *Hypochoeris* and fireweed are the fifth and sixth most frequent species, respectively, out of the eleven plant species recorded.

3.2.1.2 Roadside Plants Within the Astronomy Precinct

The Access Road within the Astronomy Precinct traverses the unconsolidated cinder slopes of the summit *Pu'u* with three switchbacks. The road is paved, has paved shoulders and there is a concrete retaining wall on the up-hill side of the road on each switchback. Individuals of 11 species of plants were found growing in association within these constructed features (Table 7). The plants were most

Table 7. Plants found during Roadside Survey of Access Road within the Astronomy Precinct and 500 m Buffer zone, listed in order of decreasing abundance (sum) within 100 m segments (n=24).

Origin	Scientific Name	% Freq	Sum
X	*Bromus catharticus*	0.5	32
I	*Asplenium adiantum-nigrum*	0.5	31
E	*Trisetum glomeratum*	0.38	25
X	*Senecio madagascarensis*	0.5	22
E	*Agrostis sandwicensis*	0.25	10
X	*Hypochoeris radicata*	0.21	7
I	*Pellaea ternifolia*	0.13	6
X	*Senecio sp.*	0.08	4
X	*Poa pratensis*	0.04	2
X	*Anthoxanthum odoratum*	0.04	2
E	*Asplenium trichomanes*	0.04	1

Notes:

1. Origin: E = Endemic, I = Indigenous, X = Introduced.
2. Sum = Index of Abundance; see Sec. 2.232.

often found in a 1-2 cm-wide crack between the asphalt pavement of the road and the paved shoulder, inside drain-holes at the base of the retaining wall, at the base of the retaining wall where it meets the pavement, or on the uphill side of the retaining wall where the slope of the *Pu'u* and the wall make an acute angle. A very small number of *Agrostis* and *Trisetum* were observed growing between 0.5 and 1.0 m away from the pavement on more-or-less undisturbed cinder substrate. We could not determine if the presence of the road did or did not influence the establishment of these few grasses.

The species found along the roadside are about equally divided in number and abundance between native species and introduced species (Table 7). The native species include *Trisetum*, *Agrostis*, and *Asplenium adiantum-nigrum*, all of which are typical of the summit flora as well as *Asplenium* *trichomanes* and *Pellaea*, native ferns that are present at the summit at very low frequencies. The most abundant introduced species along the roadsides are fireweed and *Hypochoeris*, the most frequent weedy herbs throughout the summit region. The introduced plants include three very low frequency species which are not otherwise found at the summit, and one introduced grass, *Bromus catharticus*, that has the highest frequency and abundance of any plant along the roadsides, but does not generally occur above Hale Pohaku, except along the roadside of Access Road.

3.2.1.3 Plants Found Near Observatories

No vascular plants were found along or near the foundations of any of the observatories or their out-buildings, parking areas, or other constructed facilities near the observatories. The extensive unoccupied spaces between and around the observatories are cinder substrates that are also devoid of vascular plants. One individual *Hypochoeris* plant was found (then uprooted) next to a retaining wall along the road that joins the telescopes on *Pu'u Kea* with those on *Pu'u Hauoki*.

While most of the observatories are built on cinder substrate associated with the summit *pu'u*, the Caltech Submillimeter Observatory is partially surrounded by a pad of gravel that adjoins the relatively undisturbed lava substrate nearby. No plants were found within the gravel or near the observatory, but the native grasses, *Trisetum* and *Agrostis*, and the introduced herb, *Hypochoeris*, are frequent on the nearby unaltered lava substrate.

3.2.1.4 Plants of the Astronomy Precinct *Pu'u*

The *pu'u* (cinder cones) that were modified by construction of observatories are described above (Section 3.13). Most of the upper slopes and peaks of *Pu'u Wekiu* and *Pu'u Poliahu* are less disturbed by construction, but have been affected by pedestrian traffic and, previously, by an unauthorized jeep road on *Pu'u Poliahu*. We observed these *pu'u* from roads, trails and other vantage points. The surface of these features is almost entirely unconsolidated, loose cinder with a very few, small areas of lava outcrop or spatter that has accreted into small boulders. We found the cinder surfaces almost entirely devoid of vascular plants. A very few grass plants (either *Trisetum* or *Agrostis*) were seen growing one to two meters away from the Access Road on the lower slopes of *Pu'u Wekiu* (Section 3.2.1.2). We could not determine if these plants occurred there "naturally" or were facilitated by the presence of the road. We found one cluster of consolidated spatter on *Pu'u Poliahu* that supported a single clump of *Agrostis* and numerous individuals of the common lichen, *Lecanora polytropa*. It is almost certain that a few other individual plants, perhaps of several species, grow on the undisturbed cinder of these *pu'u*, but it is also certain that these plants are few in number and very widely scattered.

3.2.2 Access Road Corridor in the Alpine Ecosystem

The Access Road Corridor is 400 m wide and extends through the Alpine Ecosystem downward from the boundary of the Astronomy Precinct and its buffer at 13,000 ft./4,000 m to the upper boundary of the Subalpine Ecosystem at approximately 10,000 feet (3,050 m). The portion of the Access Road within the Subalpine Ecosystem is discussed with Hale Pohaku. Within the Alpine Ecosystem, plant presence/absence data were recorded at 969 sample points along almost 100 km of transects along the east side of Access Road. The sample methodology was the same as used in the Astronomy Precinct, presented above.

This section presents a floristic analysis of the Access Road Corridor as it traverses the Alpine Stone Desert and the Alpine *Pūkiawe* Shrubland. For this study, these two units are defined by these altitudinal bounds:

- *Pūkiawe* (*Leptechophylla*) Shrubland 10,000 ft./ 3,050m to 11,150 ft./ 3,400m

- Alpine Stone Desert   11,150 ft./3,400 m to 13,000 ft./4,000 m

3.2.2.1 Vascular Plant Species of the Alpine Stone Desert

The plant life of the Access Road Corridor in the Alpine Stone Desert is extremely sparse. From many or most observation points, no plants are visible. The plants of this community are tussock grasses, usually less than 50 cm high, and small ferns and herbs that are most commonly found at the bases of boulders or in protected crevices. Plant cover is far too low to be accurately measured.

There are more native than introduced plant species (Tables 8 and 9). All of the most frequent plants in the Stone Desert are native species. The only introduced plant with more than 10% frequency is *Hypochoeris*, with 16%, and fireweed follows with less than 5%.

We did not find the high-elevation endemic fern, *Cystopteris douglasii*, in the transects of the Alpine Access Road Corridor. This fern was found sparingly within this elevation zone during reconnaissance excursions of the Science Reserve (Section 3.2.3).

In three 100-m segments, we found *'āhinahina* (Mauna Kea silversword) plants that had been planted. These segments are between 12,100 ft./3,690 m and 12,250 ft./3,735 m near the VLBA Observatory.

3.2.2.2 Vascular Plant Species of the Alpine *Pūkiawe* Shrubland

The *Pūkiawe* Shrubland is dominated by several native shrubs (Table 8) that are associated with alpine and subalpine ecosystems as well as arid and early succession environments at much lower elevations. The shrubs, 0.5 to 1.5 m high, exhibit typical alpine "cushion" form. In a few places, especially at the lower elevations within the zone, the cover of these shrubs may approach an estimated 50%. In many places, especially near the upper boundary with the Alpine Stone Desert, it is far less.

A number of native grasses and ferns are associated with this community, some at high frequencies (Table 8.) Additionally, many introduced species of grasses and herbs have invaded this community. Most frequent among these are fireweed*, Rytidosperma*, mullein and *Rumex acetosella* (sheep sorrel). The groundcover may be dominated by these introduced species, especially in the lower-elevations of this community, where a much larger number of introduced grasses and herbs are found. These are weedy species, such as *Nassella cernua* (needlegrass), *Bromus catharticus*, and *Heterotheca grandiflora* (telegraph weed) that are abundant in the Subalpine Woodland and around Hale Pohaku.

Table 8 . Percent frequencies of vascular plants in 100-m segments within the Access Road Corridor. Same data is presented in Table 2, but rearranged here from high to low frequency within Stone Desert for comparison of these two communities. Native species shown in bold font.

Scientific Name	Alpine Community	
	Pūkiawe Shrubland N = 356	Stone Desert N = 613
Trisetum glomeratum	**75.00**	**66.72**
Agrostis sandwicensis	**26.40**	**56.28**
Asplenium adiantum-nigrum	**37.92**	**39.97**
Asplenium trichomanes **subsp.** *densum*	**33.15**	**9.62**
Pellaea ternifolia	**80.34**	**9.46**
Pseudognaphalium sandwicensium	**7.87**	**1.31**
Luzula hawaiiensis **var.** *hawaiiensis*	**1.97**	**0.49**
Argyroxiphium sandwicense		**0.49**
Dryopteris wallichiana		**0.16**
Senecio madagascariensis	79.21	4.89
Hypochoeris radicata	17.98	16.31
Rytidosperma pilosum	54.49	1.31
Epilobium billardierianum subsp. *cinereum*	15.73	0.33
Taraxacum officinale	3.65	0.82
Anthoxanthum odoratum	2.25	0.65
Senecio Spp.	0.84	0.16
Leptecophylla tameiameiae	**84.83**	**0.16**
Tetramolopium humile **subsp.** *humile*	**71.35**	**1.63**
Vaccinium reticulatum	**60.67**	**1.79**
Geranium cuneatum **subsp.** *hololeucum*	**46.07**	
Dubautia ciliolata	**8.99**	
Silene struthioloides	**8.99**	
Carex macloviana **subsp.** *Subfusca*	**5.06**	
Coprosma ernodeoides	**3.37**	
Agrostis avenacea	**2.81**	
Carex wahuensis	**2.25**	
Rumex giganteus	**2.25**	
Deschampsia nubigena	**0.56**	
Dubautia arborea	**0.56**	

Table 8 . (Continued). Percent frequencies in 100-m segments of vascular plants within the Access Road Corridor.

Scientific Name	Alpine Community	
	Pukiawe Shrubland N = 356	Stone Desert N = 613
Sophora chrysophylla	**0.56**	
Dodonaea viscosa	**0.28**	
Oxalis corniculata	**0.28**	
Rumex acetosella	51.97	
Verbascum thapsus	35.96	
Erodium cicutarium	16.29	
Nassela cernua	12.92	
Bromus catharticus	7.87	
Heterotheca grandiflora	2.25	
Vulpia bromoides	2.25	
Achillea millefolium	1.69	
Verbascum virgatum	1.12	
Holcus lanatus	0.84	
Senecio vulgaris	0.56	
Ehrharta calycina	0.56	
Lolium sp.	0.28	
Ungulate Dung	36.24	3.26

Table 9. Comparison of the numbers of native and introduced species in the 100-m segments in the two alpine communities within the Access Road Corridor.

Alpine Community	Native	Introduced	Total
Stone Desert	12	7	19
Pukiawe Shrubland	23	20	43

3.2.3 Natural/Cultural Preservation Area (N/CPA)

The purpose of this reconnaissance survey was to generally characterize the plant-life of the N/CPA, and to determine if the plant-life and physical conditions in the N/CPA were comparable to similar elevations along the Access Road or in the Astronomy Precinct, and to evaluate the probability that there are plant species in the N/CPA not recorded elsewhere.

We found that the plant-life and conditions were similar to comparable areas of the UH Management Area that had been intensely surveyed. The landscape of the Alpine Stone Desert within the N/CPA is near-barren, as is the Stone Desert along the Access Road Corridor, described in section 3.2.2. Plants are widely scattered, nearly always in protected microsites. Twenty plant species were recorded at the 240 subjectively-chosen sample points during eight "excursions" that constituted the major effort of this survey (Table 10). These included twelve native species of shrubs (2), grasses (4), herbs (1) and ferns (5). The eight species of introduced plants were all herbs except the grass, *Rytidosperma*. The only other species noted on our excursions were the small population of *'āhinahina* (silverswords) in the enclosure within the southwest section of the N/CPA near the boundary with the Natural Area Reserve, and a single clump of *Dactylis glomerata* (orchardgrass) on P*u'u Makanaka*.

We did not find any plant species not recorded elsewhere in the UH-Management Area nor did we find unique or unusual plant communities within the N/CPA. Although this reconnaissance provides a very low intensity sample, the finding of consistently near-barren substrate and the failure to find new Mauna Kea records supports the proposition that there is a low probability that more extensive surveys would find new records or other unexpected discoveries of plant-life.

We did find these three species that were not recorded at similar elevations within the Access Road Corridor at comparable elevations:

1. We found the endemic fern, *Cystopteris douglasii*, at 12,031 ft./3,668 m, our lowest record on Mauna Kea.

2. We found the indigenous *Agrostis avenacea* (*he'upueo*) at a few points, the highest at 12,856ft./3,920 m, our highest record on Mauna Kea.

3. We found one individual of the introduced *Verbascum virgatum* (wand mullein) growing at 12,224 ft/3,727 m, more than 1,600 ft./488 m higher than the next highest record.

None of these records are particularly significant in themselves, but they show that individuals of common native and introduced species are capable of growing in the N/CPA at elevations not recorded elsewhere in this study.

The excursions were planned to explore all portions of the N/CPA and to visit areas representative of the major substrate types within the area. Plant frequencies of occurrence were calculated for three substrate types (Table 10). Eighteen points that were distributed among three minor types were not analyzed.

Three tentative trends can be seen in these data. 1) Certain species (marked with green background in table) that are ubiquitous in all other parts of the UH-Management Area are frequent both on the lava flows (l and hm substrates) and the unconsolidated glacial till (lmt). 2) Other species (flagged with gray backgrounds) are frequent only on the lava flows and much less frequent or absent on the till. 3) Some species (shown by golden backgrounds) are markedly more frequent on the ancient Hamakua lava flows (hm) than on the more recent Laupahoehoe flows (l). Together, these observations support the general finding of higher frequency and species diversity on lava flows than on

Table 10. Percent frequencies of vascular plants at sample points on Excursions 3 through Excursion 10. Native species shown in bold typeface, introduced species shown with normal font. Percent frequency of occurrence shown for "All Points" sampled and percent frequency of occurrence at sample points of various substrates: l = older Laupahohoe lava (14-65,000 yrs. old), lmt = glacial till, and hm = ancient Hamakua lava (>65,000 yrs. old). Colors explained in following text.

Life Form	Species	All Points n = 240	Substrate l n=90	Substrate lmt n=104	Substrate hm n=28
Grass	***Agrostis sandwicensis***	72	73	80	57
Fern	***Asplenium adiantum-nigrum***	46	50	47	57
Grass	***Trisetum glomeratum***	36	48	31	32
Fern	***Cystopteris douglasii***	16	30	7	18
Fern	***Asplenium trichomanes***	21	23	9	71
Grass	***Agrostis avenacea***	3	1	0	18
Fern	***Pellaea ternifolia***	5	3	2	25
Herb	***Pseudognaphalium sandwicensium***	4	4	0	14
Fern	***Dryopteris walliciana***	4	6	1	11
Grass	***Luzula hawaiiensis***	2	3	0	4
Shrub	***Tetramolopium humile***	1	2	1	0
Shrub	***Vaccinium reticulatum***	2	2	1	0
Herb	*Hypochoeris radicata*	32	29	32	64
Grass	*Rytidosperema seiannulare*	5	10	0	4
Herb	*Senecio madagascariensis*	25	26	13	82
Herb	*Taraxacum officinale*	13	23	0	39
Herb	*Verbascum virgatum*	0	0	0	4
Herb	*Senecio sp.*	1	0	0	11
Herb	*Verbascum thapsus*	0	1	0	0
Herb	*Epilobium billardierianum*	2	3	0	4

unconsolidated materials and give some suggestion that the ancient Hamakua lava flows may be more conducive to diverse plant life than the more recent Laupahoehoe flows.

The only known natural population of silversword in the N/CPA is on the Hamakua Lava substrate. It is not known if the survival of this population is linked to characteristics of the Hamakua Lava or possibly to the rugged terrain. More intensive plant surveys of the Hamakua lava flows might reveal a generally more frequent distribution of common native and introduced plants and, speculatively, occurrences of rarer plant species.

Although only a few sample points were recorded on the *Pu'u* of the N/CPA, we did investigate Pu'u Mahoe, Poepoe, Ala, and Makanaka. We found these scoria cones (mapped as lc: Laupahoehoe scoria) to be nearly barren of plant-life, just as we had all other areas of this substrate type.

3.2.4 Hale Pohaku and the Subalpine *Māmane* Woodland

The lower part of Access Road and Hale Pohaku are within the Subalpine Ecosystem. This Subalpine Ecosystem includes all of the UH-Management Area below 10,100 ft./3,080 m on the west side of Access Road and all of the UH-Management Area below 9,800 ft./3,000 m on the east side of the road. Because of the switchbacks in this area, the Access Road Corridor, projected as all the area within 400 m of the road, assumes a fairly compact shape comprising approximately 290 acres/ 121 ha (Figure 1). This entire area was sampled using the same transect and sample point methodology described in Figure 2 and Section 2.2.2. Four hundred and three sample points were established, 67 of them within the 20 acre/8 ha parcel known as Hale Pohaku. As in other components of this study, presence/absence of vascular plant species was recorded in 2-m and 6-m diameter circular plots and in 100 x 30 m transect segments.

3.2.4.1 The Tree-Line

The upper elevational limit of *māmane* is the tree line within the UH-Management Area and, reportedly, on most of Mauna Kea. We use this tree line to delineate the boundary between the subalpine and the alpine ecosystems. *Māmane* is the only tree species present in the study area, with the exception of a very few individuals of *Coprosma montana* and *Dodonaea viscosa*, and, a few individual *Eucalyptus* sp. and apple trees (*Malus domestica)* planted at Hale Pohaku.

The *māmane* tree-line is visually distinct within the UH-Management Area. At tree line, the *māmane* are approximately 6 ft./2 m high and widely scattered. Within a few hundred meters distance, the trees become taller and cover increases. *Māmane* grows to slightly higher elevations in ravines than on ridges. It can also be seen that *māmane* favors the sandy-ash substrate over rocky outcrops or *'a'a* lava flows where the species of the Alpine Shrubland, especially *pūkiawe*, *ohelo*, and *hinahina* dominate. This association of taller, denser *māmane* on the sandy-ash substrate and native shrubs on rocky surfaces persists at all elevations within the Subalpine Ecosystem of the UH-Management Area.

3.2.4.2 Vegetation of the *Māmane* Woodland in the Subalpine Ecosystem

We classify all the vegetation of all of the UH-Management Area within the Subalpine Ecosystem as *Māmane* Woodland. *Māmane* forms an open to very open canopy of multiple-stem trees or tree clumps that reach 2 to 5 meters in height. The native shrubs of the Alpine Shrubland and the ubiquitous native grasses, *Agrostis* and *Trisetum*, are frequent, but not uniformly distributed. The native shrubs and grasses dominate, with minimal *māmane* cover, on localized rocky substrates, such as outcrops, *'a'a* and rubble fields. *Māmane* prevails on the more widely distributed substrate of sandy-ash that overlays the lava flows. The groundcover under and around the *māmane* is usually predominantly introduced grasses, including *Nassella, Bromus* spp*.,* and *Rytidosperma*, and herbs, especially fireweed and mullein.

The *Māmane* Woodland is the most diverse and structurally-complex community within the UH-Management Area on Mauna Kea. In addition to having more species—a total of 65 (Table 2)--than any of the alpine communities, the *Māmane* Woodland has six general life-form categories, one more than is found in any of the alpine ecosystem (Table 3). The *māmane* trees provide much greater biomass and more vertical structure than is found in the tree-less alpine communities.

The *Māmane* Woodland supports a larger number (39) of introduced species than is found in the entire alpine ecosystem (Table 2). Thirty-seven of the thirty-nine introduced plants of the UH-Management Area occur in the *Māmane* Woodland (and many of them in alpine communities, as well).

It is only in this community that the introduced plants are a conspicuous and important component of the vegetation. In much of this community, introduced grasses dominate the ground cover, often forming thick swards, especially under and around *māmane* trees. Both Nassella (needlegrass) and *Rytidosperma* are more frequent than *Trisetum*, the most frequent native grass (Table 2). Additionally, *Bromus catharticus*, *B. diandrus*, *Vulpia bromoides*, and *Poa pratensis* are very frequent and, collectively, have far more cover than the 6 species of native grass that are present.

A large number of introduced herbs are also present in the ground cover in the *Māmane* Woodland. Some are intermixed with the grasses, but some, such as mullein (*Verbascum* spp.) and *Heterotheca*, grow well in areas of otherwise open cinder, giving this community a "weedy" appearance. Fireweed is ubiquitous and in spots forms a nearly complete cover by itself. The weedy flora of the subalpine ecosystem apparently provides the immediate source of seeds for the invasion of the alpine communities. However, it should be pointed out that only six of these weeds—fireweed, *Hypochoeris*, common mullein, *Epilobium*, *Erodium*, and *Rumex acetosella*—are more than four percent frequent in the Alpine *Pūkiawe* Shrubland, and only fireweed, dandelion and *Hypochoeris* are more than one percent frequent in the Alpine Stone Desert (Table 2).

3.2.4.3 Evidence of Human Impact at Hale Pohaku

Hale Pohaku has been a center of human activity on the southern slope of Mauna Kea for many decades. The *Hale Pohaku* (stone cabins) were built long ago and have been used by travelers and hunters. There are many items of evidence of relatively intensive use and disturbance of the vegetation, including foundations, abandoned equipment and various roads or driveways. Today, Hale Pohaku is the location of the mid-elevation astronomy facilities as well as the visitor center. Apparently, this site receives more daily visitors and use than the surrounding area within the UH-Management Area. The following analysis compares the presence and frequency of both native and introduced plant species between the 67 sample points within Hale Pohaku and the 336 sample points within the Access Road Corridor outside Hale Pohaku. It is reasonable to assume that differences are due, at least in part, to the higher level of human disturbance at Hale Pohaku.

Adverse impact of human activity would be expected to include reduction of the abundance and frequency of some or all native plant species at Hale Pohaku and the increase in the abundance and frequency of introduced species there.

A review of the 13 native plant species that have frequencies above ten per cent in 100-m segments in the *Māmane* Woodland shows that nine of these species have markedly reduced frequencies at Hale Pohaku (Table 11). These species with reduced frequencies include native shrubs, ferns and grasses. In contrast the dominant and only native tree in this group, *māmane* itself, shows a modestly higher frequency at Hale Pohaku. Returning to the native plants with lower frequencies, two shrubs, *Tetramolopium* and ohelo (*Vaccinium reticulatum*), and the ferns, *Pellaea* and *Asplenium adiantum-nigrum*, appear to have been extirpated at Hale Pohaku. Other native species that are important components of the subalpine vegetation, including *pūkiawe*, *hinahina*, and the grasses, *Trisetum* and *Agrostis sandwicensis* have greatly reduced frequencies within Hale Pohaku.

Many introduced species have markedly higher frequencies within Hale Pohaku (Table 11). Thirteen introduced species occur within Hale Pohaku that were not recorded in the 100-m segments elsewhere in the Subalpine Ecosystem. Of the 18 introduced species present with frequencies below ten percent outside of Hale Pohaku, 8 have markedly higher frequencies within.

The above findings support the hypothesis that long term human use has altered the composition of the vegetation at Hale Pohaku, generally diminishing the frequency of many native species and leading to the establishment and proliferation of many introduced species.

Table 11. Percent Frequencies within sample units of the Subalpine *Māmane* Woodland. Data from transects in the subalpine zone excluding Hale Pohaku (Subalpine Transects), transects within Hale Pohaku,and from random sample points within Hale Pohaku (HP Intensives). Diff is the difference in frequency in 100-m transects between Hale Pohaku Transects and Subalpine Transects. Green indicates native species with markedly higher frequencies within Hale Pohaku; red indicates native species with markedly lower frequency within Hale Pohaku and introduced species with markedly higher frequency within Hale Pohaku.

	Subalpine Transects			Hale Pohaku Transects			Diff	HP Intensives	
	n = 336			n = 67				n = 97	
	2-m	6-m	100-m	2-m	6-m	100-m	HP-Sub	2-m	6-m
Frequent Native Species									
Sophora chrysophylla	11.3	29.2	70.2	9.0	32.8	85.1	14.8	23.7	52.6
Stenogyne microphylla	0.3	0.9	12.2	0.0	1.5	26.9	14.7	1.0	5.2
Leptecophylla tameiameiae	11.6	29.8	63.7	0.0	0.0	1.5	-62.2	0.0	0.0
Trisetum glomeratum	6.3	20.5	58.9	3.0	4.5	14.9	-44.0	0.0	1.0
Tetramolopium humile	8.6	23.8	57.1	0.0	0.0	0.0	-57.1	0.0	0.0
Pellaea ternifolia	9.8	21.7	56.8	0.0	0.0	0.0	-56.8	0.0	0.0
Geranium cuneatum	5.4	14.3	44.6	1.5	4.5	9.0	-35.7	0.0	0.0
Agrostis sandwicensis	8.6	17.6	35.4	0.0	0.0	3.0	-32.4	0.0	0.0
Vaccinium reticulatum	1.8	3.0	31.8	0.0	0.0	0.0	-31.8	0.0	0.0
Asplenium trichomanes	1.8	6.0	28.3	0.0	0.0	4.5	-23.8	0.0	0.0
Asplenium adiantum-nigrum	0.3	1.2	14.6	0.0	0.0	0.0	-14.6	0.0	0.0
Chenopodium oahuense	3.9	7.4	25.6	3.0	7.5	22.4	-3.2	0.0	1.0
Deschampsia nubigena	0.3	1.5	13.7	1.5	4.5	14.9	1.2	1.0	3.1
Infrequent Native Species									
Stenogyne rugosa	0.3	0.6	2.1	0.0	0.0	10.4	8.4	1.0	2.1
Argemone glauca	0.3	0.3	2.1	4.5	4.5	6.0	3.9	0.0	0.0
Silene struthioloides	1.5	2.1	6.5	0.0	0.0	0.0	-6.5	0.0	0.0
Dubautia ciliolata	0.6	0.9	7.7	3.0	3.0	7.5	-0.3	0.0	0.0
Carex macloviana	0.6	0.9	5.4	1.5	1.5	1.5	-3.9	0.0	0.0
Agrostis avenacea	0.0	0.6	3.6	0.0	0.0	3.0	-0.6	0.0	1.0
Pseudognaphalium sand.	0.0	0.3	3.0	0.0	0.0	1.5	-1.5	0.0	0.0
Coprosma ernodeoides	0.0	0.0	2.4	0.0	0.0	1.5	-0.9	0.0	0.0
Coprosma montana	0.0	0.0	2.1	0.0	0.0	0.0	-2.1	0.0	0.0
Oxalis corniculata	0.6	0.6	0.9	0.0	0.0	0.0	-0.9	0.0	0.0
Rumex giganteus	0.0	0.0	0.9	0.0	0.0	0.0	-0.9	0.0	0.0
Carex wahuensis	0.0	0.6	1.2	0.0	0.0	1.5	0.3	0.0	0.0
Pteridium aquilinum	0.3	0.3	0.6	0.0	0.0	0.0	-0.6	0.0	0.0
Osteomeles anthyllidifolia	0.0	0.0	0.6	0.0	0.0	0.0	-0.6	0.0	0.0

Table 11. (Continued) Percent Frequencies of the Subalpine *Māmane* Woodland.

Introduced Spp.	Subalpine			Hale Pohaku			Diff	HP	
	2-m	6-m	100-m	2-m	6-m	100-m	HP-Sub	2-m	6-m
Senecio madagascariensis	43.8	74.7	95.5	32.8	56.7	92.5	-3.0	47.4	81.4
Verbascum thapsus	10.1	28.3	84.5	19.4	46.3	80.60	-3.9	38.1	82.5
Rhytidosperema semiannulare	23.8	39.9	74.1	16.4	25.4	43.3	-30.8	5.2	21.6
Rumex acetosella	4.8	14.6	66.4	0.0	7.5	32.8	-33.5	3.1	13.4
Bromus catharticus	14.6	25.6	52.1	0.0	0.0	7.5	-44.6	2.1	6.2
Epilobium billardierianum	0.6	3.0	17.3	0.0	0.0	0.0	-17.3	0.0	0.0
Nassella cernua	22.0	33.3	65.2	34.3	62.7	85.07	19.9	53.6	74.2
Erodium cicutarium	9.2	18.8	52.7	19.4	43.3	79.10	26.4	39.2	68.0
Vulpia bromoides	1.2	2.7	9.5	3.0	6.0	28.36	18.8	11.3	19.6
Verbascum virgatum	0.9	2.1	7.1	6.0	14.9	59.70	52.6	7.2	22.7
Lepidium sp.	0.0	0.3	3.6	1.5	6.0	11.9	8.4	1.0	5.2
Heterotheca grandiflora	0.0	0.9	3.3	7.5	16.4	38.8	35.5	1.0	3.1
Anthoxanthum odoratum	0.3	0.3	3.3	4.5	10.4	35.8	32.5	2.1	8.2
Poa pratensis	0.3	0.6	2.7	7.5	9.0	46.27	43.6	26.8	44.3
Achillea millefolium	0.0	0.0	2.4	0.0	3.0	13.4	11.1	0.0	0.0
Marrubium vulgare	0.0	0.0	0.6	0.0	0.0	6.0	5.4	0.0	0.0
Bromus diandrus	0.0	0.0	0.0	13.4	35.8	82.09	82.1	30.9	64.9
Trifolium arvense	0.0	0.0	0.0	6.0	10.4	35.8	35.8	2.1	2.1
Oenothera stricta	0.0	0.0	0.0	3.0	3.0	19.4	19.4	3.1	5.2
Malus domestica	0.0	0.0	0.0	4.5	4.5	9.0	9.0	0.0	0.0
Pennisetum clandestinum	0.0	0.0	0.0	0.0	0.0	6.0	6.0	0.0	0.0
Foeniculum vulgare	0.0	0.0	0.0	1.5	1.5	4.5	4.5	0.0	0.0
Cytisus palmensis	0.0	0.0	0.0	0.0	0.0	4.5	4.5	0.0	2.1
Eucalyptus sp.	0.0	0.0	0.0	0.0	0.0	4.5	4.5	1.0	3.1
Eschscholzia californica	0.0	0.0	0.0	0.0	1.5	3.0	3.0	0.0	0.0
Geranium homeanum	0.0	0.0	0.0	0.0	0.0	3.0	3.0	1.0	2.1
Lolium sp.	0.0	0.0	0.0	0.0	0.0	3.0	3.0	0.0	0.0
Tragopogon porrifolius	0.0	0.0	0.0	0.0	0.0	3.0	3.0	0.0	0.0
Pennisetum setaceum	0.0	0.0	0.0	0.0	0.0	1.5	1.5	0.0	0.0
Senecio sylvaticus	0.0	0.3	5.7	0.0	0.0	0.0	-5.7	0.0	0.0
Hypochoeris radicata	0.0	0.6	4.5	1.5	4.5	9.0	4.5	0.0	1.0
Holcus lanatus	0.0	0.0	3.9	1.5	3.0	6.0	2.1	0.0	1.0
Mollugo cerviana	0.0	0.6	1.8	0.0	0.0	0.0	-1.8	0.0	0.0
Dactylis glomerata	0.0	0.0	0.6	0.0	0.0	0.0	-0.6	0.0	0.0
Taraxacum officinale	0.0	0.0	0.6	0.0	0.0	0.0	-0.6	0.0	1.0
Erharta calycina	0.0	0.0	0.6	0.0	0.0	0.0	-0.6	0.0	0.0
Melilotus sp.	0.0	0.0	0.3	1.5	1.5	1.5	1.2	0.0	0.0
Poa annua	0.0	0.0	0.3	0.0	0.0	0.0	-0.3	0.0	0.0

3.2.5 Roadside Survey

3.2.5.1 Special Methods

The purpose of the roadside survey is to detect changes in plant frequency associated with the construction or the existence of the road. Possible causes of changes in plant frequencies include physical changes to the habitat, such as crushing or compaction of the original lava or cinder substrate or the change in distribution of run-off water, and the transport of seeds or propagules by traffic using the road.

The special survey of the roadside of Access Road consisted of establishing transects on both sides of Access Road through the Access Road Management Corridor. (Data from the east-side of the road were recorded as "RE" and from the west-side as "RW.") These roadside transects were defined as 3-m wide beginning at the edge of the drive-able roadway or shoulder of Access Road. This 3-m wide belt transect contains most of the observable habitat alterations associated with the Road. This transect was divided into segments 50 m long. Since the road is not straight or running with a cardinal direction, the length of each segment was measured by GPS units. The UTM coordinates at the ends of each segment were recorded. The number of each species within the 50-m long segment was counted and recorded as "a" = only one present, "b" = 2 to 10 present, and "c" = more than ten present.

In conjunction with the roadside survey, the 30-m wide strip of UH-administered land between the west side of the Access Road and the Natural Area Preserve, and west of the road at Hale Pohaku, was surveyed in 50 m long roadside segments using the same data codes given above. (These 50 by 27-meter roadside segments were recorded as "WW" and called "West-side Transects.")

The data were analyzed by comparison of the frequency of occurrences (any value, a, b, or c) within the combined RE and RW roadside segments to the frequency within 100-m segments of the transect study within each community.

Since the sample units of the roadside survey and the transect survey are not identical in size and shape we use the frequencies as indexes of plant distributions rather than in a direct quantitative analysis. In comparing these non-identical sample units, we established an arbitrary threshold of difference termed, "markedly different." The magnitude of difference criteria for determining "marked difference" between two values is dependent upon the magnitude of the lower of the two values according to this scale:

Range of Lower Value	Threshold Difference
Lower value of zero	any non-zero value
Lower value $\leq$ 10.0	higher value must be 4 times greater
Lower value > 10.0 $\leq$ 50	higher value must be 2 time greater
Lower value > 50	higher value must be 0.5 times greater

Examples:

Lower Value	Higher Value	Determination
0	0.9	Yes
1.0	3.0	No
1.0	12	Yes
6.0	22	No
6.0	25	Yes
12	20	No
12	25	Yes
50	80	Yes

3.2.5.2 Introduced Species

We analyzed distributions of introduced plant species on the roadsides to detect species that have higher frequencies associated with the road. This information may be useful in managing invasive species. Species that have higher frequencies on the roadside may indicate that they are newly invading along the road and might be expected to spread into the neighboring habitat, or higher frequency on the roadside may indicate that these species can grow in the altered conditions of the roadside but have not successfully invaded the neighboring habitat.

Seven of the 27 introduced plant species found on the roadsides, for example *Rumex acetosella*, do not show a marked difference in frequency in our analysis (Table 12). These species are now widely established and any role that the road may have had in their invasion is no longer apparent.

Nineteen of the 27 introduced plant species found on the roadsides do have markedly higher frequencies by the road. Ten of these have higher frequencies only in the highest elevation community in which they are found. Mullein and *Nassella cernua* are good examples of these. One interpretation of this pattern is that these species are advancing along the road relatively slowly and as they move upward they are also spreading into the neighboring habitat in the lower communities. These species may have only recently reached their current highest communities and have not yet invaded the neighboring habitat. One of the most troublesome species, fireweed appears to have no distinct association with the roadside in the Subalpine or in the Alpine Shrubland communities where this species is widely well-established, but it does show a strong positive association with the roadside in the Alpine Stone Desert (Table 12).

Species that have higher frequencies on the roadsides in every community, such as *Epilobium billardierianum* and *Heterotheca grandiflora* appear to be species that become established more successfully in the roadside conditions and are less successful in the neighboring habitat.

3.2.5.3 Native Species

Analysis of the roadside data gives an indication of how the road has decreased or increased the establishment of native plants (Table 13). It might be expected that native trees or the larger shrubs, such as *māmane* or *pūkiawe*, would necessarily have been removed from the roadside by road construction or maintenance. It is possible that dust or other factors from the road may suppress establishment or growth of native plants.

Seven of the 24 native plant species present on the roadside exhibit markedly lower frequencies than in the neighboring habitat (Table 13). Surprisingly, these do not include the trees and shrubs (except *āweoweo* (C*henopodium oahuense*)) but some of the grasses and especially the small, native ferns that are near-ubiquitous within the UH-Management Area. The depression of the frequencies of these fern species, *Pellaea ternifolia*, *Asplenium trichomanes* and *A. adiantum-nigrum*, may possibly indicate the effects of dust settling on the plants.

Nine of the native plant species show a marked increase in frequency along the roadside in one or more community. These may represent species that can take advantage of the changed habitat conditions, such as water run-off, of the roadsides. Of particular note is the increased establishment of the *Deschampsia* along the roadside in the Alpine Shrubland, a community where this grass is otherwise very infrequent. The distribution of the now-rare native shrub, *Dubautia arborea*, hints at a positive association with the Access Road. Five individual shrubs of this species were recorded in the entire UH-Management Area. Two were found in neighboring transect segments in the Alpine Shrubland while three individuals occur on the roadside.

Table 12. A comparison of the frequencies of Introduced plant species found on roadside surveys of three communities with the frequencies of 100-m segments of the transect survey. Stone desert does not include Roadsides in Astronomy Precinct. Red shading indicates the species has markedly higher frequency than in the transect study within the same community. Note. The sample plots used to calculate the frequencies are not identical in size and shape and should be used as indexes of plant distributions rather than in a direct quantitative analysis.

Scientific Name	Subalpine		Alpine Communities			
	Woodland		Shrubland		Stone Desert	
	Road-side	Tran-sect	Road-side	Tran-sect	Road-side	Tran-sect
Anthoxanthum odoratum	2.8	9.6	1.3	2.3	3.0	0.7
Senecio madagascariensis	91.9	96.2	84.3	79.2	47.4	4.9
Hypochoeris radicata		4.3	10.7	18.0	38.6	15.1
Taraxacum officinale		0.5		3.7	6.8	0.8
Bromus catharticus	5.6	45.6	5.3	7.9	3.8	
Holcus lanatus		4.3		0.8	3.0	
Verbascum thapsus	71.8	85.6	52.0	36.0	3.0	0.7
Erodium cicutarium	47.9	57.7	13.3	16.3	0.8	
Poa pratensis	2.8	11.1			0.8	
Epilobium billardierianum	31.0	15.4	37.3	15.7	12.1	0.3
Nassella cernua	81.7	70.8	30.7	12.9		
Verbena litoralis			1.3			
Bromus diandrus	45.1	14.9	1.0			
Heterotheca grandiflora	53.5	8.8	4.0	2.3		
Verbascum virgatum	31.0	16.9	4.0	1.1		
Trifolium arvense	28.2	6.6				
Oenothera stricta	22.5	3.8				
Coreopsis basalis	2.8	0.3				
Pennisetum clandestinum	9.9	1.0				
Rytidiosperema semiannulare	69.4	68.8	44.1	54.5		
Senecio vulgaris		8.6	1.3	0.6		
Rumex acetosella	52.1	61.0	34.7	52.0		
Vulpia bromoides	15.5	13.1		2.3		
Lepidium sp.	9.9	5.3				
Achillea millefolium	5.6	4.3		1.7		
Tragopogon porrifolius	1.4	0.5				
Dactylis glomerata	5.6					

Table 13. A comparison of the frequencies of native plant species found on roadside surveys of three communities with the frequencies of the 100-m segments of the transect surveys. Red shading indicates the species has markedly lower frequency and green indicates markedly higher frequency than in the transect study within the same community. Note. The sample plots used to calculate the frequencies are not identical in size and shape and should be used as indexes of plant distributions rather than in a direct quantitative analysis.

Scientific Name	Subalpine		Alpine Communities			
	Woodland		Shrubland		Stone Desert	
	Road-side	Tran-sect	Road-side	Tran-sect	Road-side	Tran-sect
Dryopteris wallichiana			2.7		3.0	0.2
Dubautia ciliolata	15.5	6.3	14.7	9.0	0.8	
Tetramolopium humile	33.8	46.9	80.0	71.4	7.6	1.6
Pseudognaphalium sandwicensium	1.4	2.5	9.3	7.9	6.1	1.3
Dubautia arborea			2.7	0.6	0.8	
Agrostis sandwicensis	39.4	30.5	86.7	26.4	62.1	56.3
Deschampsia nubigena	15.5	14.4	16.0	0.6		
Chenopodium oahuense	9.9	24.4	1.3			
Sophora chrysophylla	53.5	74.6	2.7	0.6		
Agrostis avenacea	0	3.0	1.3	2.8		
Carex macloviana	0	4.8	1.3	5.1		
Asplenium trichomanes	1.4	24.2	12.0	33.2	7.6	9.6
Pellaea ternifolia	9.9	46.6	44.0	80.3	4.6	9.5
Rumex giganteus		0.8	1.3	5.3		
Coprosma ernodeoides	5.6	2.0	0.0	3.4		
Asplenium adiantum-nigrum	7.0	12.1	32.0	37.9	17.4	40.0
Trisetum glomeratum	47.9	51.6	98.7	75.0	78.8	66.7
Vaccinium reticulatum	22.5	26.2	57.3	60.7	0.8	1.8
Leptecophylla Tameiameiae	40.9	52.6	70.7	84.8		
Geranium cuneatum	35.2	37.0	34.7	46.1		
Silene struthioloides	14.1	5.5	14.7	9.0		
Carex wahuensis	1.4	1.0	1.3	2.3		
Stenogyne microphylla	4.2	14.9				
Osteomeles anthyllidifolia	1.4	0.5				

3.3 Substrate Associations

3.3.1 Substrate Data

We recorded a description of the substrate within the 6-m diameter plot at each sample point. We found that the substrate was heterogeneous on many scales. i.e. small patches of very different substrates often occur within a plot. Commonly, we saw distinctly different surface conditions within our 2-m and 6-m sample plots that would affect the establishment of plants. For example, a plot that is predominantly on a consolidated lava flow might have an overlay of tephra, glacial debris or alluvium that might inhibit plant establishment; conversely, a plot on a near-barren cinder surface might contain an aggregation of spatter that could support a grass or fern plant. Because of this heterogeneity, we were unable to satisfactorily categorize our substrate field descriptions for quantitative analysis of plant distribution. Instead, we categorizes the sample points by surface types assigned by the GIS data mapped by (Trusdell, Wolfe and Morris 2006) (Figure 4). We grouped together certain substrate types as indicated below (Table 14).

3.3.2. Analytical Methods

We examine the differences in plant distributions associated with substrate type within each community and then differences across the four communities. This analysis of geological substrates includes a different combination of substrates present and sampled in each community. The only two substrates sampled in the Alpine Stone Desert are Older Lava (l) and Older Cinder (lc). These two types are found in all four communities and serve as reference standards (Table 14).

The vegetation parameters that we analyzed are percent of 6-m plots ("Occupied 6") and of 100-m segments ("Occupied 100") with at least one recorded observation of a vascular plant species, the mean number ("Mean Num") of vascular plant species recorded in the 6-m plots, and the percent frequency of occurrence of a selected set of species.

The species selected for analysis are all of the species present in the Alpine Stone Desert (from Astronomy precinct) transects with frequency of occurrence in 100-m segments greater than 0.5% and the native and introduced species from the *Pūkiawe* Shrubland with frequencies in 100-m segments greater than 20% (Table 15).

The sample points are regularly spaced on pre-determined transects. They are not random. The sample sizes from the substrate types varies widely reflecting both the unequal distribution of substrates in nature, but importantly, our protocol of not sampling on the *pu'u* (cinder cones), thus deliberately excluding most of the cinder substrate. As stated above, the substrate classification is based on mapped values, not determined in the field at the time of sampling. Some points may be misclassified. Further, as stated above, the substrate is heterogeneous on many scales and a mapped substrate unit often includes anomalous features of micro-topography. A very low frequency value within a substrate unit may reflect presence of a species only at misclassified or anomalous points.

We found patterns of species richness (Table 16) related to the mapped geological substrates that are generally consistent in the two communities of the alpine ecosystem and similar, but less pronounced, in the *Māmane* Woodland of the subalpine ecosystem.

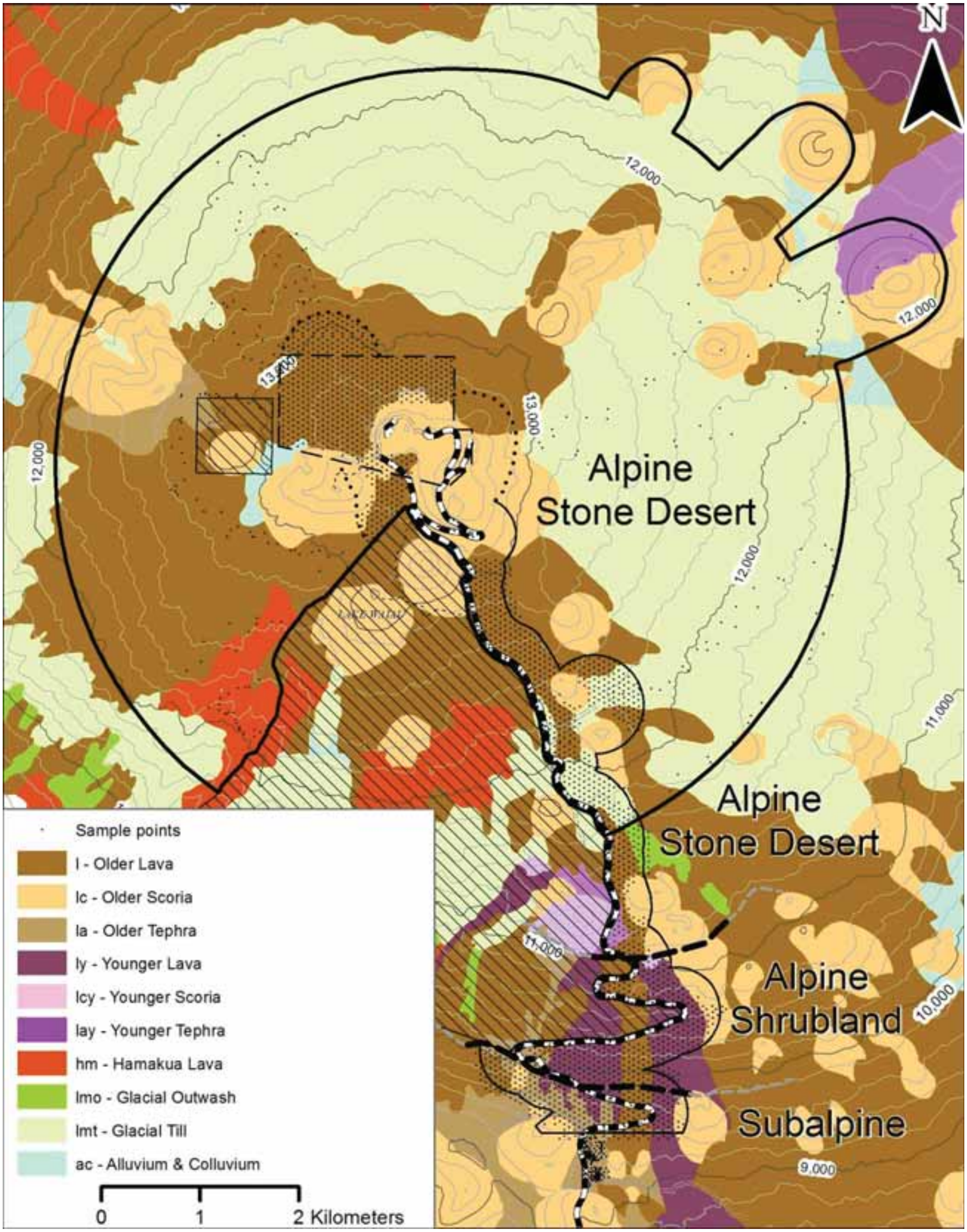


Figure 4. Surface geology of the UH-Management Area from Trusdell, Wolfe and Morris (2006).

Table 14. Substrate types used in analysis of geological relationships. "Map symbol" and "Map Unit Name" are from Trusdell, Wolfe and Morris (2006).

Community	Name Used in This Report	Our Sample Size (n)	Map Symbol	Map Unit Name
Stone Desert Astronomy Precinct	Older Lava	616	l	Older Lava
	Older Cinder	61	lc	Older Cinder
	Not Analyzed	5	ac	Alluvial
Stone Desert Access Road	Older Lava	253	l	Older Lava
	Older Cinder	14	lc	Older Cinder
	Glacial Deposits	10	lmo	Glacial Outwash
		167	lmt	Glacial Til
Pūkiawe Shrubland	Older Lava	141	l	Older Lava
	Older Cinder	8	la	Older Tephra
		40	lc	Older Cinder
	Younger Lava	249	ly	Younger Lava
	Younger Cinder	13	lay	Younger Tephra
		10	lcy	Younger Cinder
	Glacial Deposits	22	lmo	Glacial Outwash
Māmane Woodland	Older Lava	92	l	Older Lava
	Younger Lava	95	ly	Younger Lava
	Older Cinder	44	lc	Older Cinder
		172	la	Older Tephra

Table 15. Vascular plant species selected for substrate analysis, arranged in ecological groups. Acronyms are used in Figures 4 and 5.

Ubiquitous Natives		Native Shrubs	
Acronym	Botanical Name	Acronym	Botanical Name
TriGlo	*Trisetum glomeratum*	LepTam	*Leptecophylla tameiameiae*
AgrSan	*Agrostis sandwicensis*	GerCun	*Geranium cuneatum*
AspAdi	*Asplenium adiantum-nigrum*	VacRet	*Vaccinium reticulatum*
AspTri	*Asplenium trichomanes*	TetHum	*Tetramolopium humile*
PelTer	*Pellaea ternifolia*		
High Alpine Natives		**Introduced Plants**	
Acronym	Botanical Name	Acronym	Botanical Name
CysDou	*Cystopteris douglasii*	SenMad	*Senecio madagascariensis*
DryWal	*Dryopteris walliciana*	VerTha	*Verbascum thapsus*
		RytSem	*Rytidosperema semiannulare*

3.3.3 Substrate-Plant Patterns in the Astronomy Precinct/Alpine Stone Desert

Most of the 6-m plots within the Alpine Stone Desert are barren (not occupied) (Table 16), and we found that most of the occupied plots contain only one plant species (analysis not shown). The pattern of lava substrate having more occupied plots than the cinder and a higher mean number of species per plot is apparent here and continues throughout the alpine ecosystem. The profile of the selected species present is very similar on both substrate types (Figure 4), with the Older Cinder plots having frequencies one-half or less of the Older Lava plots. Most of the selected species present are members of the ubiquitous native group, the introduced herbs, especially fireweed, and the two high alpine ferns. All of these species have far higher frequencies on the older lava substrate than on the older cinder.

All of the sample plots on the Older Cinder substrate were at the margins of larger cinder areas. We found the frequency of occupied 100-m segments on the Older Cinder to be less than half of what it is on Older Lava (Table 16). Even the presence of these few species at very low frequencies might be attributable to boundary conditions, and do not accurately reflect the degree of barrenness of the Older Cinder substrate at this high elevation.

Table 16. Vegetation parameters analyzed by substrate type and community. "Occupied 6" and "Occupied 100" are percentages of sample plots with at least one vascular plant species recorded within 6-m circles and 100-m segments, respectively. "Mean Num" is the mean number of vascular plant species within 6-m circles. "NP" indicates that substrate type not found within community.

Com-munity	Parameter	Substrate Type				
		Older Lava	Younger Lava	Older Cinder	Younger Cinder	Glacial Deposits
Stone Desert-Astronomy Precinct	Occupied 6	27	NP	5	NP	NP
	Occupied 100	82	NP	36	NP	NP
	Mean Num	0.32	NP	0.25	NP	NP
Stone Desert-Access Road	Occupied 6	36	NP	0	NP	37
	Occupied 100	94	NP	21	NP	84
	Mean Num	0.44	NP	0	NP	0.5
Pukiawe Shrubland	Occupied 6	70	86	66	26	23
	Occupied 100	98	99	89	91	73
	Mean Num	2.25	2.87	1.24	0.39	0.23
Mamane Woodland	Occupied 6	98	99	93	NP	NP
	Occupied 100	100	100	100	NP	NP
	Mean Num	4.84	4.25	4.13	NP	NP

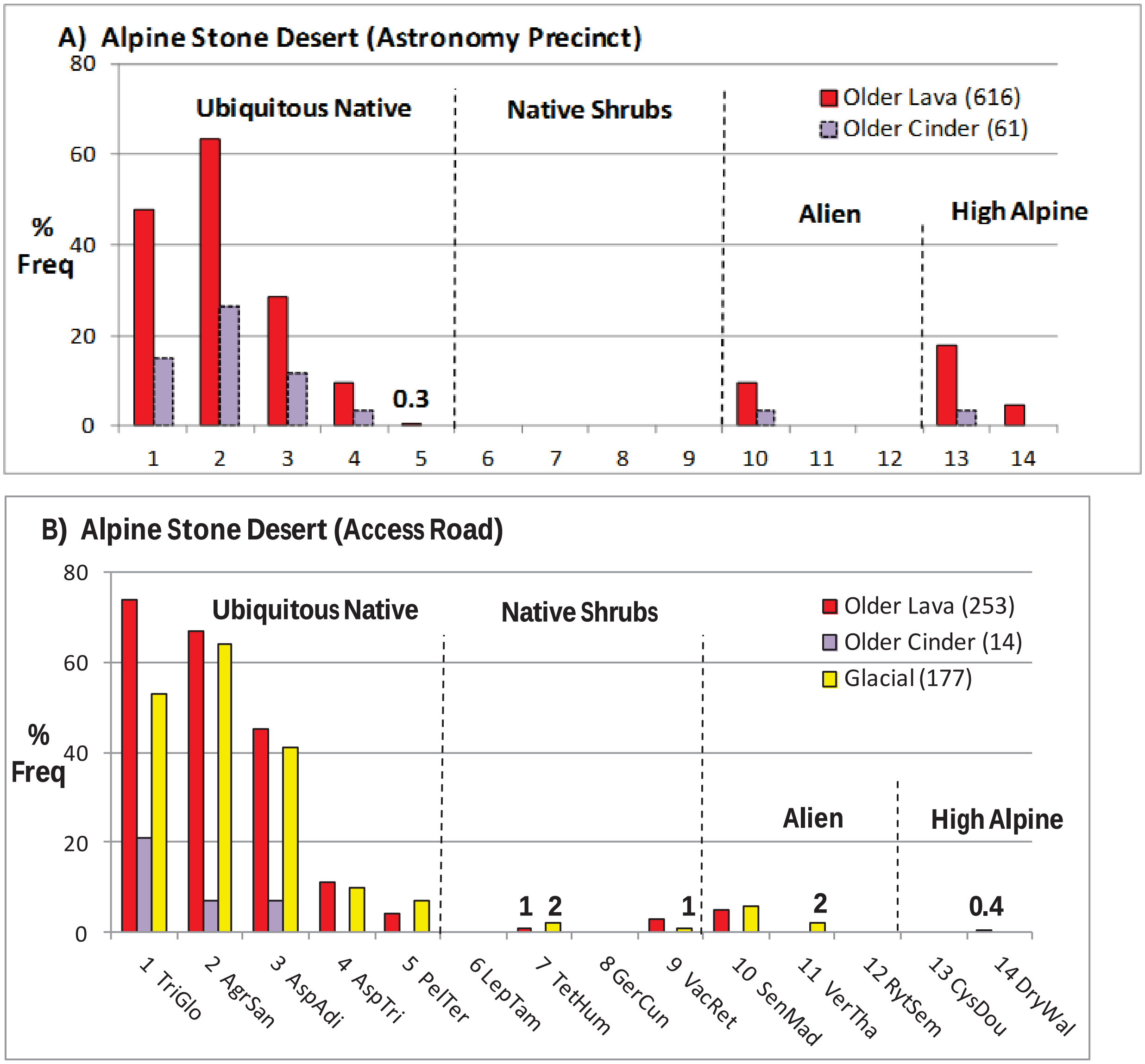


Figure 5. Frequency in 100-m segments of Selected Spp. in the Alpine Stone Desert within the Astronomy Precinct (A) and the Access Road Corridor (B) displayed by substrate types. Sample size in parentheses.

3.3.4 Substrate-Plant Patterns in the Access Road Corridor/Alpine Stone Desert

All of the plant-life parameters on the Older Lava are modestly higher here than in the Astronomy Precinct (Table 16). The extensive areas of Glacial Deposits in this community have parameters quite similar to the Older Lava. The species composition on these two substrates is primarily the ubiquitous native grasses and ferns with frequencies slightly higher than in the Astronomy Precinct, and a small representation of native shrubs and introduced herbs. The high elevation native ferns are almost absent (Figure 5).

The number of 6-m plots on Older Cinder is very small (n=14) and no plants at all were recorded at any of these points (Figure 5). Three of the ubiquitous native grasses and herbs are present in low frequencies within the 100-m transects.

3.3.5 Substrate-Plant Patterns in the *Pūkiawe* Shrubland

The substrate of this community is a complex of five different mapped types, including Younger Lava and Younger Cinder in addition to the three substrate types of the Alpine Stone Desert. This complex permits a comparison of plant life on Older and Younger Lava and on Older and Younger cinder, as well as on Glacial Deposits.

The diversity and density of plant-life is greater in the *Pūkiawe* Shrubland than in the Alpine Stone Desert. About 90%, or more, of the 100-m segments on lava and cinder substrates are occupied by vascular plants, far higher than the Alpine Stone Desert (Table 16). However, the Glacial Deposit substrates still exhibit a high frequency of unoccupied segments. The mean number of species per 6-m plots shows the highest values on the Younger and the Older Lava substrates (Table 16). A generalized statement of the decrease in frequency and density of vascular plants across the five substrates based on the vegetation parameters is

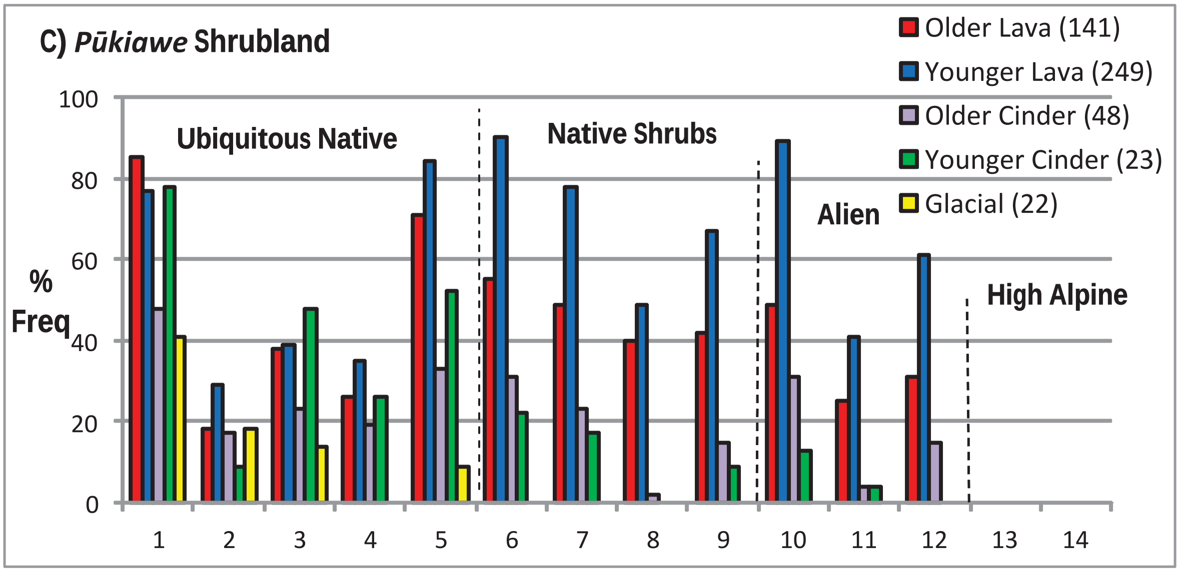
- Younger Lava > Older Lava>Older Cinder>Younger Cinder >Glacial Deposits.

Generally, all of the selected species, except the high alpine ferns, occur at relatively high frequencies on lava and cinder substrates of all ages (Figure 6.) The Glacial Deposits support fewer species and lower frequencies of those present. The high alpine ferns were not found at any of the sample points within the *Pūkiawe* Shrubland, although *Dryopteris wallichiana* does occur sparingly on the roadside of Access Road.

Each species of the ubiquitous native grasses and ferns group has similar frequencies on the Older and Younger Lava and the Younger Cinder, and lower frequencies on Older Cinder and the Glacial Deposits. In contrast, the native shrubs have strikingly higher frequencies on the younger lava than on the older lava, and then higher frequencies on older Cinder over Younger. These shrubs were not found at all on the Glacial Deposits in this community. The group of introduced grasses and herbs are distributed similarly to the native shrubs, favoring Younger Lava and Older Lava over the cinder substrates and Glacial Deposits. If the three unconsolidated substrate types are combined (older and younger cinder and glacial deposits) are taken together, they show a strong association of native shrubs and introduced species with the consolidated (lava) substrate.

3.3.6 Substrate-Plant Patterns in the *Māmane* Woodland

All, and almost all, of the 100-m segments and the 6-m plots, respectively, were occupied by vascular plants and the mean number of species per 6-m plot was much higher than in any of the Alpine Ecosystem (Table 16). Differences among the substrate types are small, but the lava substrates have slightly higher vegetation parameter values than the cinder. The small difference between the Older Cinder and lava substrates in this community, alone, may be an elevation and substrate interaction, or may be attributable to the large proportion of Older Tephra (map symbol "la") within the Older Cinder category (Table 14) and indicating that the tephra and cinder substrates have markedly different properties for supporting vegetation.



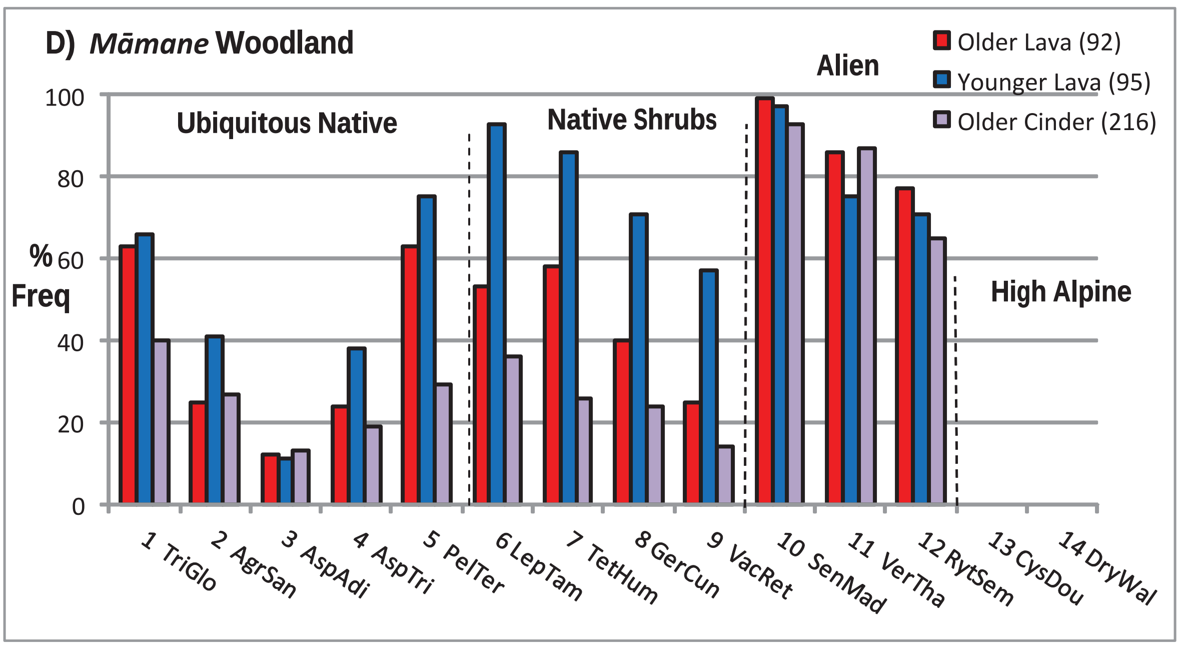


Figure 6. Frequency in 100-m segments of Selected Spp. in the *Pūkiawe* Shrubland (C) and the Subalpine *Māmane* Woodland (D) displayed by substrate types. Sample size in parentheses.

The profiles of the Ubiquitous Native and Native Shrubs in the *Māmane* Woodland do not appear markedly different from their profiles in the *Pūkiawe* Shrubland (Figure 6). However, these profiles of selected species do not include *māmane*, the dominant species in this community which is present in 75% of 100-m segments (Table R1) and in 30% of the 6-m plots (data not shown). I estimate that the *māmane* has biomass equal to all of the other species in the community combined. *Māmane* occurs in less than 1 % of 100-m segments and none of the 6-m plots in the *Pūkiawe* Shrubland.

Apart from the presence of *māmane,* a marked difference in the vegetation of the *Māmane Woodland* is the contrast in the response of native and introduced plants to the substrate differences. Nearly all the Ubiquitous Native and especially the Native Shrubs species have markedly higher frequencies on the lava substrates than on the cinder, but the introduced species have high, and nearly equal, frequencies on both. The lower preference of native species for cinder substrate is not shared by the introduced species (Figure 6).

The Native Shrub species, and to a lesser extent the Ubiquitous Natives consistently have higher frequencies on the Younger Lava than on the Older Lava substrate. This difference is negatively correlated with a strong difference in the frequency of *māmane* on two different age lava substrates. We found *māmane* in 79% of the 100-m segments on the Older Lava and in only 43% on the Younger Lava (data not shown). It is possible that the increased presence of *māmane* on the Older Lava inhibits the native shrubs and is responsible for the lower frequencies of shrubs on the older substate. Interestingly, *māmane* is most frequent (83%) on the Older Cinder.

3.3.7 Substrate-Elevation Interactions and Susceptibility to Invasive Plants

The rule first established in the Stone Desert that plants are more frequent and more species are present on lava than on cinder becomes weaker with decreasing elevation. We found that in the *Pūkiawe* Shrubland, the Ubiquitous Native species were as frequent on the Younger Cinder as on the lava substrates, but the Native Shrubs and Introduced species continued to show a preference for the lava. In this community, all species showed lower preference for both the Older Cinder and the Glacial Deposits.

It is in the *Māmane* Woodland that we see that some species of plants, including *māmane* itself and the selected Introduced weeds, no longer show a preference for lava substrates. In general, introduced plants in Hawaii show a preference for establishment on unconsolidated materials, such as natural cinder or disturbed roadsides (personal observation). This preference may be seen as the rule in the Subalpine Ecosystem and lower elevations, while the opposite appears to hold as a generalization in most of the Alpine Ecosystem.

3.4 Ungulate Dung

The history and adverse impacts of feral sheep (*Ovis aries*), mouflon sheep (*Ovis musimon*), and feral goats (*Capra hircus*) is reviewed in the Mauna Kea Natural Resources Management Plan (MKNRMP 2009). No specific information about the identity, current frequency of presence, or density of these ungulates is available.

We recorded the presence of ungulate dung (not differentiated by species) within our sample plots and segments (Table 17). Pellets (sheep or goat dung) of any age or state of deterioration were recorded. We could not determine the time since deposition of the pellets. It is reasonable to assume that at high elevation the pellets would break-down slowly due to low temperature and lack of precipitation. The pellets that we observed may have been deposited over a period greater than one year. We do not attempt to estimate ungulate density or frequency of presence from our data. Our data do provide positive evidence that feral sheep, mouflon, or feral goats were at times present in the UH-Management Area.

Table 17. Frequency of ungulate dung recorded at sample points in four communities.

	% Frequency of Dung		
	2-m Plot	6-m Plot	100-m Segment
Stone Desert- Astronomy Precinct	1.1	2.97	18.9
Stone Desert - Access Road	0.16	0.18	3.26
***Pūkiawe* Shrubland**	3.93	7.58	36.2
***Māmane* Woodland**	2.27	3.53	15.62

3.5 Lichen Study

3.5.1 Lichens of the Astronomy Precinct

Twenty-six species of lichens (Table 18) were recorded within the portion of the Astronomy Precinct surveyed by Smith and Berryman (2011; See Appendix D1). Two species, *Lecidea baileyi* and *L. maunakeansis*, are endemic to the Hawaiian Islands. The remaining species are indigenous to Hawaii.

Although lichens may be the most frequent life-form in the Astronomy Precinct, their cover is estimated to be much less than 1% (Berryman and Smith 2011). The most abundant species is the near-ubiquitous *Lecanora polytropa*, a small, light-colored, crustose lichen that can be found most places where the substrate is stable, as well as on rocks buried below the surface of course textured material. The bright yellow *Candelariella vitellina* and the relatively large, black, foliose lichen, *Umbilicaria decussata*, are the next most common and commonly seen species.

A distinct community or association of lichen species occurs on certain microsites. The most abundant species in this community is *Umbilicaria decussata*, a large species with substantial biomass within the very small confines of these micro-communities. These communities occur on near-vertical surfaces of large, dense lava blocks that are oriented away from solar exposure for most of the year, i.e. generally north or north-east facing. *Pseudophoebe minuscule*, *Rhizocarpon geographicum*, and *Lecidea baileyi* are the other members of this more-or-less predictable association (Berryman and Smith 2011).

Identification of many species is an on-going work. Assignment of specimen to the proper species, and sometimes the genus, is made difficult because the reproductive structures used for identification and classification may be poorly developed or entirely absent. It is thought that more of these species will be properly identified as studies of the lichen flora at lower elevation provide better specimen that can be related to the summit specimen (Berryman and Smith 2011).

Table 18. Lichen species of the Astronomy Precinct recorded by Smith & Berryman (2011) and by botanical baseline survey. Species names printed in bold face are endemic to the Hawaiian Islands; all others are indigenous.

Lichen Name	% Abundance[1]	% Freq (n=682)[2]	
	(n=29)	2-m Circle	6-m Circle
Acarospora cf. depressa[3]	28	*	*
Acarospora sp. #1[4]	72	*	*
Acarospora sp. #3	41	*	*
Buellia sp. #1	3	*	*
Buellia cf. fuscochracea	21	*	*
Buellia punctulata	rare	*	*
Buellia punctiformis	rare	*	*
Caloplaca lithophila	14	*	*
Candelariella vitellina	79	6.89	24.19
Carbonea vitellinaria	3	*	*
Lecanora polytropa	100	23.17	61.58
Lecanora cf. subaurea	66	*	*
Lecidea baileyi	86	2.93	5.57
Lecidea cf. maunakeanensis	3	*	*
Lepraria 'incana'[5]	10	1.76	7.48
Lepraria 'vouaxii'	21	*	*
Physcia dubia	10	0.59	2.05
Pseudephebe miniscula	48	0.88	2.35
Rhizocarpon geographicum	31	0.59	4.4
Umbilicaria decussata	45	3.37	17.45
Umbilicaria deusta	3	*	*
Umbilicaria hirsuta	3	0	1.17
Undetermined #1	3	*	*
Undetermined #2	3	*	*
Undetermined #3	38	*	*
Undetermined #4	3	*	*

Notes:
[1] "Abundance" is frequency of occurrence from Berryman and Smith (2011)
[2] "Freq" is from frequency of occurrence from botanical baseline survey. Field workers did not attempt to identify species marked with asterisk.
[3] "cf." (confer) indicates a tentative identification at the species level.
[4] Names enclosed in single quotes (') indicate a form that may not have taxonomic authority.
[5] Numbered species are assigned to genera but not yet identified to species.
[6] Undetermined have not yet been assigned to genera.

The four environmental factors that appear to determine the distribution of lichens are substrate type, moisture, temperature and exposure to the ultra-violet light (UV) component of solar radiation (Berryman and Smith 2011).

The substrate type with the greatest abundance of lichens is glaciated pahoehoe lava that is vesicular and usually shades of brown and red. The second substrate type is the dense (lacks vesicles), gray lava that fractures along sharp lines producing a jumble or relatively large blocks and slabs. This dense lava supports few lichens, with one very important exception, i.e. the *Umbillicaria decussata* community. The third substrate type is glacial rubble that usually does not support lichens at the surface. However, rocks buried as deep as ten centimeters beneath the surface may have lichens, especially *Lecanora polytropa*, *Lecanora* cf*. subaurea*, *Acarospora* sp. 3, and *Buellia* sp. 1. The fourth substrate type, cinder and ash, supports very few lichens. This type includes the *pu'u* and widely dispersed pockets of wind-blown fine ash (Berryman and Smith 2011).

The micro-site conditions of moisture, temperature and UV were not measured in this study, but their aggregate effects can be inferred from characteristics of the locations where lichens are most abundant. With the exception of *Lecanora polytropa*, lichens rarely are found on exposed horizontal surfaces of rocks or lava flows. Rather, they occur in micro-sites that afford protection from the elements, such as shallow caves, overhangs or beneath rocks and boulders; or, on vertical faces that are oriented generally northwards, away from most sun exposure. No environmental measurements are available to discern the relative effects of sun exposure, wind exposure and moisture availability, but observations support the conclusion that harsh environmental conditions restrict most lichen growth to the protected micro-sites. (Berryman and Smith 2011).

3.5.2 Lichens on Elevation Gradient from Hale Pohaku to Summit

Analysis and discussion of the findings of the lichen survey on the elevation gradient is included in an appended preliminary report by C. W. Smith (Unpublished, Appendix D-3). This report includes a discussion of the difficulty of identification of lichens in the Mauna Kea environment and a preliminary analysis of lichen community structure and the environmental factors that may shape the communities. These findings are briefly presented in this section.

The work of identifying the unidentified species is continuing. Identification is made difficult or impossible because many specimen lack reproductive structures and spores. It appears that the usually-dry environment of the alpine environment on Mauna Kea supports reproduction in many lichen species only during atypical periods of higher than normal moisture (Smith Unpublished). Furthermore, at the present time, the systematic and methods of identifying lichens are in revision as molecular techniques continue to be applied.

A total of 69 identified species or collections were recorded from seven different sites between Hale Pohaku and the summit (Table 19; full data table in Appendix D-4). Thirty of these have been assigned to a species or a tentative species. Eight numbered collections have been assigned to the genus, *Acarospora*, and eleven to the genus *Buellia,* with no species determination. Single species in four other genera have been assigned numbers in lieu of species determination. No determination to genus has been made for another thirteen collections.

Only a preliminary and tentative ecological analysis of these findings can be made for two reasons:

1) At this time it is not possible to know if each numbered collection represents a unique species or if some of the tentatively identified or undetermined species are duplicate records of the same species.

Table 19. A summary of lichen species within the UHH Management Lands sampled at seven sites along an elevation gradient.

Acarospora cf. depressa [1]	*Lecidea baileyi*
Acarospora spp. Numbered 1-8[2]	*Lecidia cf. maunakeae*
	Lecidia sp.#1
Aspicilia cf. desertorum	
	Lepraria 'incana'
Buellia cf. fuscochracea	*Lepraria ‘vouaxii’*
Buellia cf. maunakeansis	*Lepraria sp. #1*
Buellia cf. punctiformis	
Buellia cf. punctulata	*Pseudoparmelia caperata*
Buellia cf. subdisciformis	
Buellia spp. Numbered 1-11	*Parmotrema sp. #1*
Caloplaca lithophila	*Peltula euploca*
Candelarilella vitellina	*Physcia adscendens*
	Physcia dubia
Carbonea vitellinaria	
	Pseudophebe pubescens
Diploicia canescens	
	Rhizocarpon geographicum
Heterodermia 'albicans'[3]	
	Rinodina hawaiiensis
Immersaria sp. #1	*Rinodina sp. #1*
Lecanora muralis	*Umbilicaria decussata*
Lecanora polytropa	*Umbilicaria deusta*
Lecanora cf. subaurea	*Umbilicaria hirsuta*
	Umbilicaria hyperborea
	Undetermined Numbered 1-13

[1] “cf.” (confer) indicates a tentative identification at the species level.
[2] Numbered species are assigned to genera but not yet identified to species.
[3] Names enclosed in single quotes (‘) indicate a form that may not have taxonomic authority.
[4] Undetermined indicates collection have not yet been assigned to genera.

2) The study area is a narrow corridor along the Access Road and cannot be considered representative of Mauna Kea as a whole. Further, lichen presence is strongly correlated with substrate characteristics and the substrate types within the study area at each elevation sampled is very limited.

Substrate relationships noted in the Astronomy Precinct (Section 3.5.1) generally apply along the elevation gradient within the Alpine Ecosystem. While small crustose thalli (especially *Lecanora polytropa*) can be found on the underside of rocks in areas of unconsolidated material, such as scoria and glacial till, most lichens are found on rock outcrops and consolidated lava flows. Very specific substrate and aspect relationships have been described (Section 3.5.1) within the Astronomy Precinct

(Berrymann and Smith 2011), but these environmental correlations are not as well established along most of the elevation gradient.

The lichen species and collections recorded include seven ubiquitous species (Table 20). Five of these are distributed from the Subalpine ecosystem (2,800 m) at Hale Pohaku to the Summit region. Another two extend from tree-line (3,000 m) to the summit.

Of the 50 species that were found at only one site, a large group was found only at the summit and another only at the lowest sample site, in the Subalpine ecosystem. Smith (unpublished) notes an obvious change in the lichen flora that coincides with the treeline and the subalpine-alpine ecosystem boundary. Within the study area, nineteen of the recorded sixty-seven species were found only at the 2800 m site, in the Subalpine ecosystem. Many of these are corticolous (growing on trees or bark) species that grow on the trees on the Subalpine *Mamane* Woodland but do not occur on the shrubs of the Alpine *Pukiawe* Shrubland or elsewhere n the Alpine environment (Table 20).

Eleven of the sixty-seven species were recorded only at the summit. While some of these species may have their ecological optimum in the summit reason, it is probable that the high number of species found here is related to the sampling protocol and method of data presentation in Table 20. The “Summit” sample site includes much of the Astronomy Precinct, an area much larger than the other sample site and containing a higher proportion of consolidated rock substrate. Lichens favor these pahoehoe flows and rock outcrops over the loose material that is prevalent at many of the other sample sites (Berryman and Smith 2011).

Further preliminary analyses are included in Appendix D-3 (Smith unpublished).

Table 20. The distribution of lichen species and collections from Hale Pohaku to the Summit. Presence data for "Summit" includes observations at 4000 m along Access Road and all observations within the Astronomy Precinct (see Table 18.) Naming and numbering conventions as in Table 18.

Species or Collection Name	Elevation (m above sealevel)						Summit
	2,800	3,000	3,200	3,400	3,600	3,800	
Undetermined sp. #2							x
Undetermined sp. #5							x
Lecanora cf. subaurea							x
Acarospora cf. depressa							x
Acarospora sp. #4							x
Buellia sp. #4							x
Lepraria 'vouaxii'							x
Lepraria sp. #1							x
Undetermined sp. #3							x
Undetermined sp. #12							x
Undetermined sp. #11							x
Umbilicaria decussata					x	x	x
Lecanora polytropa				x	x	x	x
Lecidea baileyi		x	x	x	x	x	x
Umbilicaria hirsuta		x	x	x	x	x	x
Rhizocarpon geographicum	x	x	x	x	x	x	x
Candelarilella vitellina	x	x	x	x	x	x	x
Lepraria 'incana'	x	x	x	x		x	x
Lecidia cf. maunakeae	x			x		x	x
Carbonea vitellinaria			x		x		x
Umbilicaria hyperborea				x	x		x
Pseudophebe pubescens					x		x
Acarospora sp.#5					x		x
Acarospora sp. #1				x			x
Physcia dubia	x	x	x				x
Undetermined sp. #4						x	
Undetermined sp. #10						x	
Undetermined sp. #9					x		
Undetermined sp. #6					x		
Undetermined sp. #7					x		
Immersaria sp. #1					x		
Buellia cf. punctiformis					x		
Buellia sp. #6					x		
Umbilicaria deusta					x		

Table 20. (Continued) The distribution of lichen species and collections from Hale Pohaku to the Summit.

Species or Collection Name	Elevation (m above sealevel)						Summit
	2,800	3,000	3,200	3,400	3,600	3,800	
Diploicia canescens		x		x	x		
Buellia sp. #5				x			
Buellia sp. #9				x			
Buellia cf. maunakeansis		x		x			
Lecidia sp. #1			x				
Buellia sp. #7			x				
Buellia sp. #10			x				
Undetermined sp. #13			x				
Heterodermia 'albicans'	x	x	x				
Lecanora muralis	x	x	x				
Xanthoparmelia wyomingensis	x	x					
Buellia cf. punctulata		x					
Parmotrema sp. #1		x					
Peltula euploca		x					
Undetermined sp. # 1		x					
Undetermined sp. #8		x					
Buellia cf. subdisciformis	x						
Buellia sp. #1	x						
Buellia sp. #2	x						
Buellia sp. #3	x						
Buellia sp. #8	x						
Rinodina hawaiiensis	x						
Rinodina sp. #1	x						
Xanthomendoza fallax	x						
Physcia adscendens	x						
Acarospora sp. #2	x						
Acarospora sp. #3	x						
Acarospora sp. #6	x						
Acarospora sp. #1	x						
Acarosproa sp. #8	x						
Aspicilia cf. desertorum	x						
Buellia cf. fuscochracea	x						
Pseudoparmelia caperata	x						
Buellia sp. #11	x						
Caloplaca lithophila	x						

4 Discussion and Recommendations

4.1 Control Introduced Plants

4.1.1 Goals and Strategic Principles

Immediate Action Points

- Initiate a basic roadside and facility monitoring plan
- Train personnel in recognition and control of introduced plants
- Develop cooperative efforts with DLNR and other Mauna Kea land owners
- Initiate approval process for use of herbicides and other eradication methods

The reason to control introduced plants is to prevent them from further alterring the character of the vegetation, landscape, arthropod, and other ecosystem factors within the Uh Management Area.

The key principles to achieve this goals are similar to those used to control introduced plants in other habitats.

- Detect and prevent the establishment of new species
- Eradicate localized species before they become more abundant
- Prevent the spread of exisitng species into new areas by controlling them at the margins of their distributions, along corridors of movement (i.e. heavily used roads, trails, parking lots), and, when possible, push back their margins
- Allocate resources to achieve the above objectives before attempting to eradicate dense populations in the core of their distributions.
- Train personnel to recognize introduced plants, to be alert for new sightings and to report observations to the natural resources manager.

Certain characteristics of the University Lands suggest other principles. The geometry of the area presents certain opportunities and challenges. The Science Preserve, including the Astronomy Precinct is a compact shape with minimal edge ajoining lands managed by other entitities. On the other hand, the Access Road Management Corridor is little more than 400 m wide and shares boundaries with other publicly-owned lands under different management. Thus, the Astronomy Precinct and the entire summit area is within land under the control of OMKM and can be independently managed. The narrow Access Road Management Corridor and Hale Pohaku are vulnerable to plant invasion from neighboring Mauna Kea Forest Reserve and the Natural Area Reserve. Effective management of these units will require cooperative efforts.

Plant populations can be eradicated by various methods, including mechanical (pulling by hand), incineration with hand-held propane torch, and herbicides. Since all of the UH Management Area on Mauna Kea are both culturally and ecologically sensitive, care must be taken to select appropriate methodology. OMKM should begin the approval process for methods, such as herbicide use, that may be necessary to combat introduced plants.

Appropriate objectives and methods should be developed for each management unit and each ecological community. Recommendations for introduced plant control in each unit follows.

4.1.2 Recommendations for Introduced Plants in the Astronomy Precinct

Immediate Action Points

- Monitor
  - Train rangers to recognize new introduced plants
  - Implement a protocol for rapid response to all introduced plants
- Eradicate
  - Eradicate all introduced plants visible near observatories, roads or other facilities
  - Eradicate introduced plants in pavement cracks and retaining walls along Access Road

Introduced plants are not abundant in the summit area and it appears that they are relatively slow to spread. However, if permitted, populations of plants such as fireweed are likely to become more numerous and visible, thus altering the aesthetics of the natural environment. Initially, invasion by introduced plants depends on seeds arriving from elsewhere, but if these plants become established and produce seed, there will be many more seeds available at the summit. Over time, it is also possible that the populations at the summit will become better adapted to the harsh conditions there, and these plants will spread more rapidly. Thus, control efforts will be less costly now. Volunteers may be willing to do this work.

Undoubtedly, seeds will continue to blow or be carried into the summit area in the future. Monitoring and eradication efforts should also be continued.

4.1.2.1 Continuously Monitor all Sites Near Facilities for Introduced Species

The Natural Resources Management Plan (MKNRMP 2009) stipulates that a comprehensive monitoring plan should be developed and implemented. A monitoring program for introduced plants need not be complicated. No sample plots or statistical analyses are needed. Monitoring only requires vigilant observers who are familiar with the plant species in each area who understand the importance of reporting any new species or changes in the distribution of any species.

A key, and easy to implement, component of this plan will be constant observation along roads, parking areas and trails for the establishment of introduced plants. Since plants, native or introduced, are rare in the summit area, it may be a simple matter for all appropriate personnel to be trained and instructed to report plant sightings to the Natural Resources Manager who may initiate appropriate action.

4.1.2.2 Eradicate all accessible introduced plants

It is recommended that efforts be made to eradicate all introduced plants from the summit, especially fireweed. Only four species of introduced plants were found on our transects and four more on the very-easy-to-manage roadsides (Table 5).

Eradication efforts can begin near all summit facilities and, especially, along the Access Road switchbacks at the base of *Pu'u Wekiu*. Very few plants were found near the facilities during this survey. The greatest concentrations of introduced plants are along the *Pu'u Wekiu* switchbacks, in the crack between the roadway and the paved shoulder and in the drain pipes embedded in the retaining walls above the switchbacks. These microsites harbor three species of introduced grasses, *Bromus catharticus*, *Holcus lanatus*, and *Poa pratensis*, that have the potential to become more widely established at high elevations. These grasses were found nowhere else near the summit at this time. Native grasses and ferns also grow in these microsites. However, these man-made features are not part of the natural habitat for these native species. In my opinion, injury to these native plants during eradication does not represent damage to the native ecosystem and is an acceptable cost of introduced species control.

Transect data from the present study will help locate some of the plants farther from the roads and trails. Although the summit is rugged and the climate is harsh, the entire Astronomy Precinct is accessible to determined workers. The Astronomy Precinct consists of 525 acres/212 ha area, or 900 acres/364 ha with the added 500-m buffer zone that we surveyed. Approximately 40% is cinder substrate that is very resistant to plant establishment and would require little monitoring or maintenance. The baseline botanical survey spent 50 person days covering slightly more than 200 ha on lava substrate with transects spaced 30 m/100 ft. apart. This provides an estimate of the amount of effort that might be required to have teams periodically scour the Astronomy Precinct for introduced plants.

4.1.3 Recommendations for Introduced Plants in the Access Road Management Corridor

Management of introduced plants along the Access Road has the advantage of easy access for both monitoring and eradication. Plant density is very low within the Alpine Stone Desert (above 11,150 ft./3,400 m) but becomes much greater in the Alpine *Pūkiawe* Shrubland and the Subalpine *Māmane* Woodland, requiring different strategies in these ecological communities.

4.1.3.1 Access Road within the Alpine Stone Desert

<u>Immediate Action Points</u>

- Monitor
    - Train rangers to recognize new introduced plants above 11,000 ft. elevation
    - Implement a protocol for rapid response to all introduced plants
- Eradicate
    - Eradicate all introduced plants visible along the road or near parking areas above 11,000 ft. elevation
    - Eradicate introduced plants in pavement cracks along Access Road

Similar to the Astronomy Precinct, plant density is very low within the Alpine Stone Desert, and the Access Road provides easy access to the Management Corridor.

Table 12. (Roadside Plants) shows ten introduced species found along the roadside (within 3-m strip) compared to 6 species found on the transects of the 400-m wide corridor. Six of these occur at markedly higher frequencies on the roadside than in the transects. The other four were not found on the transects. This suggests that the road does encourage the establishment of introduced plants in this environment. The most frequent of these, fireweed, *Hypochoeris radicata*, and *Epilobium billardieranum*, have frequencies above ten per cent along the roadsides, the other seven are lower. Eradicating these populations along the road will reduce the source of seeds for further invasion.

Eradication of all introduced plants within several meters of the roadway will provide the highest benefit for the resources expended in this unit. Later, resources may be used to control (eradicate) all introduced plants in the Stone Desert within the Access Road Management Corridor.

4.1.3.2 Access Road within the Alpine *Pūkiawe* Shrubland and Subalpine *Māmane* Woodland

<u>Immediate Action Points</u>

- Eradicate needlegrass along the roadside above 10,000 feet elevation
- Eradicate kikuyugrass and fluffy thistle along the roadside everywhere

Introduced plants have much higher densities both along the roadside and across the Management Corridor in the *Pūkiawe* Shrubland and the *Māmane* Woodland (Table 11). Eradication of these introduced plants would take much more effort than in the two higher-elevation communities. Eradication within a narrow strip along the roadside might have a positive effect on the roadside aesthetics, but would probably have little influence on the distribution and further spread of introduced plants, with the three following exceptions:

1) Needlegrass (*Nassella cernua*) is a dominant ground-cover species in the *Māmane* Woodland but, in the *Pūkiawe* Shrubland, it is denser along the road than farther away. Control along the road might slow its establishment here.

2) Kikuyugrass (*Pennisetum clandestinum*) is more abundant along the roadside in the *Māmane* Woodland and could possibly be eliminated from the University Lands. This grass species has aggressively invaded native habitat in other places and is an invasive threat. It might be prudent to attempt its removal.

3) Fluffy thistle (*Tragopogon porrifolius*) is sparingly established within the Management Corridor. This large herb forms relatively dense stands in some nearby lands and its windblown seeds are easily dispersed. In my opinion, this species has the potential to become much more widespread and could be controlled now, while it is infrequent.

4.1.4 Recommendations for Introduced Plants at Hale Pohaku

<u>Immediate Action Points</u>

- Monitor
  - Monitor the roadside for any new species invading the University Lands
  - Notify pesonnel specifically to look for and report fountaingrass along the roadside
- Eradicate
  - Eradicate small populations of potentially invasive plants, especially broom, kikuyugrass, fluffy thistle and common yarrow
  - Eradicate small populations of several species that were once intentionally planted at Hale Pohaku, including California poppy, eucalyptus and apple

The fundamentals of monitorring for new invasions and eliminating species with small populations should be applied to all of Hale Pohaku. The shrub, broom (*Cytisus palmensis*), is one of the several potentially disruptive species. Broom is found at a couple of locations in and near Hale Pohaku and could easily be controlled. Fluffy thistle, previously discussed, can probably be eliminated. Kikuyugrass and common yarrow are somewhat more frequent, but may be controllable.

One clump of fountaingrass (*Pennisetum setaceum*) was found along Access Road in Hale Pohaku during the botanical survey and was uprooted. At this time, fountaingrass does not appear to be common at high elevations, but it is well-known as a disruptive, fire-adaptive grass in much of west Hawaii. This species should be aggressively controlled on UH Management Area and on nearby lands in cooperation with the appropriate agencies.

Attempts have been made to eradicate the once-intentionally planted eucalyptus and California poppies (*Eschscholzia californica*) from Hale Pohaku. Both of these species persist. Additionally, a number of saplings of what appears to be domestic apple (*Malus domestica*) are scatterred about Hale Pohaku. These three species should be eradicated.

A specific vegetation management plan should be devised for Hale Pohaku. Although the native *māmane* forms a relatively healthy tree cover within much of Hale Pohaku, the ground cover is dominated by introduced grasses and herbs to the extent that the plant community is not really native or in a “natural” state. In addition to the fireweed and two species of mullein, six species of introduced grasses are ubiquitous at Hale Pohaku. Furthermore, this site has been used by people for many decades and shows scars of heavy use, including considerable construction activity.

Hale Pohaku is 20 acres in size and viewed by the many visitors who come to see Mauna Kea. The site might be small enough to permit comprehensive control of introduced species and some restoration of the native plant community. A proposal for ecological restoration is given below, in section 4.2.

4.2 Native Plant Restoration at Hale Pohaku

Anyone with an understanding of Hawaiian ecology sees that the vegetation at Hale Pohaku is severely degraded. Despite the considerable cover of *māmane*, much of the site is infested with fireweed and mullein and dense stands of needlegrass, rescuegrass (*Bromus catharticus*), ripgut (*Bromus diandra*) and wallaby grass (*Rytidosperema semiannulare*), and a host of other introduced weeds. The areas dominated by native shrubs like *pūkiawe* and *nohoanu* (*Geranium cuneatum*) and native grasses such as *Agrostis spp.*, *Trisetum glomeratum*, and *Deschampsia nubigena*, are much less extensive.

Restoration of the native vegetation of at least parts of Hale Pohaku could be considered. The primary purpose would be to educate the public and visitors about the natural conditions of this ecosystem and the changes that humans and their introduced species have brought to Mauna Kea, while limiting habitat opportunities for deliterious invasive arthropods. Ecosystem restoration is challenging and requires a long-term commitment. It is recommended that restoration activity begin on a small scale, perhaps within a small area immediately surrounding the visitor center.

While it may be reasonably easy to establish more *māmane* trees at Hale Pohaku, restoration of the natural ecosystem cannot proceed without significant control of the introduced herbs and grasses named above. These plants can be pulled by hand within small areas; larger areas will require a large amount of man-power or the use of other methods, such as plant-killing herbicides and pre-emergent herbicides. Following approval of herbicide use, it will be necessary to determine methods that can safely be used without harming the existing native plants. Fortunately, many of the weed-infested areas do not support many native plants.

If the introduced grasses and herbs can be removed, it will be desirable to establish native grasses and shrubs in the cleared areas. Research should begin on methods to establish grasses such as as *Agrostis sandwicensis*, *Trisetum glomeratum*, and *Deschampsia nubigena* and the native shrubs that occur on the site. The large shrub, ‘*āweoweo* (*Chenopodium oahuense*) is common a Hale Pohaku. Although a native plant, this species is somewhat “weedy,” meaning it increases following disturbance of the site. *‘Āweoweo* may be used in restoration, but it should be seen as a transitional species. The more permanent shrub component would include *pūkiawe*, *Tetramolopium*, *ohelo*, and *nohoanu*. Restoration efforts might include propagation and outplanting of the rare Mauna Kea dubautia (*Dubautia arborea*).

The diversity of the tree layer, now consisting only of *māmane*, could be increased using mountain *pilo* (*Coprosma montana*) and *a’ali’i* (*Dodonaea viscosa*).

4.3 Evaluation of Human and Feral Herbivore Impacts

The extent and the nature of human impacts on the plant-life of the University lands varies among the different units and ecological communities.

The extensively degraded nature of the vegetation at Hale Pohaku is discussed above in Section 4.2, and will not be covered here. This discussion will focus largely on the high elevation communities—the Alpine Stone Desert within the Astronomy Precinct and along Mauna Kea Access Road. I briefly summarize our observations of the association of introduced plants with human activities (Sections 4.31 and 4.32) and then explore other possible human influences on the native plants and natural vegetation (Section 4.33).

4.3.1 Introduced Plants Are Not Associated with Facilities in Astronomy Precinct

We did not detect a spatial association of introduced plants with human activity in the Astronomy Precinct, except at specific microsites described in Section 3.2.1.2. (i.e. pavement cracks and retaining walls). The special survey around the observatories found no plants at their foundations or near any other structures, with the exception of exactly one *Hypochoeris radicata* plant found growing behind a concrete retaining wall (Section 3.2.1.3). The substrate adjacent to the observatories and other structures appears similar to the barren undisturbed cinder that surrounds the areas where the observatories were built.

Transect segments crossing the 4-wheel drive roads in the Astronomy Precinct and the moderately well-travelled pathways of the Submillimeter Array did not have a higher frequency of introduced plants than other segments.

In many, if not most, Hawaiian ecosystems there is a conspicuous association of introduced plants with certain human activities. Two major reasons for this is that humans, their livestock and their vehicles and machines carry seeds with them; and, activities such as road building or agriculture, break-up lava substrates into finer particles improving growing conditions for many weedy plants. Although we found no plants at these disturbed sites, human activities, especially road-building and construction, have broken-up the lava substrate in parts of the study area and it is reasonable to assume that human activities, as well as the wind, have carried seed to these sites. Thus, our observations stand in contrast with the positive association of introduced plants with human activity seen in many other Hawaiian Ecosystems.

The findings of the current study support the conclusion that construction activities do not pose a significant threat of invasion by introduced plants if the following prudent precautions are taken:

1) Procedures to minimize the introduction of plant seeds should be implemented. These would include prohibition of transporting soil, fill, or similar materials to Mauna Kea and careful cleaning of all construction equipment before it is deployed to Mauna Kea.

2) Constant monitoring of all construction areas, as well as all areas where people are active, should be implemented as a formal procedure. Any new plant growth should be reported immediately to the Natural Resources Manager and an appropriate management action taken. Man-made microsites that aid plant establishment, such as described in Section 3.1.2, should be identified and appropriate actions taken to eliminate the risk that they may favor the establishment of introduced species.

These recommendations are designed to minimize the risk that at some time in the future an introduced species that is well-adapted to the environmental conditions might be transported to and become established at the summit. Such an invasion could be similar to the arrival and establishment of fountaingrass (*Pennisetum setaceum*) in the formerly barren lava fields of South Kohala and North Kona that profoundly altered that ecosystem.

4.3.2 Some Association of Introduced Plants with Access Road in the Alpine Stone Desert

We found that nine of the ten introduced species that we recorded in the Stone Desert were markedly more frequent within 3 meters of the road than on the transects of the Management Corridor (Table 12). Another four introduced species were found only on the roadsides and not in the transects of the Management Corridor. Some of these introduced species, most noticeably rescue grass (*Bromus catharticus*) was found growing only in the crack between the roadway and the paved shoulder. It is my opinion that the other introduced grasses are more frequent along the roadside because traffic on the road transported seeds, rather than because of physical, environmental impact to the roadside.

Section 4.1.3.1 recommends that all introduced plants along the roadside within the Stone Desert be eradicated.

4.3.3 Importance of Understanding Factors Affecting Vegetation of Mauna Kea

The very low cover of plants and their strong preference for protected microsites implies that some strong factor or factors restrict plant establishment. Although this botanical study did not include investigations to determine which factors are most important in controlling the presence and abundance of plants within the study area, it does provide some data relevant to this question. A list of possible controlling factors would include 1) harsh environmental conditions; 2) relatively young geological age and short time elapsed since last glacial period; 3) the effects of human activities.

Protection or conservation of the botanical resources of the summit requires knowing if the current state is "natural" or if it has been substantially alterred by human activities of the past or present. There have been no previous scientific studies of the plant life of the entire summit and upper slopes. The most significant study (Smith, Hoe and Connor 1982) covered only specific astronomy-related sites within the Astronomy Precinct. The findings of that study, in terms of the species present and the very low cover of all plant species, are similar to those of the current study, but that study may not have been sufficiently early to document natural conditions. Historic accounts from the 19th and early 20th century are too general and do not accurately identify the elevation and locale of observations to provide a reliable comparison.

Understanding the natural conditions are necessary to 1) set management goals for conservation for native plant species, possibly including restoration (such as outplanting), and 2) as a baseline for scientific studies, including possible studies of global climate change. The goals of conservation management and ecosystem restoration are, respectively, the maintenance or the re-creation of the "historic, indigenous community" of the site (Primack 2006). In this context, "historic" means a specific plant community that actually existed at a time in the past, and "indigenous" means made up of species not introduced by man. Managers of Mauna Kea may want to define their conservation goal as maintaining or restoring the ecosystem that existed before western contact, accepting any influence of the indigenous people as a "natural" part of this ecosystem. This is the standard used to manage biological resources at the Hawaii Volcanoes National Park.

Modern conservation management does not have the goal of static preservation of a rigidly defined community or ecosystem (Primack 2006). Ecologists recognize that ecosystems are dynamically changing rather than at static equilibrium. The conservation goal is to see that the changes are driven by natural factors rather than predominantly human interventions. Achieving this goal may require actively subtracting human influence from the system.

4.3.3.1 Climate and Site Factors

Harsh conditions at the summit include aridity (dryness) from very low precipitation in combination with excessively well-drained volcanic substrate. Average annual rainfall is less than ten inches (Giambelluca et al. 2011); the amount of snowfall is not documented. No soil has developed on the cinder and lava substrate. Air temperature often drops below the freezing point at night even in the summer months while summer average maximum temperatures are below 50^{o} F (10^{o} C). Snow may be on the ground at any time of the year, although more common in winter months, and may hamper establishment and survival of poorly adapted plants. Wind of moderate or greater strength is common and may hamper plants in a number of ways. Wind desiccates plants and substrates and through wind-chill enhances the impact of cold. While wind may disperse seeds to suitable sites for germination, constant wind also moves and disturbs seeds, possibly preventing rooting. Wind may carry particles of cinder or ash that abrade plants or seedlings. Finally, ultraviolet radiation as a part of sunlight, is strong at high elevation and is damaging to unprotected living tissue, such as germinating seedlings.

4.3.3.2 Age of Site and Primary Succession

The lava and cinder substrates of the summit appear to be between 14,000 and 65,000 years old (Wolfe and Morris 1996) and the summit was beneath glacial ice as recently as 13,000 years ago. These data coupled with our observation that the substrate of the study area appears un-weathered and no soil has developed indicate that the site is an early stage of primary succession. Weathering, soil formation and plant establishment are all hampered by aridity.

4.3.3.3 Biogeography and Evolution in the Hawaiian Alpine Ecosystem

The "youth" of the summit environment explains, at least partly, why Mauna Kea does not have a flora of endemic species adapted to alpine conditions: not enough time has elapsed since the summit has been free of ice or new lava flows (about 13,000 years) to permit alpine species to evolve from the non-alpine species more typical of the Hawaiian Islands. Perhaps of equal importance, is the very small area of alpine habitat to support evolution of a flora. Within the Hawaiian Islands, only the very young and volcanically active Mauna Loa reaches into the alpine zone (9,500 ft.), along with a very small area at the summit of Haleakala. The nearest alpine habitats beyond the Hawaiian Islands are in North and South America and the islands of Indonesia and New Guinea. Throughout the geological history of the Hawaiian Islands, alpine habitat would have been limited in spatial extent and temporal stability. The great distance to seed sources of potential immigrants of alpine species and the very small, temporally changing, alpine habitat available to either colonization by, or the evolution of, alpine species may explain the lack of well-adapted plant species that could vegetate the alpine ecosystem.

4.3.3.4 Possible Influence of Humans and Feral Herbivores

Given the geological and biogeographical considerations just discussed, harsh environmental conditions may be a sufficient explanation of the extremely sparse plant cover at high elevations that we documented. Environment is a more obvious explanation than human activity for the following reasons:

1) The young substrate, lacking any developed soil, and the cold, dry, windy climate present a very formidable challenge to plant growth; and,

2) Adverse influence of the human activities associated with astronomy is not apparent. This assertion rests largely on a) the finding that construction and related activities have not fostered the establishment of introduced plants in the study area and, more importantly, b) our finding that the frequency of native plants near the road, observatories and other constructed facilities is about the

same as at more distant locations within and outside the Astronomy Precinct when comparing similar substrates.

However, the importance of adverse human influences cannot be dismissed without considering the impact of non-native herbivores that were brought to Mauna Kea by humans. The adverse impacts of introduced ungulates on the vegetation at lower elevations on Mauna Kea are well-known, even legendary! The long history of grazing and habitat degradation by introduced cattle, goats, domestic sheep and mouflon sheep is reviewed in the Natural Resources Management Plant (MKNRMP 2009) citing the detailed studies of Scowcroft and Conrad (1992) and Giffin (1982), as well as many others.

We found fecal pellets of sheep, mouflon or goats (not differentiated) throughout the study area, with high frequency in some places, sparingly in others (Section 3.4, Table 17). Although we have no estimate of the population density of ungulates in the study area, their pattern of activity, or their impact on the plants, we do know that they are often present. We also know nothing about the response of plants to any grazing in this environment. It is reasonable to hypothesize that plant re-growth would be slow due to harsh environmental conditions. It is possible that the current state of the plant community reflects grazing activity initiated nearly two hundred years and especially in the early 20th century when the sheep population density was estimated to be one for every 5 acres (Bryan 1937, cited in MKNRMP 2009).

4.3.4 Recommendations Regarding Introduced Herbivores

4.3.4.1 Remove Introduced Herbivores

Effective action should be taken to remove any non-native mammal detected within the study area, especially the ungulate herbivores. Sheep, mouflon or goats currently live in or visit all parts of the UH-Management Area. These introduced animals are not native to the Hawaiian Islands or Mauna Kea. It is reasonable to assume that, when present, they graze upon the sparse plants in the ecosystem and that the native plants will recover from grazing very slowly, if at all.

4.3.4.2 Field Study of Ungulate Herbivores and Their Effects on Native Plants

The current study determined that ungulates are within the study area, at least at times, and may damage native plants. Protection of the native plant ecosystem requires a better understanding of these herbivores.

4.4 Other Information Needs

Management of the botanical resources includes conservation of individual plant species, as well as entire ecosystems of the UH-Management Area. Three of the species that we found are rare. These are ‘*āhinahina*, or Mauna Kea sliversword (*Argyroxiphium sandwicense*), *Dubautia arborea* (Mauna Kea dubautia) and *Cystopteris douglasi* (Douglas bladderfern). These three species and their distributions are briefly described in Section 3.1.

Āhinahina is listed as an endangered species by both the U.S. Fish and Wildlife Service and the State of Hawaii. As the land manager, OMKM may have responsibilities regarding this plant under the two endangered species laws. Further studies of this species, or cooperation with other organizations that conserve this species, are recommended.

Dubautia arborea is a shrub that occurs only on Mauna Kea and has been reduced in number by feral herbivores in recent decades. We found only five individuals within the UH-Management Area. This species would be very appropriate for propagation and re-establishment at Hale Pohaku. Further study of the ecology of this species is warranted.

Cystopteris douglasii is an endemic Hawaiian fern that appears to be restricted to high elevation sites on the islands of Maui and Hawaii (Palmer 2003). This species is not well studied and Palmer (2003) suggests that the ferns on Mauna Kea may represent one or more undescribed species of *Cystopteris*. Taxonomic and ecological study of this fern would be helpful for its conservation.

All three of these species could be studied by graduate students of the University of Hawaii or other institutions.

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Appendix A. Plant Species List

Scientific Name / Common Name(s)	Family	Type	Origin
Achillea millefolium L. common yarrow, milfoil	Asteraceae	Herb	X[1]
Agrostis avenacea J. G. Gmel. *he'upueo*, Pacific bentgrass	Poaceae	Grass	I[2]
Agrostis sandwicensis Hillebr. Hawaii bentgrass	Poaceae	Grass	E[3]
Anthoxanthum odoratum L. sweet vernalgrass	Poaceae	Grass	X
Argemone glauca (Nutt. Ex Prain) Pope var. *decipiens* Ownbey *pua kala*	Papaveraceae	Herb	E
Argyroxiphium sandwicense DC. ssp. *sandwicense* *'āhinahina*, Mauna Kea silversword	Asteraceae	Shrub	E
Asplenium adiantum-nigrum L. *'iwa 'iwa*, Bird's nest fern	Aspleniaceae	Fern	I
Asplenium trichomanes L. subsp. *densum* (Brack.) W. H. Wagner *'olali'i, 'owali'i*	Aspleniaceae	Fern	I
Bromus catharticus Vahl rescue grass	Poaceae	Grass	X
Bromus diandrus Roth ripgut grass	Poaceae	Grass	X
Carex macloviana d`Urv. subsp. *subfuscu* (Boott) T. Koyama St. Malo's sedge	Cyperaceae	Sedge	I
Carex wahuensis C.A. Mey. Oahu sedge	Cyperaceae	Sedge	E
Chenopodium oahuense (Meyen) Aellen *āheahea, 'āweoweo,*	Chenopodiaceae	Shrub/ Tree	E
Coprosma ernodeoides A. Gray *'aiakanēnē, kūkaenēnē*	Rubiaceae	Shrub	E

[1]X = Introduced [2]I = Indigenous to the Hawaiian Islands [3]E = Endemic to the Hawaiian Islands

Scientific Name Common Name(s)	Family	Type	Origin
Coprosma montana Hillebr. alpine mirror plant	Rubiaceae	Shrub/ Tree	E
Coreopsis lanceolata L. *ko'oko'olau haole*	Asteraceae	Herb	x
Cystopteris douglasii Hook. Douglas' bladderfern	Athyriaceae	Fern	E
Cytisus palmensis (Christ) Hutch. broom, tagasate	Fabaceae	Tree/shrub	x
Dactylis glomerata L. cocksfoot, orchardgrass	Poaceae	Grass	X
Deschampsia nubigena Hillebr. alpine hairgrass	Poaceae	Grass	E
Dodonaea viscosa Jacq. *'a'ali'i*	Sapindaceae	Shrub/ Tree	I
Dryopteris wallichiana (Spreng.) Hyl. alpine woodfern	Dryopteridaceae	Fern	I
Dubautia arborea (A. Gray) D.D. Keck Mauna Kea dubautia, *na'ena'e*	Asteraceae	Shrub/ Tree	E
Dubautia ciliolata (DC) Keck subsp glutinosa G.D. Carr lava dubautia, *na'ena'e*	Asteraceae	Shrub	E
Ehrharta calycinum Sm. perennial veldtgrass	Poaceae	Grass	X
Epilobium billardierianum Ser. subsp. *cinereum* (A. Rich.) P. H. Raven & Engelhorn willow herb	Onagraceae	Herb	X
Erodium cicutarium (L.) L'Hér. alfilaria, pin clover	Geraniaceae	Herb	X
Eschscholzia californica Cham. california poppy	Papaveraceae	Herb	X
Eucalyptus sp. eucalyptus	Myrtaceae	Tree	x

Scientific Name Common Name(s)	Family	Type	Origin
Geranium cuneatum Hook. subsp. *hololeucum* (A. Gray) Carlquist & Bissing *hinahina, nohoanu*	Geraniaceae	Shrub	E
Geranium homeanum Turcz cranesbill	Geraniaceae	Herb	X
Heterotheca grandiflora Nutt. telegraph plant	Asteraceae	Herb	X
Holcus lanatus L. velvet grass	Poaceae	Grass	X
Hypochoeris radicata L. hairy cat's ear, gosmore	Asteraceae	Herb	X
Lepidium sp. peppergrass	Brassicaceae	Herb	X
Leptechophylla tameiameiae (Chaam. & Schlechtend.) F. v. Muell. *pūkiawe*	Epacridaceae	Shrub	I
Lolium sp. rye grass	Poaceae	Herb	X
Luzula hawaiiensis Buchenau var. *hawaiiensis* Hawai'i wood rush	Juncaceae	Rush	E
Malus domestica apple	Rosaceae	Tree	x
Marrubium vulgare L. horehound	Lamiaceae	Herb/Shrub	X
Melilotus indica (L.) All. sweet clover	Fabaceae	Herb	X
Mollugo cerviana (L.) Ser. carpetweed, threadstem carpetweed	Molluginacea	Herb	X
Nassella cernua (Stebbins & Á. Löve) Barkworth needlegrass	Poaceae	Grass	X
Oenothera stricta Ledeb. ex Link subsp. *stricta* Chilean evening primrose	Onagraceae	Herb	X

Scientific Name Common Name(s)	Family	Type	Origin
Osteomeles anthyllidifolia (Sm.) Lindl. *'ūlei*	Rosaceae	Shrub	I
Oxalis corniculata L. yellow wood sorell, *'ihi 'ai*	Oxalidaceae	Herb	I
Pellaea ternifolia (Cav.) Link *kalamoho, lau-kahi*	Pteridaceae	Fern	I
Pennisetum clandestinum Hochst. ex Chiov. kikuyu grass	Poaceae	Grass	X
Pennisetum setaceum (Forssk.) Chiov fountain grass	Poaceae	Grass	X
Poa annua L. annual bluegrass	Poaceae	Grass	X
Poa pratensis L. Kentucky bluegrass	Poaceae	Grass	X
Pseudognaphalium sandwicensium (Gaud.) A. Anderb. *'ena 'ena*	Asteraceae	Herb	E
Pteridium aquilinum (L.) Kuhn var. *decompositum* (Gaudich.) R. M. Tryon bracken	Dennstaedtiaceae	Fern	E
Rumex acetosella L. sheep sorrel	Polygonaceae	Herb	X
Rumex giganteus W. T. Aiton *pāwale*	Polygonaceae	Shrub/ Liana	E
Rytidosperma semiannulare wallaby grass	Poaceae	Grass	X
Senecio madagascariensis Poir. fireweed	Asteraceae	Herb	X
Senecio sylvaticus L. woodland ragwort, woodland groundsel	Asteraceae	Herb	X
Senecio vulgaris L. common groundsel	Asteraceae	Herb	X

Scientific Name Common Name(s)	Family	Type	Origin
Silene struthioloides A. Gray alpine catchfly	Caryophyllaceae	Shrub	E
Sophora chrysophylla (Salisb.) Seem. *māmane*	Fabaceae	Tree	E
Stenogyne microphylla Benth. littleleaf stenogyne	Lamiaceae	Vine	E
Stenogyne rugosa Benth. *mā'ohi'ohi*	Lamiaceae	Vine	E
Taraxacum officinale W. W. Weber ex F. H. Wigg common dandelion	Asteraceae	Herb	X
Tetramolopium humile (A. Gray) Hillebr. subsp. *humile* alpine tetramolopium	Asteraceae	Shrub	E
Tragopogon porrifolius L. salsify, oyster plant	Asteraceae	Herb	X
Trifolium arvense L. var. *arvense* lance clover	Fabaceae	Herb	X
Trisetum glomeratum (Kunth) Trin. *pili uka, he'upueo*, mountain *pili*	Poaceae	Grass	E
Vaccinium reticulatum Sm. *ohelo*	Ericaceae	Shrub	E
Verbascum thapsus L. common mullein, woolly mullein,	Scrophulariaceae	Herb	X
Verbascum virgatum Stokes virgate mullein, wand mullein	Scrophulariaceae	Herb	X
Verbena litoralis Kunth. *ōwī*, vervain	Verbenaceae	Herb	X
Vulpia bromoides (L.) S. f. Gray brome fescue	Poaceae	Grass	X

Appendix B. Data Description

Mauna Kea Botanical Baseline Survey
Data Description

Prepared by Grant Gerrish
April 27, 2013

This text file accompanies and documents the data file for the Survey. The data file is, "GerrishG_ MaunaKeaBotanicalSurvey_data.xlsx." This text file also references the report "Botanical Baseline Survey (2011) of the University of Hawaii's Managed Lands On Mauna Kea," by Grant Gerrish.

The column labels in the header row of the data file are explained below and the possible values of each cell in the columns are defined.

Column A "SubProject"

This column contains a label designating a subproject (Section 2.20) for each sample point and lists the Section of The Mauna Kea Botanical Baseline Survey Report (MKBBS) describing each subproject. Subprojects 7, 8 and 9 have no data in the data file, MK Bot Baseline Data.xlsx. The sub-projects of the Mauna Kea Baseline Botanical Survey are:

Label	MKBBS Section	Sub-Project Number and Description
AP Trans	Sec. 2.211	1. Transect survey of the Astronomy Precinct and Buffer Zone
ARC Trans	Sec 2.212	2. Transect survey of the Access Road Corridor
HP Trans	Sec. 2.213	3. Transect Survey of Hale Pohaku
HP Random	Sec. 2.214	4. Hale Pohaku Random Point Survey
ARC Roadside	Sec. 2.215	5. Roadside Survey of the Access Road Corridor
AP Roadside	Sec. 2.216	6. Roadside Survey of the Astronomy Precinct and Buffer Zone
(None)	Sec. 2.217	7. Astronomy Precinct Facilities Perimeter Survey No Data in File
(None)	Sec. 2.218	8. Astronomy Precinct *Pu'u* Survey No Data in File
(None)	Sec. 2.219	9. Hale Pohaku Facilities Perimeter Survey No Data in File
N/CP Excur.	Sec. 2.2110	10. Natural/Cultural Preserve Area Excursions

Column B "Date_Time"

This is the date and time that the data for the sample point were first entered into an Excel spreadsheet. This was usually, but not always, done on the same day the data were collected from the field.

Column C “Sample_Point”

These are the unique labels used to identify each sample point. The labeling system varies between the subprojects. A detailed description, titled “Sample Point Designation,” of these sample point labels is at the end of this document.

The sampling designs and field methods, including parameters recorded, for the Sample Points are described in Section 2.21 for all subprojects. Specific subsections of “Methods” are identified, above, for each subproject.

Column D “Technician”

These are the initials of the field technician that recorded the data for the sample point.

Labels are

BY	Brian Yannutz	CW	Caree Weisz	NA	Data Not Available
DD	Dan Datlof	EH	Eric Hansen		
GG	Grant Gerrish	MB	Matt Belt		

Column E “Geology”

These are the labels for the surface geology at each sample point based on a digital database (Trusdell, Wolfe and Morris 2005) derived from the map of Wolfe and Morris (1996). These labels were assigned to the sample points by the OMKM GIS (ARC 10) and are the same codes used in the database and map cited above. (See Sections MKBBS 2.11, 2.22, 3.3 and Table 14).

Label	Substrate Type
l	Older Lava
lc	Older Cinder
lmo	Glacial Outwash
lmt	Glacial Til
la	Older Tephra
ly	Younger Lava
lcy	Younger Cinder
lay	Younger Tephra
ac	Alluvial

Column F “Eco_Zone”

These are designations of ecological zonation based on the findings of this study integrated with earlier treatments describing ecosystems and biological communities on Mauna Kea. (Sections 2.1.2.2 and 3.0, Figures 1 and 3)

Label	Name and Elevation Extent
Subalpine	*Māmane (Sophora)* Woodland 9,100 ft. /2775 m to 9,800-10,100 ft./3,000-3080 m (variable)
Alpine Shrubland	*Pūkiawe* (*Leptechophylla*) Shrubland 9,800-10,100 ft./3,000/3080 m (variable) to 11,150 ft./3,400m
Alpine Stone Desert	Alpine Stone Desert w/widely scattered grasses and ferns 11,150 ft./3,400 m to 13,796 ft./4,206m

Column G “Elevation”

Elevation, in feet, was assigned to each sample point by the OMKM GIS based on the State of Hawaii Digital Elevation Model (DEM). (MKBBS Section 2.22)

Column H “UTM_East”

This is a coordinate of the sample point recorded as the UTM Easting by the GPS unit of the field technician at the time the data were recorded. Datum used is WGS84. (Section 2.211)

Column I “UTM_North”

This is a coordinate of the sample point recorded as the UTM Northing by the GPS unit of the field technician at the time the data were recorded. Datum used is WGS84. (Section 2.211)

Column J “True_UTM_East”

This is the east coordinate that the systematic layout of sample points indicated for this sample point. The “UTM_East” is the GPS record of the approximation of this point by the field technician. Datum used is WGS84.

Column K "True_UTM_North"

This is the north coordinate that the systematic layout of sample points indicated for this sample point. The "UTM_North" is the record of the approximation of this point by the field technician. Datum used is WGS84.

Column L to CQ Species' Acronyms and Presence Codes

These are six-letter acronyms (the column headers) used for the plant and lichen species recorded at each sample point and the Presence Codes (the values in the cells) recorded for each species). The acronyms are derived from the first three letters of the genus name plus the first three letters of the specific epithet.

The acronyms for vascular plants are given on the following page. "Dung" refers to ungulate dung.

Two systems of Presence Codes are used in the data file:

Presence Codes: Sub-projects 1 to 4

The Astronomy Precinct and Access Road Corridor Transect Surveys use a standard methodology of a 2-m diameter and a 6-m diameter, concentric circular plots that are within a 100-m by 30-m belt transect segments. (Sections 2.211 and 2.212, Figure 2). The Hale Pohaku Transect Survey is the same except that the belt transect segments are 50-m long by 30-m wide. Presence in 2-m circular plot also indicates presence in 6-m plot and belt transect segment; presence in 6-m plot indicates presence in belt transect segment. The Hale Pohaku Random Point Survey uses the 2-m and 6-m diameter, concentric sample plots, but no belt transect segments.

Value	Meaning
2	Present in 2-m diameter circular plot
6	Present in 6-m diameter circular plot
100	Present in belt transect segment (not used in Hale Pohaku Random Point Survey)

Presence Codes: Sub-projects 5 and 6

These sub-projects estimated the range of abundance of each species within a belt transect segment or within a specified area.

Value	Meaning
a	species observed only once in transect segment
b	observed ≥2 and < 10 times in transect segment
c	observed ≥ 10 times in transect segment

Sub-projects 7, 8 and 9 do not have data in the data file.

Presence Codes: Sub-project 10

These sub-projects estimated the range of abundance of each species at a subjectively chosen observation point without reference to a specific area.

For Vascular Plants (Columns L to CG)

Value	Meaning
a	species observed only once in transect segment
b	observed ≥2 and < 10 times in transect segment
c	observed ≥ 10 times in transect segment

For Lichens (Column CH to CQ)

Value	Meaning
y	species present at observation point

Acronyms used for vascular plant and lichen species in Excel data file: MK Bot Baseline Data.Xlsx. Lichen acronyms preceded by letter "z."

Acronym	Species	Acronym	Species
AchMil	*Achillea millefolium*	MolCer	*Mollugo cerviana*
AgrAve	*Agrostis avenacea*	NasCer	*Nassella cernua*
AgrSan	*Agrostis sandwicensis*	OenStr	*Oenothera stricta*
AntOdo	*Anthoxanthum odoratum*	OstAnt	*Osteomeles anthyllidifolia*
ArgGla	*Argemone glauca*	OxaCor	*Oxalis corniculata*
ArgSan	*Argyroxiphium sandwicense*	PelTer	*Pellaea ternifolia*
AspAdi	*Asplenium adiantum-nigrum*	PenCla	*Pennisetum clandestinum*
AspTri	*Asplenium trichomanes*	PenSet	*Pennisetum setaceum*
BroCat	*Bromus catharticus*	PoaAnn	*Poa annua*
BroDia	*Bromus diandrus*	PoaPra	*Poa pratensis*
CarMac	*Carex macloviana*	Pse San	*Pseudognaphalium sandwicensium*
CarWah	*Carex wahuensis*	PteAqu	*Pteridium aquilinum*
CheOah	*Chenopodium oahuense*	RumAce	*Rumex acetosella*
CopErn	*Coprosma ernodeoides*	RumGig	*Rumex giganteus*
CopMon	*Coprosma montana*	RytSem	*Rytidosperma semiannulare*
CorLan	*Coreopsis lanceolata*	SenMad	*Senecio madagascariensis*
CysDou	*Cystopteris douglasii*	SenSyl	*Senecio sylvaticus*
CytPal	*Cytisus palmensis*	SenVul	*Senecio vulgaris*
DacGlo	*Dactylis glomerata .*	SilStr	*Silene struthioloides*
DesNub	*Deschampsia nubigena .*	SopChr	*Sophora chrysophylla .*
DodVis	*Dodonaea viscosa*	SteMic	*Stenogyne microphylla*
DryWal	*Dryopteris wallichiana*	SteRug	*Stenogyne rugosa*
DubArb	*Dubautia arborea*	TarOff	*Taraxacum officinale*
DubCil	*Dubautia ciliolata*	TetHum	*Tetramolopium humile*
Dung	*Ungulate Dung*	TraPor	*Tragopogon porrifolius*
EhrCal	*Ehrharta calycinum*	TriArv	*Trifolium arvense*
EpiBil	*Epilobium billardierianum*	TriGlo	*Trisetum glomeratum*
EroCid	*Erodium cicutarium*	VacRet	*Vaccinium reticulatum*
EscCal	*Eschscholzia californica*	VerTha	*Verbascum thapsus*
Euclyp	*Eucalyptus* sp.	VerVir	*Verbascum virgatum*
GerCun	*Geranium cuneatum*	VerLit	*Verbena litoralis*
GerHom	*Geranium homeanum*	VulBro	*Vulpia bromoides*
HetGra	*Heterotheca grandiflora*	zCanVit	*Candelariella vitellina*
HolLan	*Holcus lanatus*	zLecBai	*Lecidea baileyi*
HypRad	*Hypochoeris radicata*	zLecPol	*Lecanora polytropa*
Lepidi	*Lepidium* sp.	zLepInc	*Lepraria incana*
LepTam	*Leptechophylla tameiameiae*	zPhyDub	*Physcia dubia*
Lolium	*Lolium* sp.	zPseMin	*Pseudephebe miniscula*
LuzHaw	*Luzula hawaiiensis*	zRhiGeo	*Rhizocarpon geographicum*
MalDom	*Malus domestica*	zUmbDec	*Umbilicaria decussata*
MarVul	*Marrubium vulgare*	zUmbhir	*Umbilicaria hirsuta*
MelInd	*Melilotus indica .*	zUmbSp	*Umbilicaria sp.*

Sample Point Designation

1. Transect survey of the Astronomy Precinct and Buffer Zone

Label of the sample points is in the form: S-*ddddd-nn*

S	Summit
ddddd	The last five digits of the UTM Northing Coordinate of the transect (Full UTM coordinate begins with the digits “21” for all transects in all subprojects)
nn	Sequential numbers of the sample points on the transect, beginning with 01 at the western boundary of the Astronomy Precinct and Buffer Zone

2. Transect survey of the Access Road Corridor

Label of the sample points is in the form: *A-ddddd-nn*

A	E: Access Road Corridor on the east side of Access Road W: Access Road Corridor on the west side of Access Road
ddddd	The last five digits of the UTM Northing Coordinate of the transect (Full UTM coordinate begins with the digits “21” for all transects in all subprojects)
nn	Sequential numbers of the sample points on the transect, beginning with 01 at the Access Road. East transects and sample points run east away from Access Road; west transects and sample points run west away from Access Road.

3. Transect Survey of Hale Pohaku

Label of the sample points is in the form: HP-*ddddd-nn*

HP	Hale Pohaku
ddddd	The last five digits of the UTM Northing Coordinate of the transect (Full UTM coordinate begins with the digits “21” for all transects in all subprojects)
nn	Sequential numbers of the sample points on the transect, beginning with 00 at the Access Road. Transects and sample points are numbered from west to east, starting at Access Road.

4. Hale Pohaku Random Point Survey

Label of the sample points is in the form: HPR-*Addd*

HPR	Hale Pohaku randomized sample points consisting of a 2-m diameter and a 6-m diameter, concentric circular plot centered on the sample point.
A	N: Points in northern intensive sample area S: Points in southern intensive sample area
ddd	three-digit sequential identifier of randomized sample points

5. Roadside Survey of the Access Road Corridor

Label of the sample points is in the form: RS-*AA*-*ddd*

RS	Roadside Survey
AA	RE: 3-m wide belt transects adjoining east side of Access Road RW: 3-m-wide belt transects adjoining west side of Access Road WW: 27-m wide belt transect adjoining the west side of the RW transect
ddd	Assigned, sequential three-digit number of belt transect segments, beginning at upper elevation limit and extending to lower elevation.

6. Roadside Survey of the Astronomy Precinct and Buffer Zone

Label of the sample points is in the form: APRS-*X*-*Y*-*dd*

APRS	Astronomy Precinct Roadside Survey
XY	X: Designation of the three switchbacks with retaining walls (A, B and C) on *Pu'u Wekiu*. See Figure on Following page. Y: Designation of above (A) or below (B) the retaining-wall on upper side of switchback.
dd	Assigned sequential two-digit number of sample point, beginning at upper elevation and proceeding down-hill..

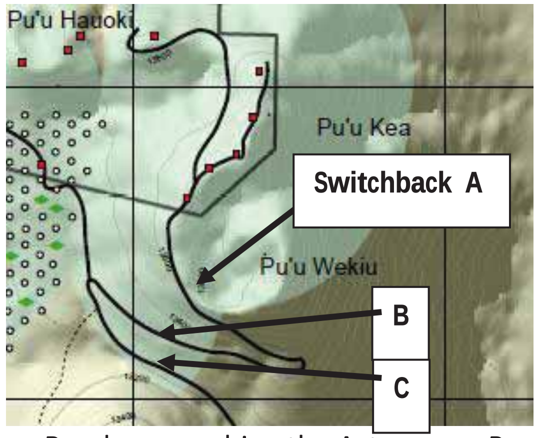


Figure APP-B1. Map of Access Road approaching the Astronomy Precinct and labeling scheme for the three switchbacks, A, B and C, that have concrete retaining walls.

7. Astronomy Precinct Facilities Perimeter Survey

No data in data file. Findings of this sub-project described in Section 3.2.1.3 of "Botanical Baseline Survey (2011) of the University of Hawaii's Managed Lands On Mauna Kea."

8. Astronomy Precinct *Pu'u* Survey

No data in data file. Findings of this sub-project described in Section 3.2.1.4 of "Botanical Baseline Survey (2011) of the University of Hawaii's Managed Lands On Mauna Kea."

9. Hale Pohaku Facilities Perimeter Survey

No data in data file. Survey described in Section 3.2.4.3 of "Botanical Baseline Survey (2011) of the University of Hawaii's Managed Lands On Mauna Kea."

10. Natural/Cultural Preserve Area Excursions

Label of the sample points is in the form: EX-*nn*-*dd*

EX	Excursion
nn	A two digit sequential number assigned to each excursion in the chronological order they were conducted.
dd	A two digit sequential number assigned to each sample point of the excursion.

The routes of the excursions are illustrated on the following map. A minimum of two technicians conducted each excursion. The map shows the tracks followed by each technician and the sample points where species data were recorded.

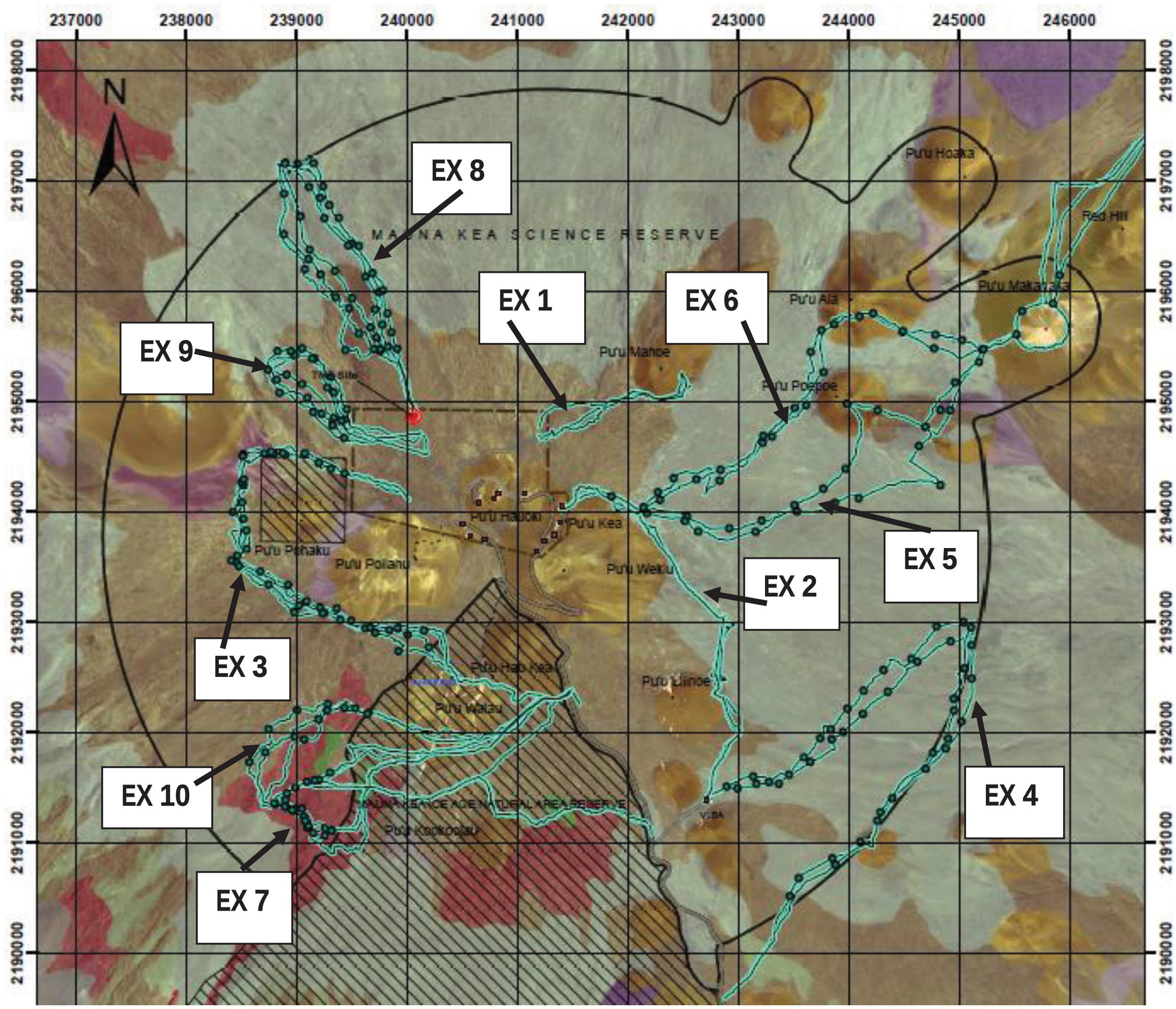


Figure APP-B2. GPS tracks and sample points (waypoints) of technicians conducting excursions numbered 1 through 10. No formal data was recorded on excursions 1 or 2.

Appendix C. Distribution Maps for Vascular Plants

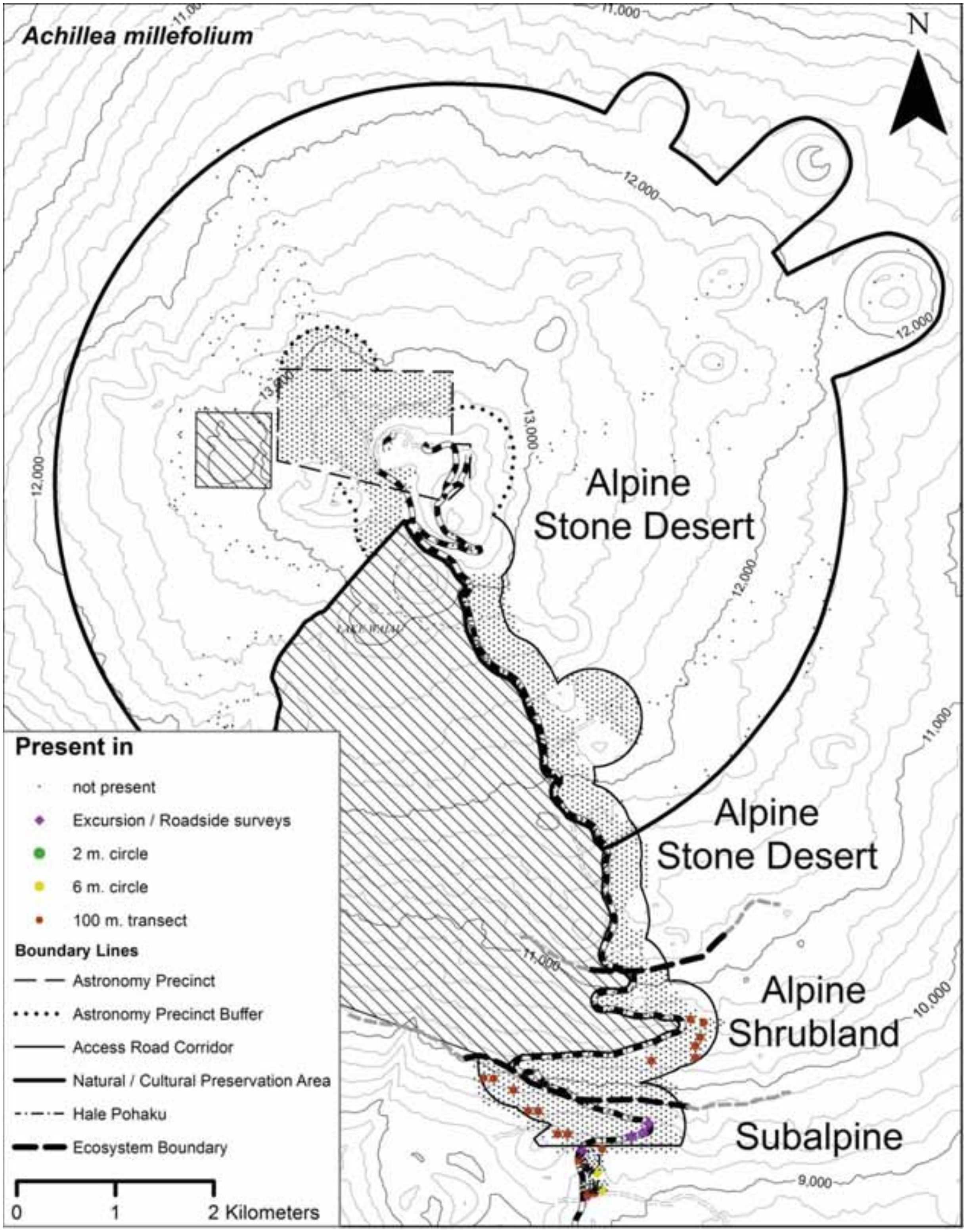


Figure APP-C1. *Achillea millefolium* or common yarrow (Asteraceae).

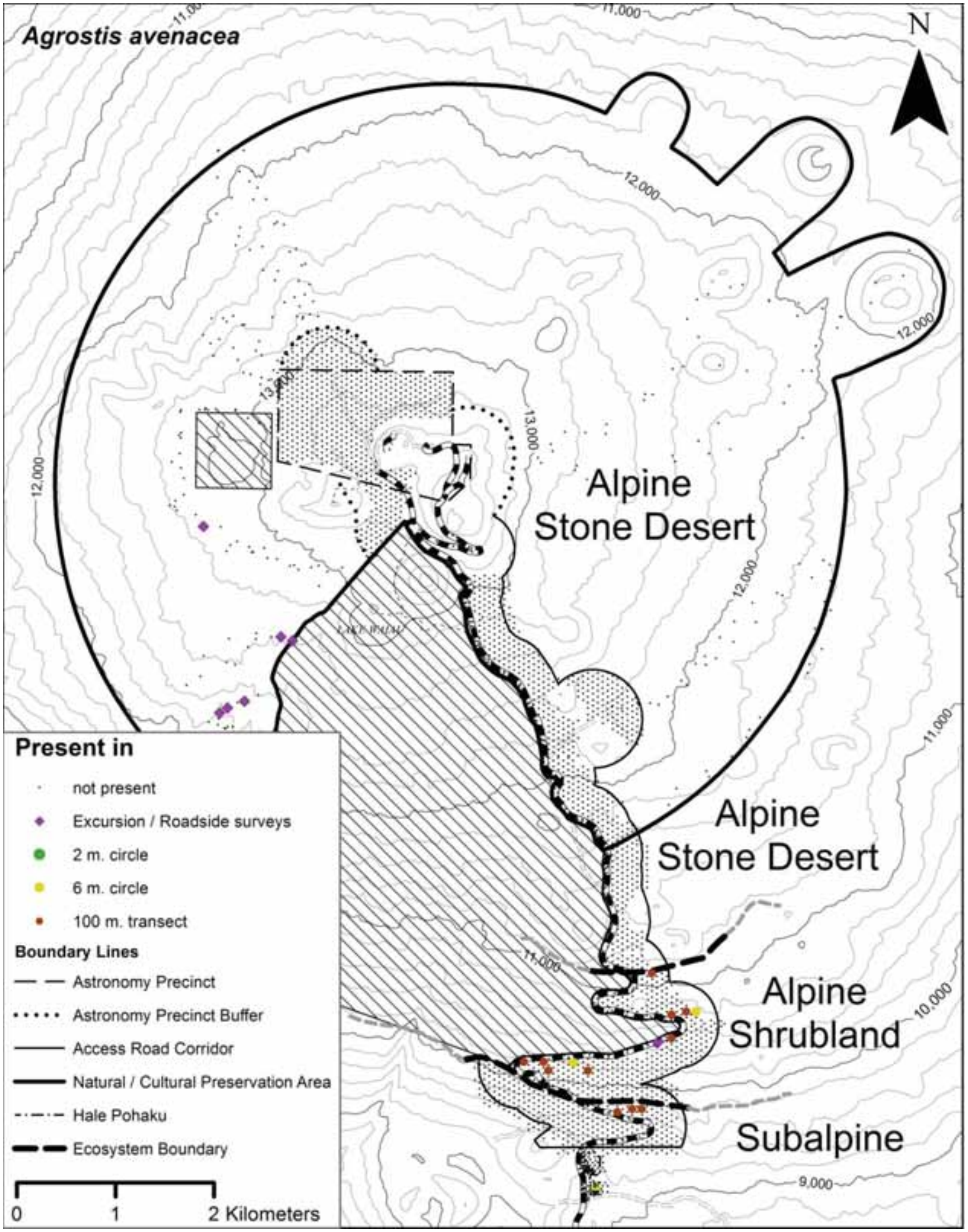


Figure APP-C2. *Agrostis avenacea* or *he'upueo* (Poaceae).

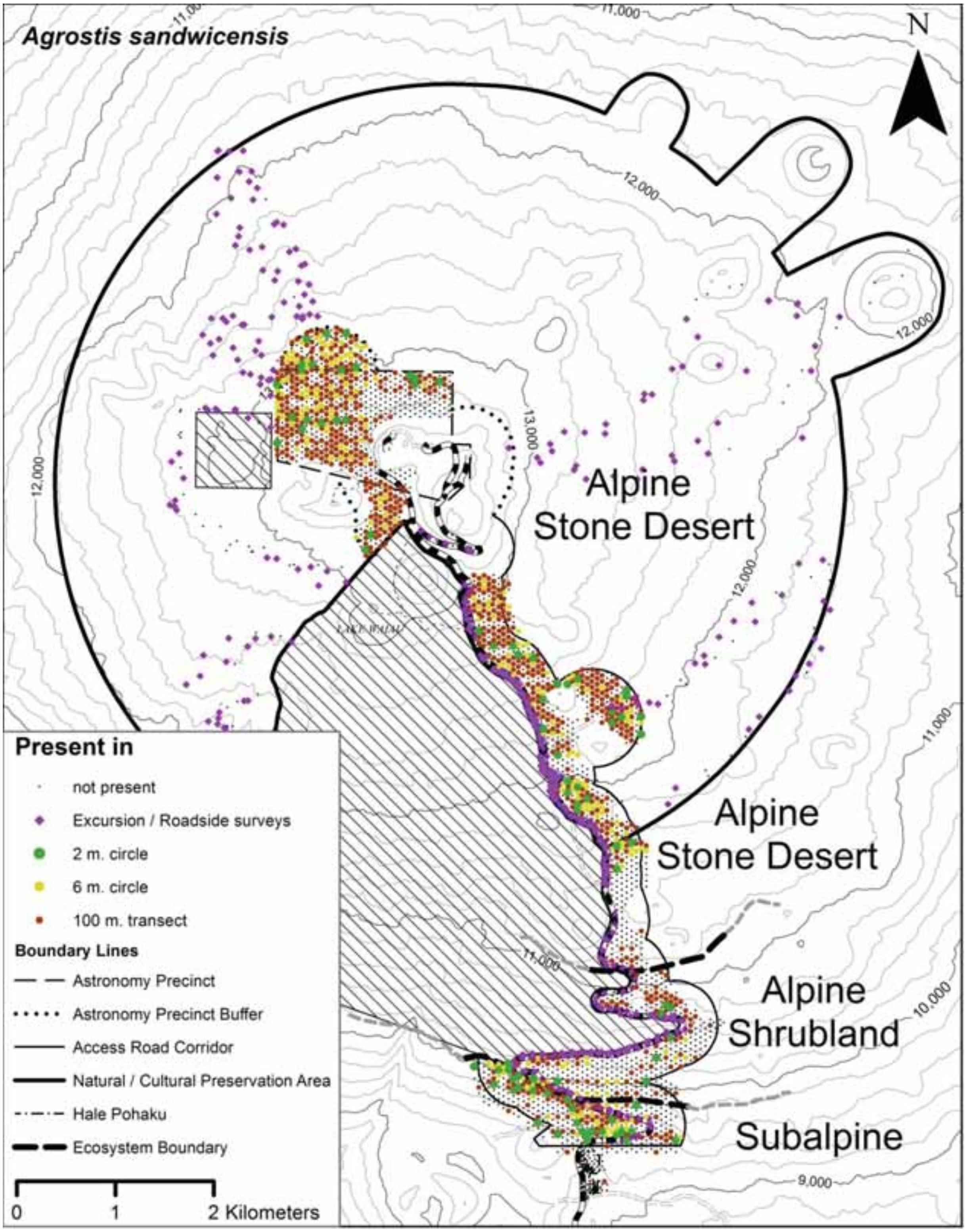


Figure APP-C3. *Agrostis sandwicensis* or Hawaii bentgrass (Poaceae).

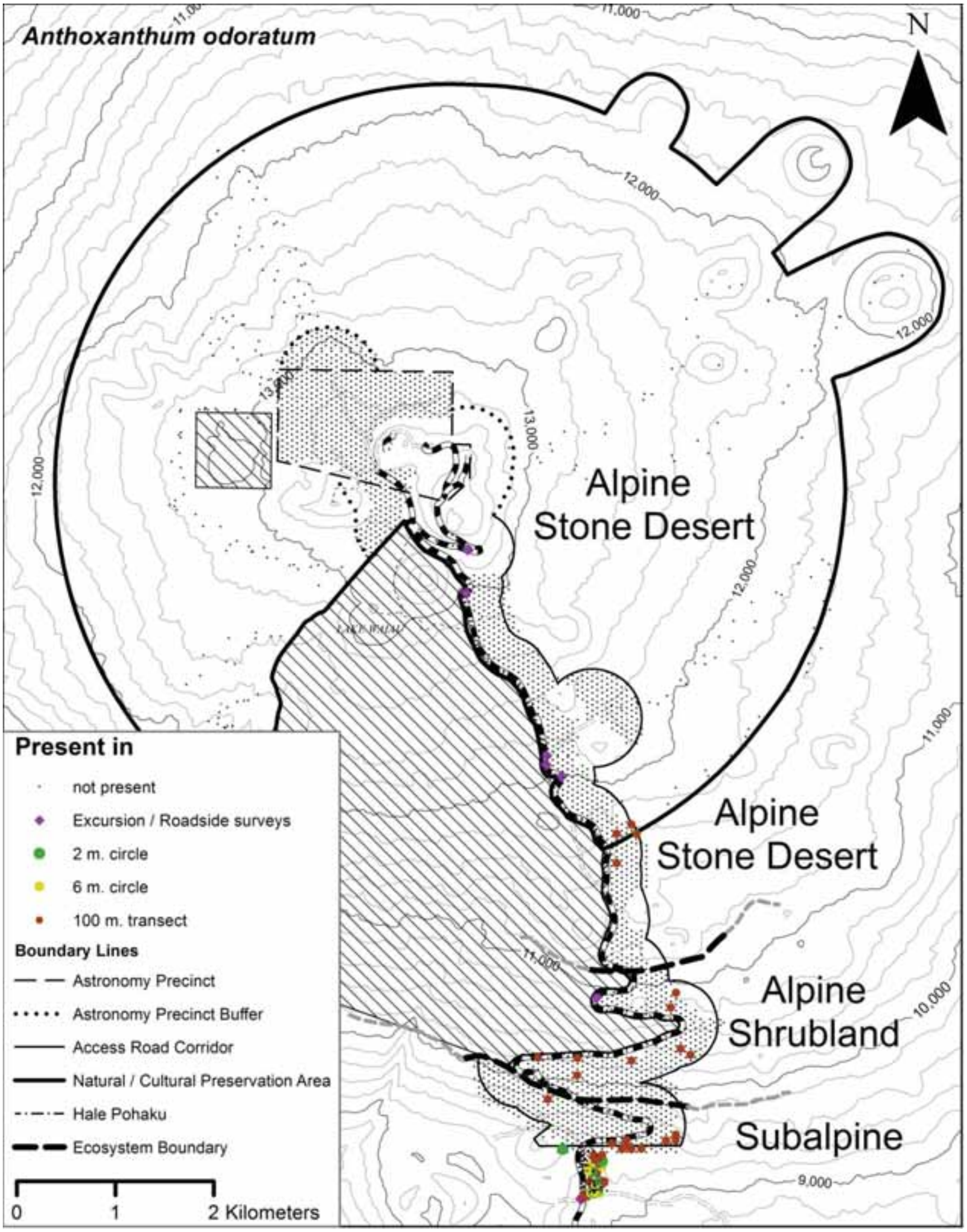


Figure APP-C4. *Anthoxanthum odoratum* or sweet vernalgrass (Poaceae).

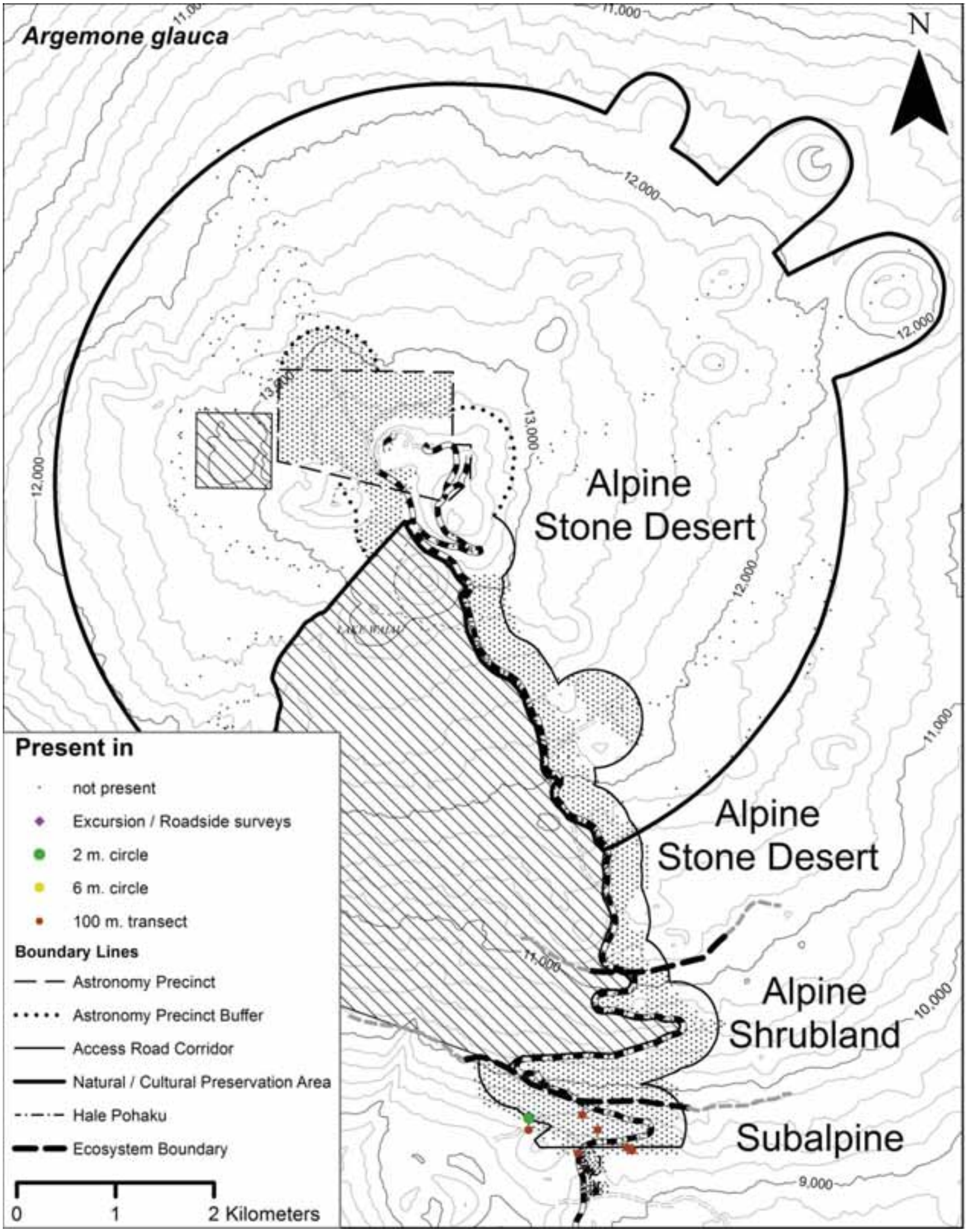


Figure APP-C5. *Argemone glauca* or *pua kala* (Papavaraceae).

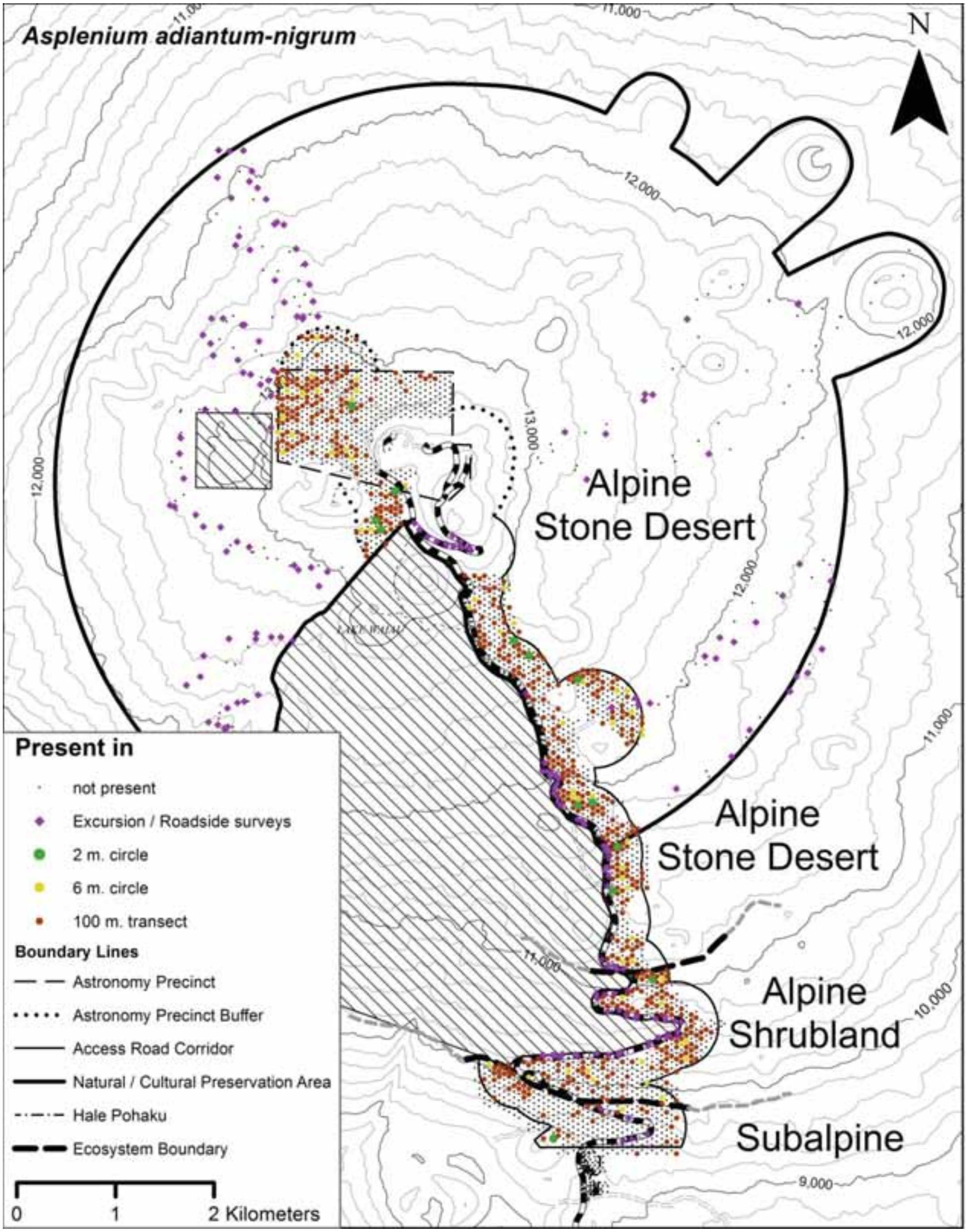


Figure APP-C6. *Asplenium adiantum-nigrum* or *`iwa `iwa* (Aspleniaceae, Pteridophyta).

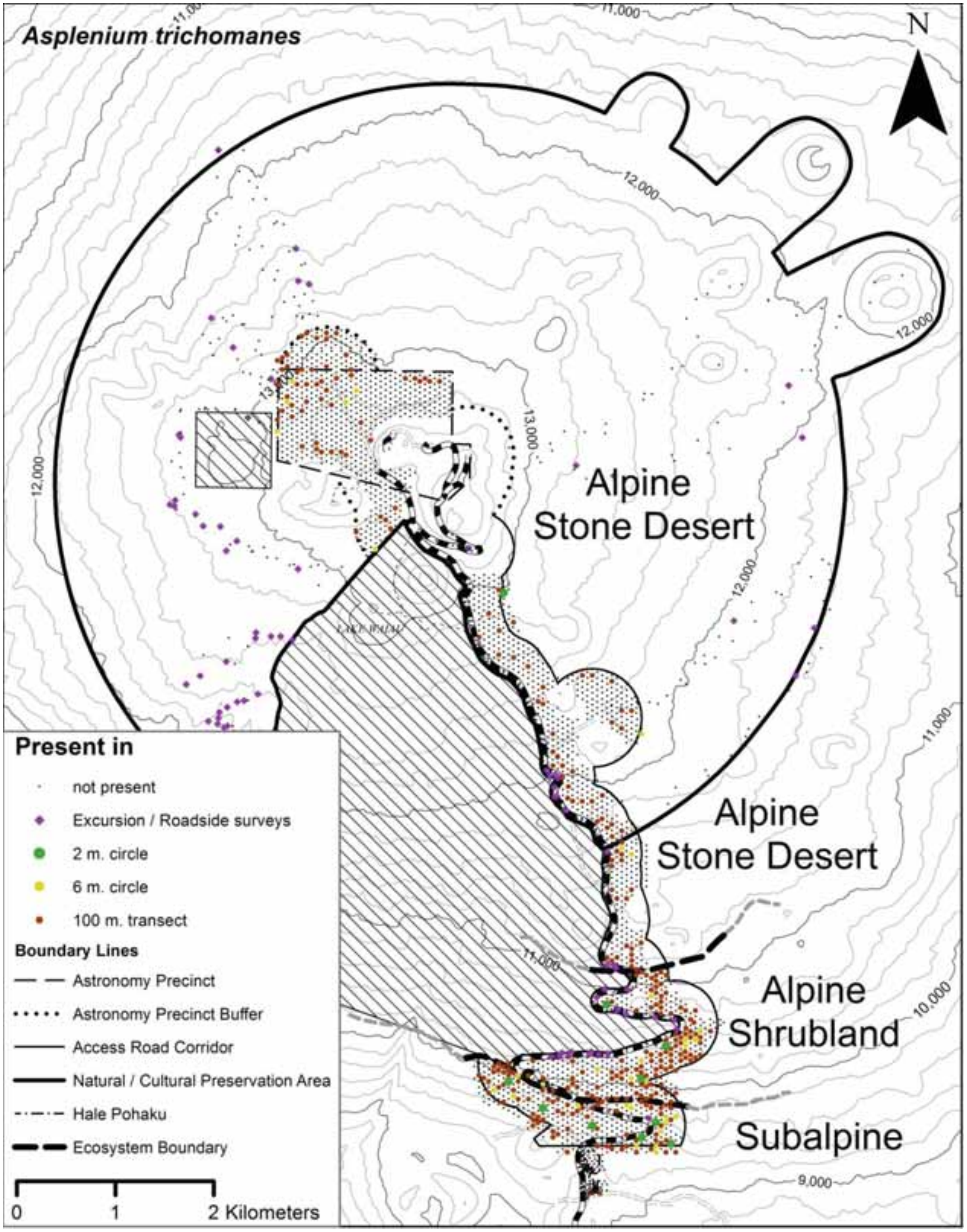


Figure APP-C7. *Asplenium trichomanes* or *`olali`I* (Aspleniaceae, Pteridophyta).

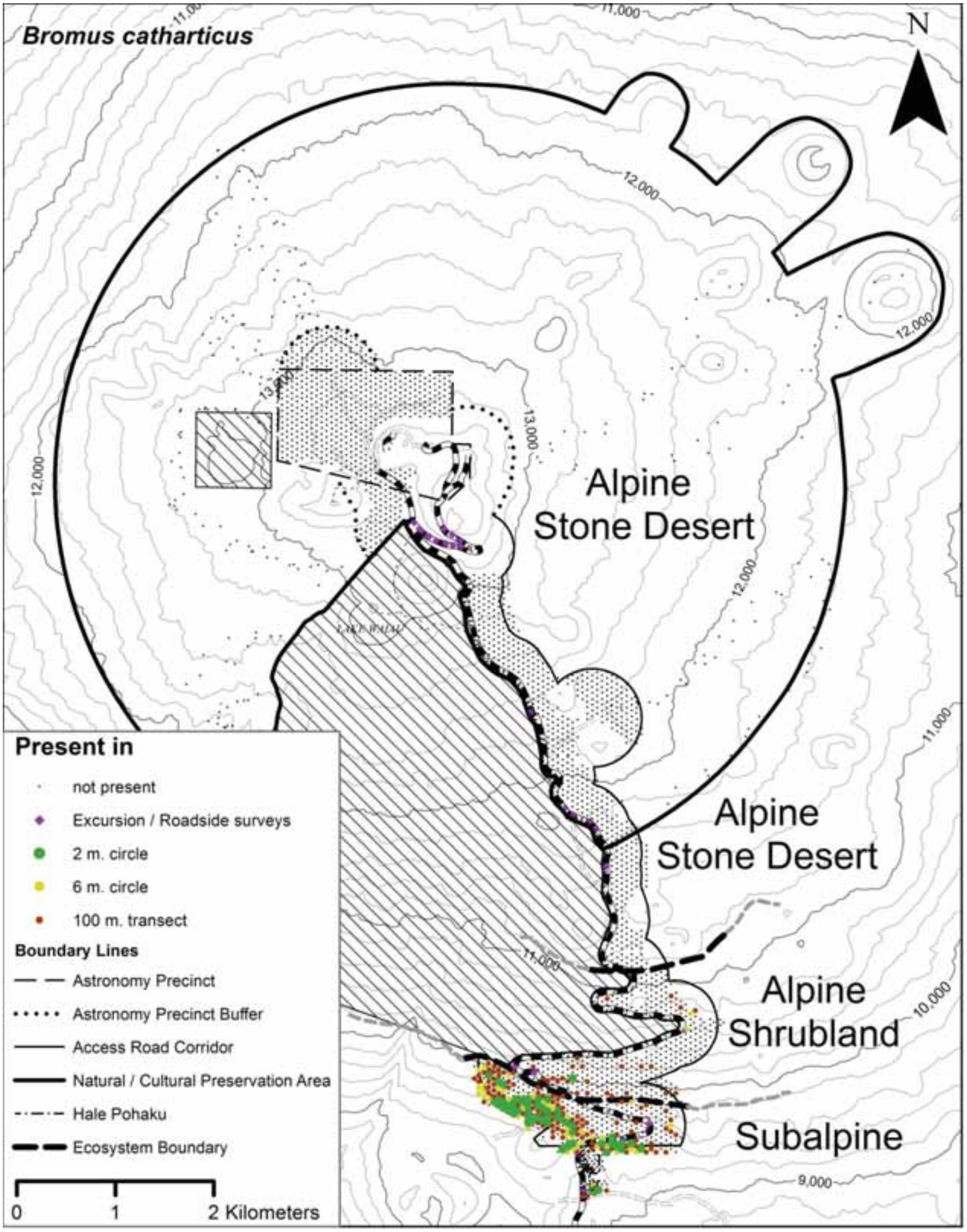


Figure APP-C8. *Bromus catharticus* or rescue grass (Poaceae).

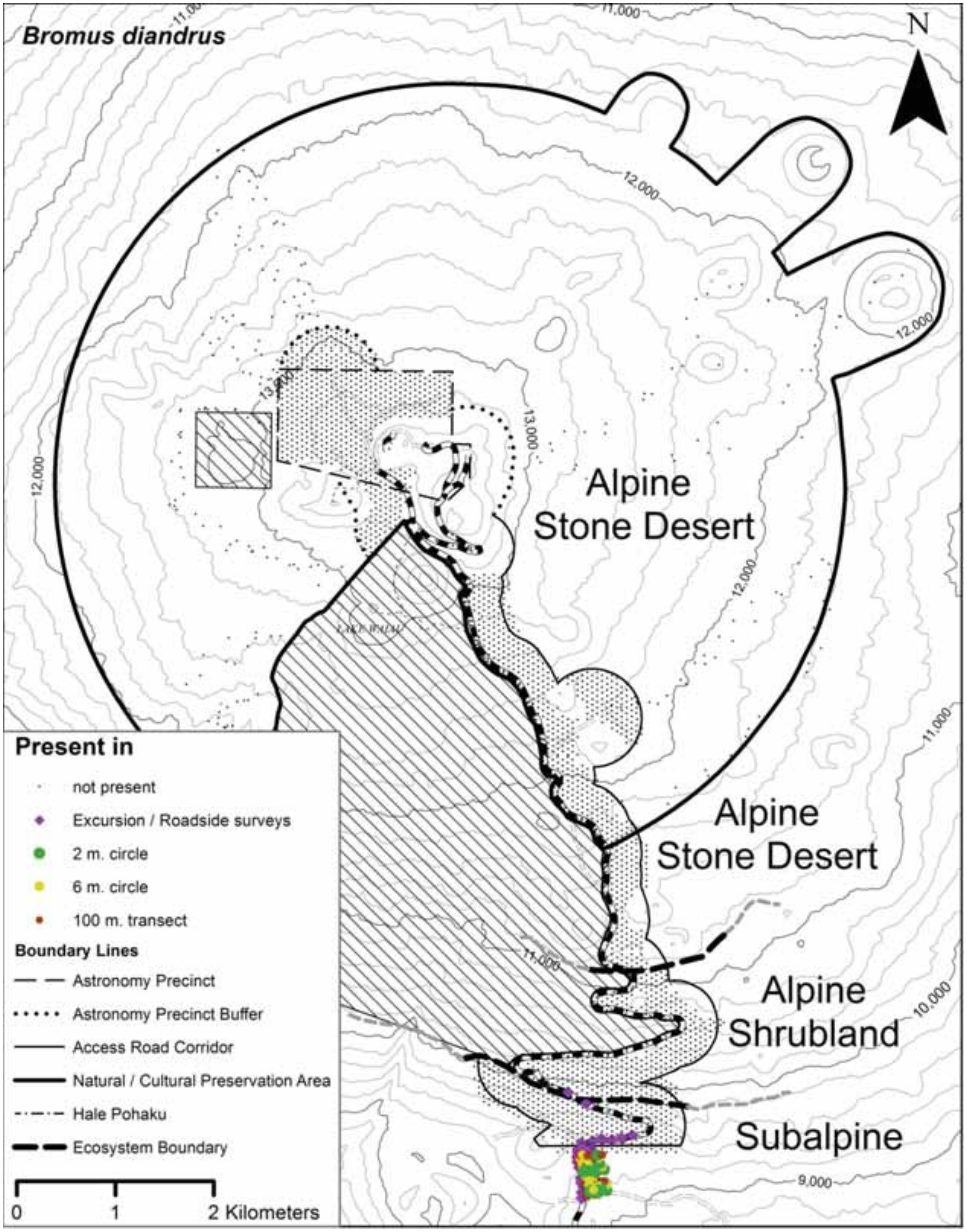


Figure APP-C9. *Bromus diandrus* or ripgut grass (Poaceae).

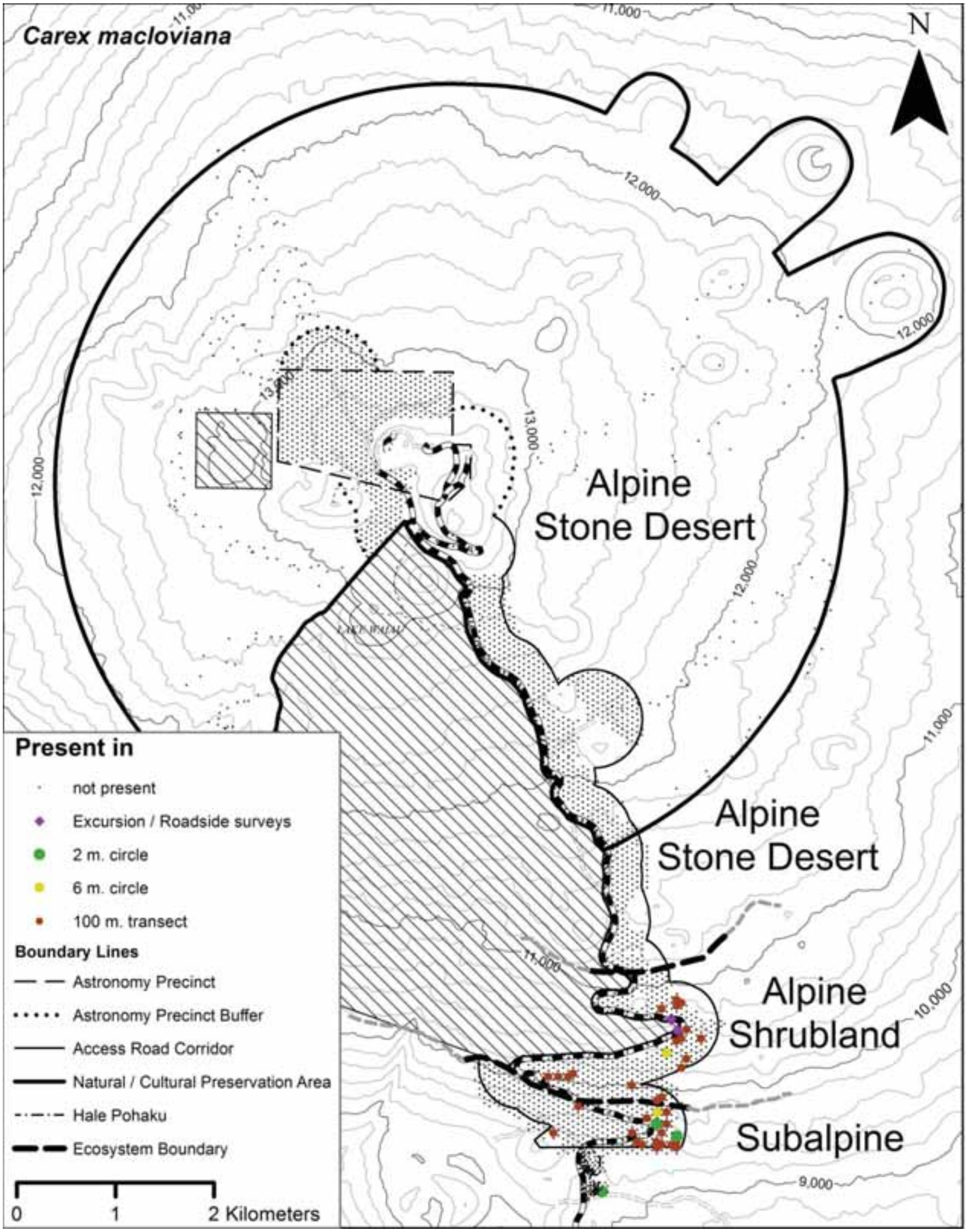


Figure APP-C10. *Carex macloviana* **subsp.** *subfusca* or St. Malo's sedge (Cyperaceae).

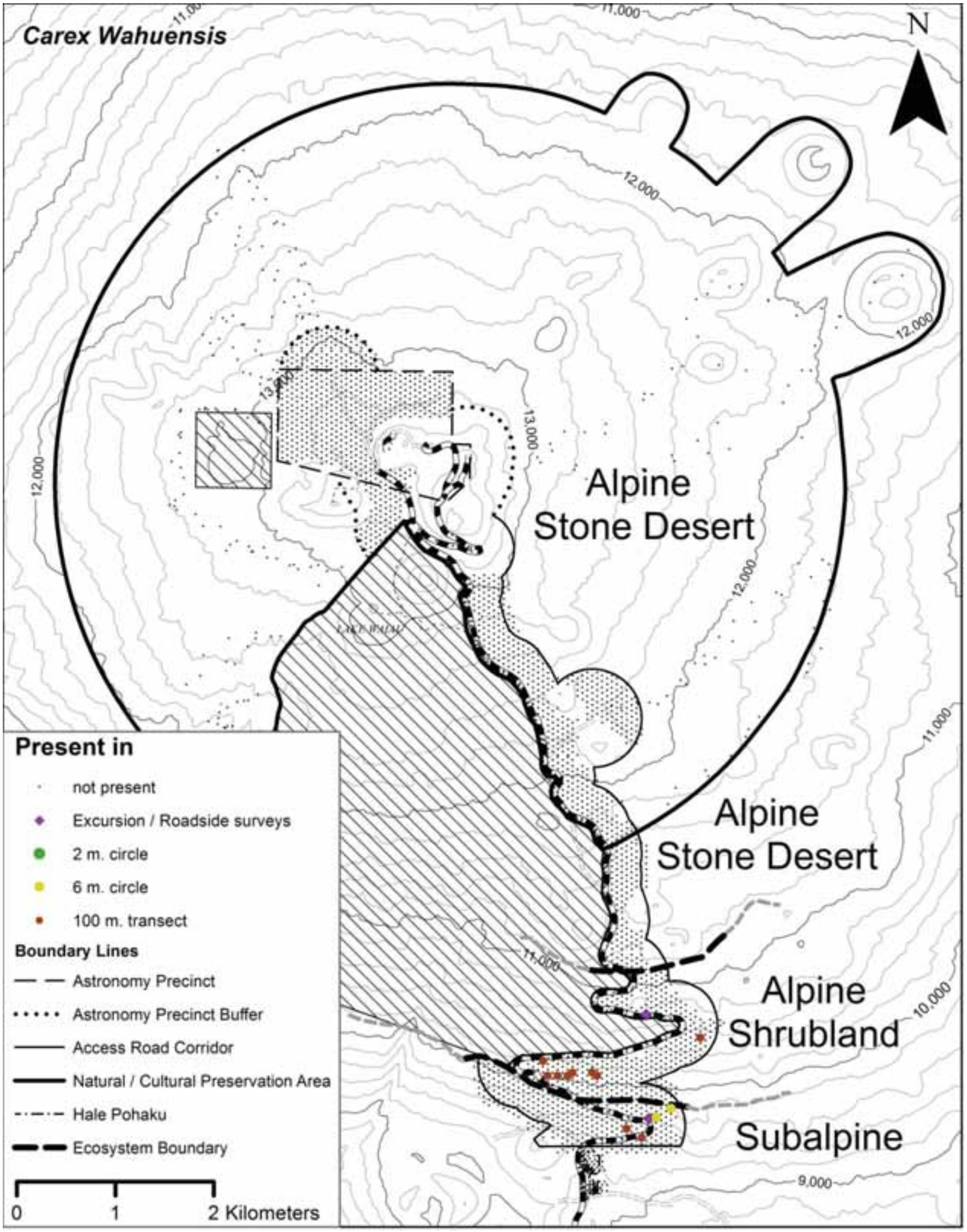


Figure APP-C11. *Carex wahuensis* or Oahu sedge (Cyperaceae).

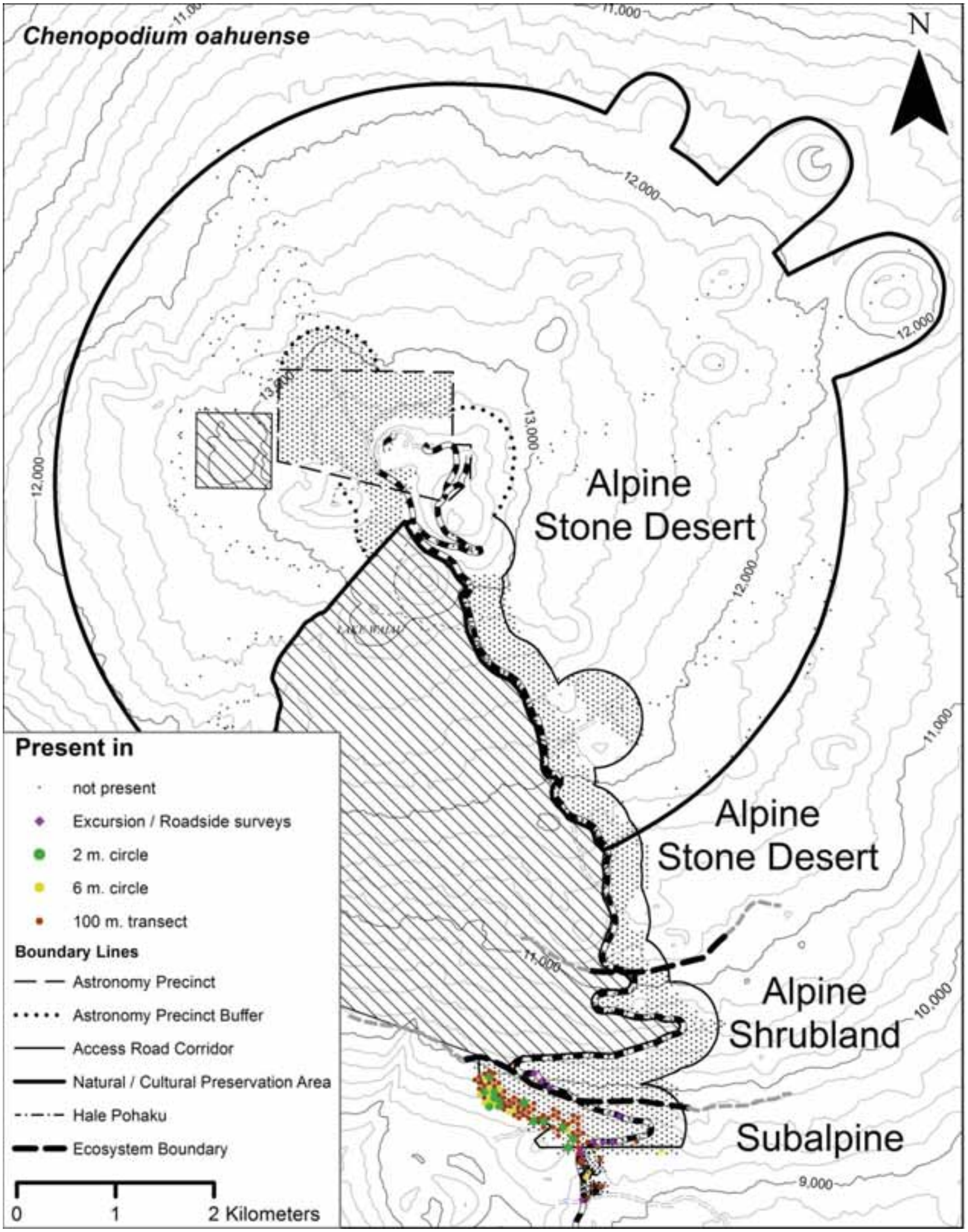


Figure APP-C12. *Chenopodium oahuense* or `*aweoweo* (Cyperaceae).

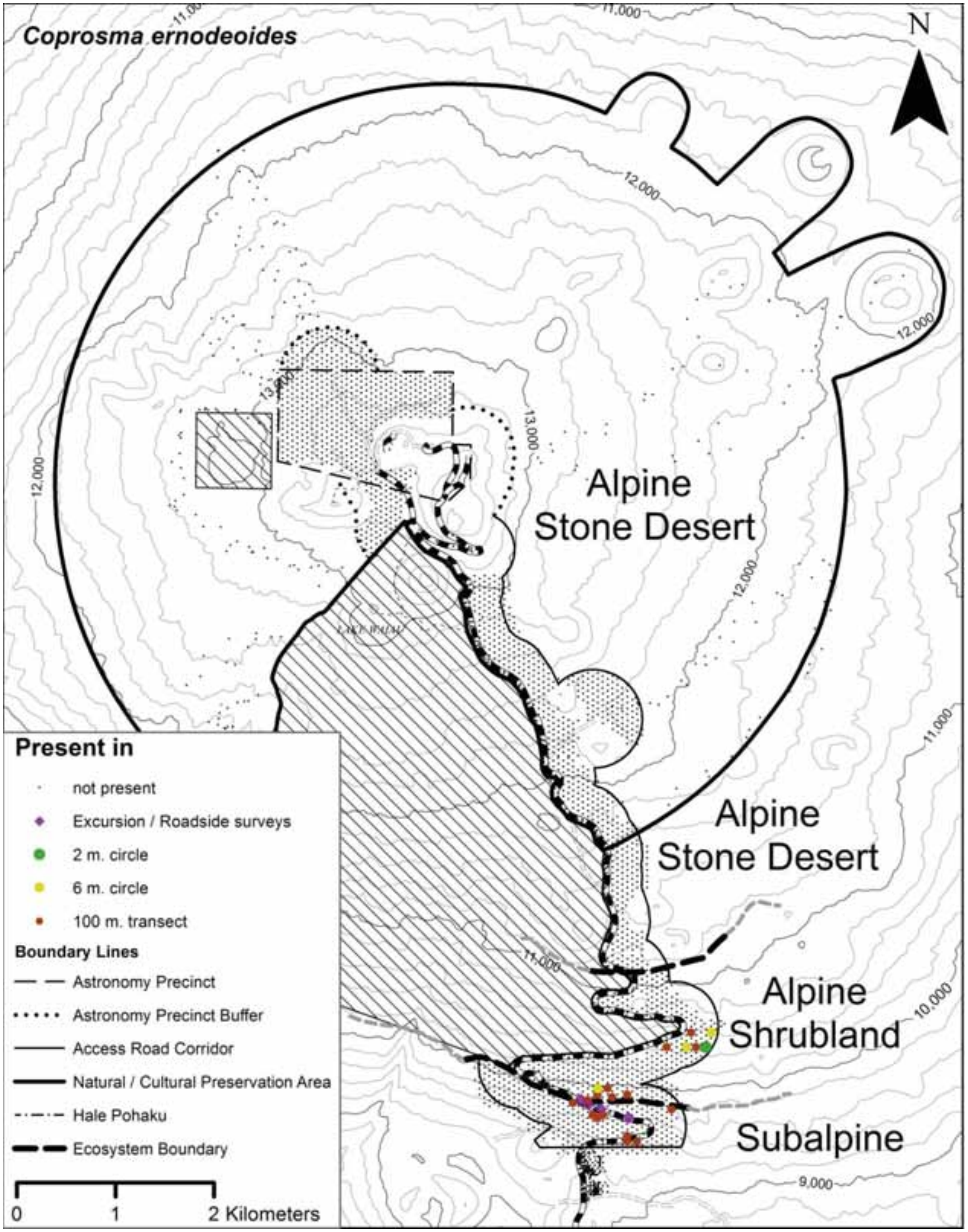


Figure APP-C13. *Coprosma ernodeoides* or *kūkaenēnē* (Rubiaceae).

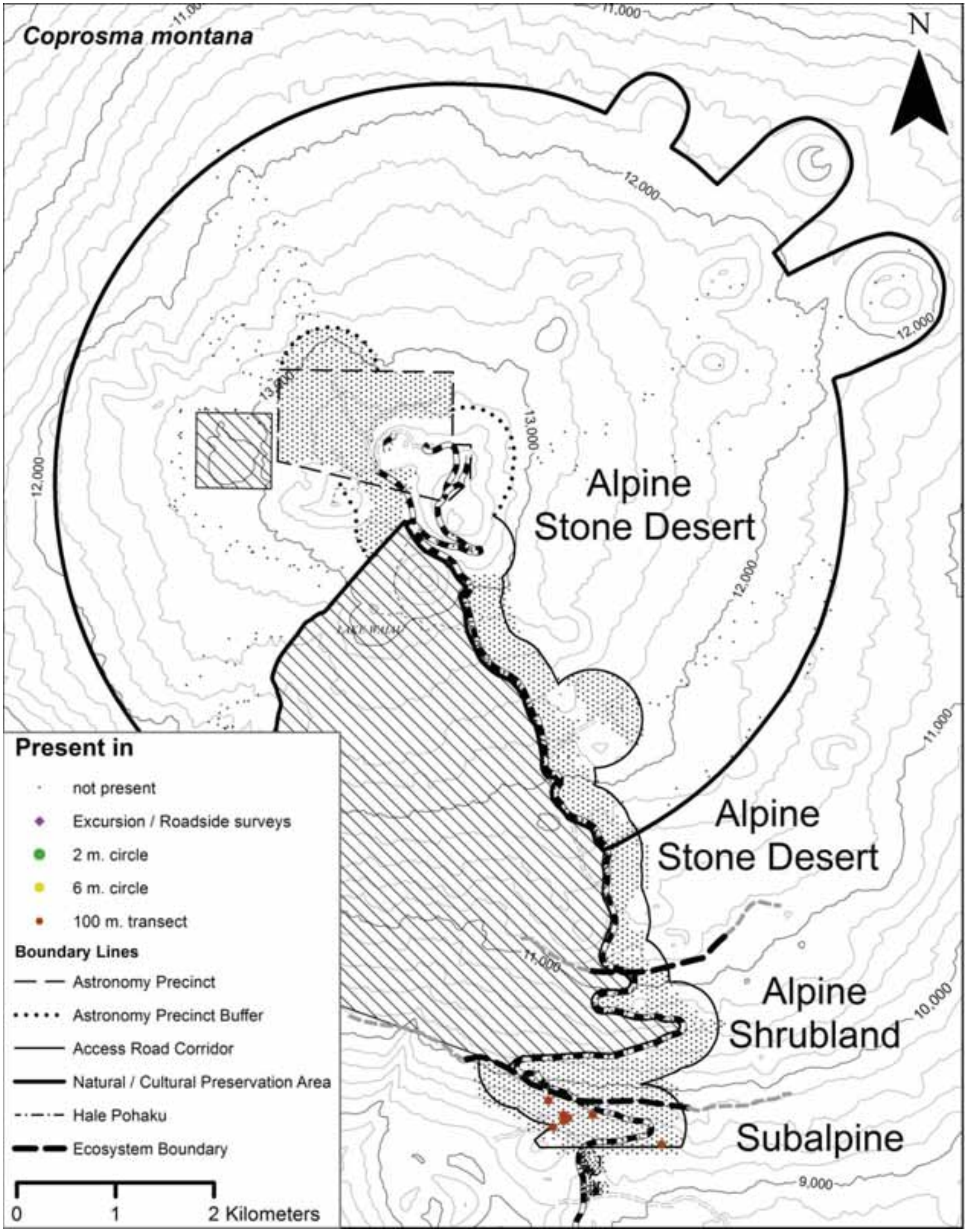


Figure APP-C14. *Coprosma montana* or alpine mirror plant (Rubiaceae).

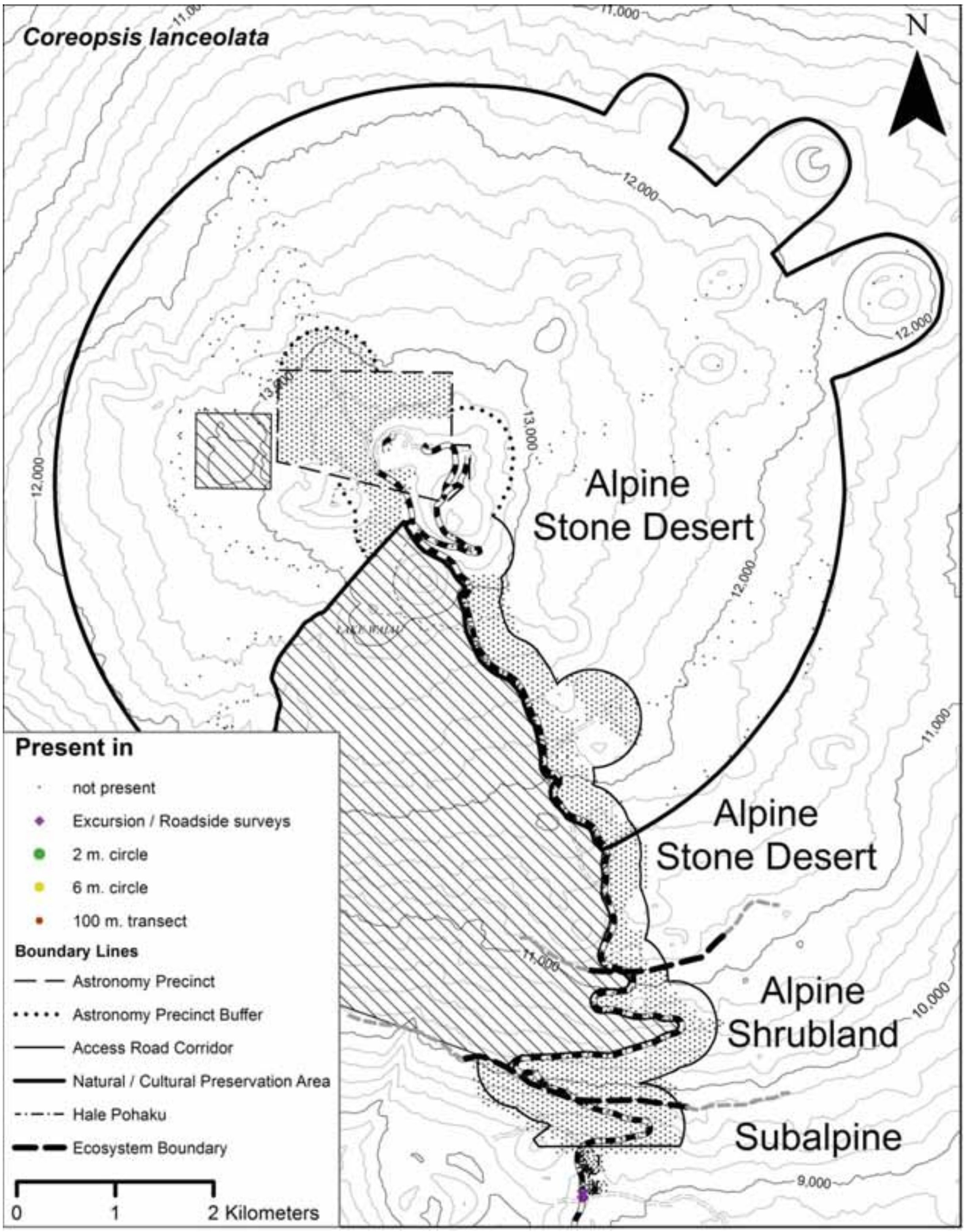


Figure APP-C15. *Coreopsis lanceolata* or *ko'oko'olau haole* (Asteraceae).

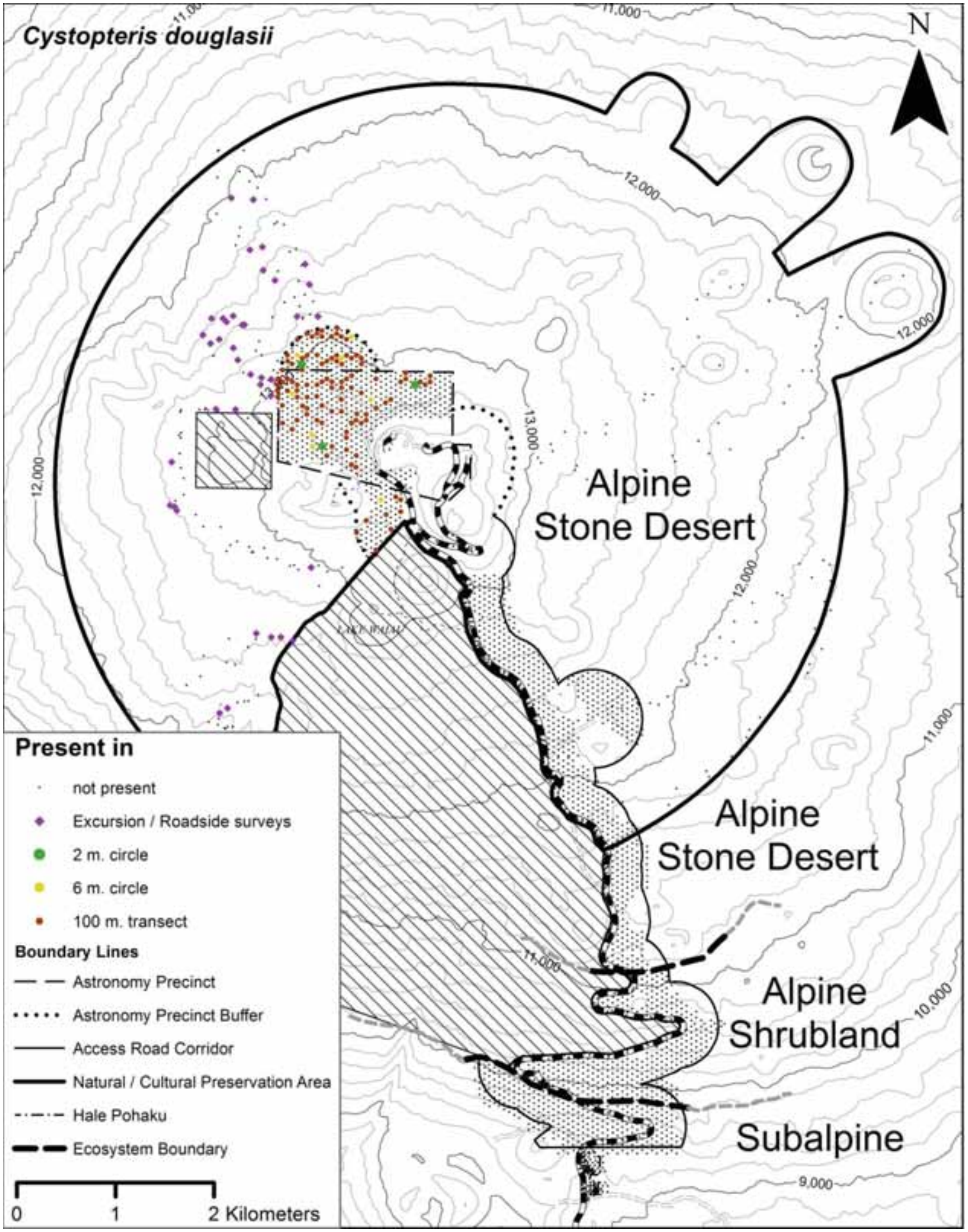


Figure APP-C16. *Cystopteris douglasii* or Douglas' bladderfern (Athyriaceae, Pteridophyta).

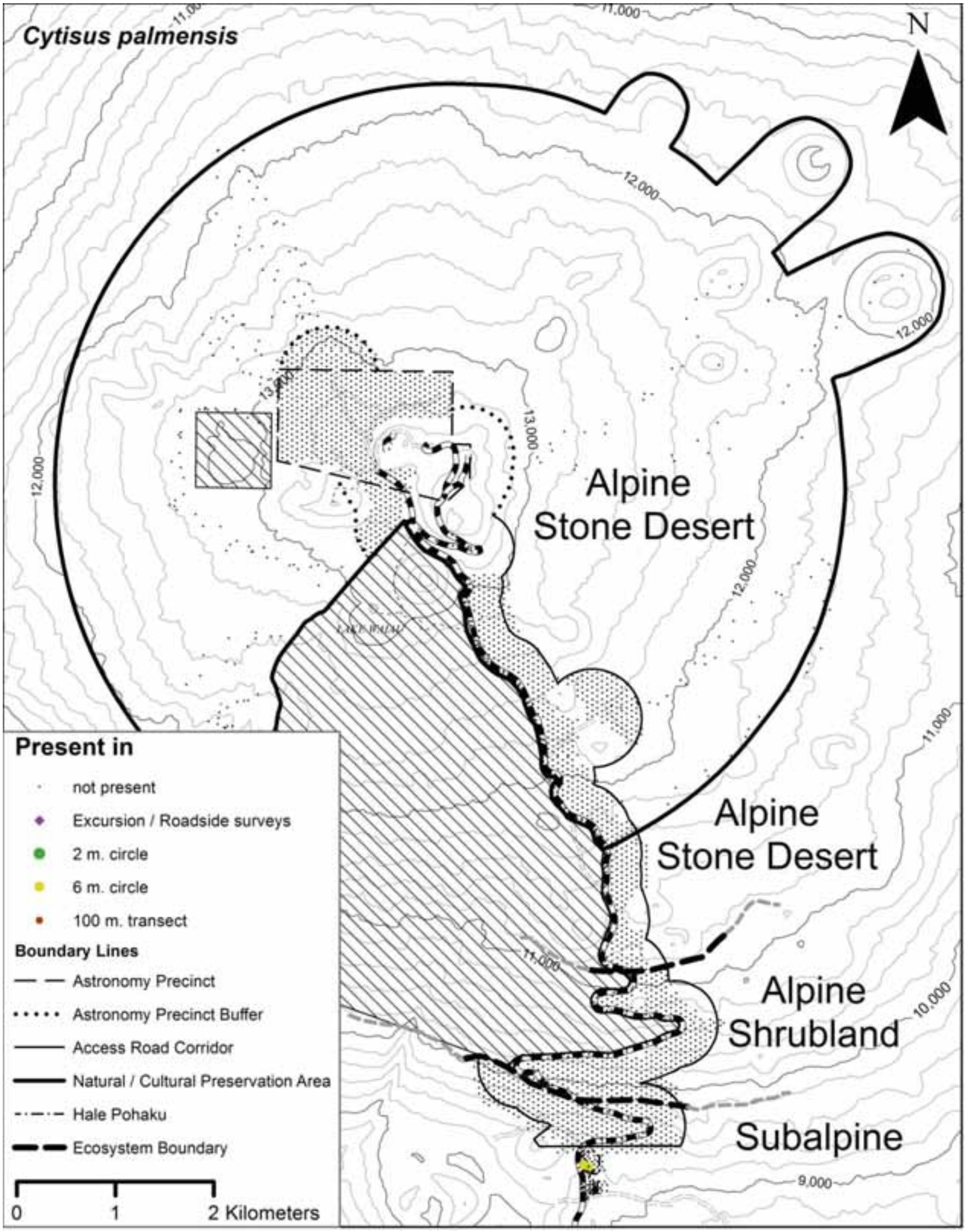


Figure APP-C17. *Cytisus palmensis* or broom (Fabaceae).

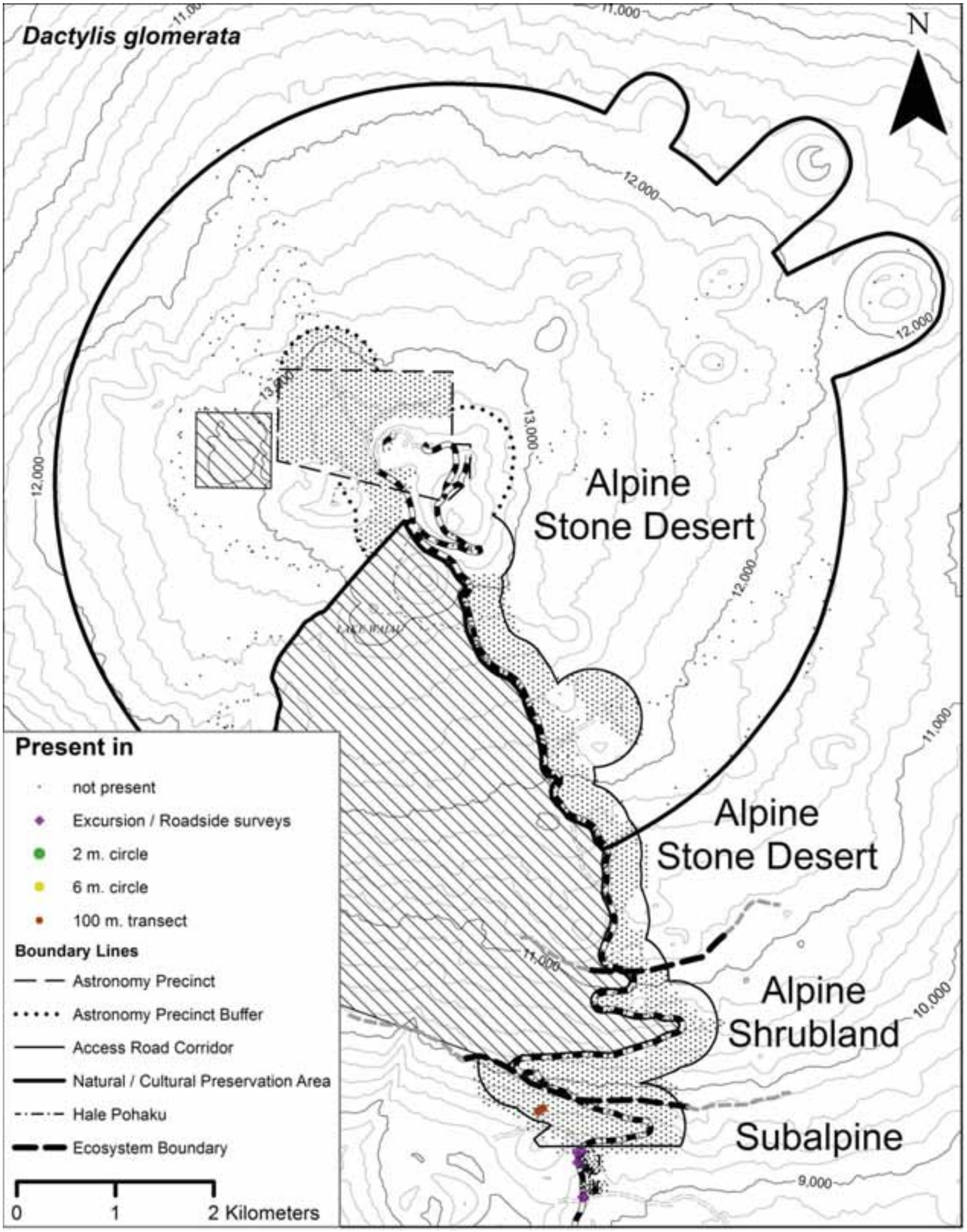


Figure APP-C18. *Dactylis glomerata* or orchard grass (Poaceae).

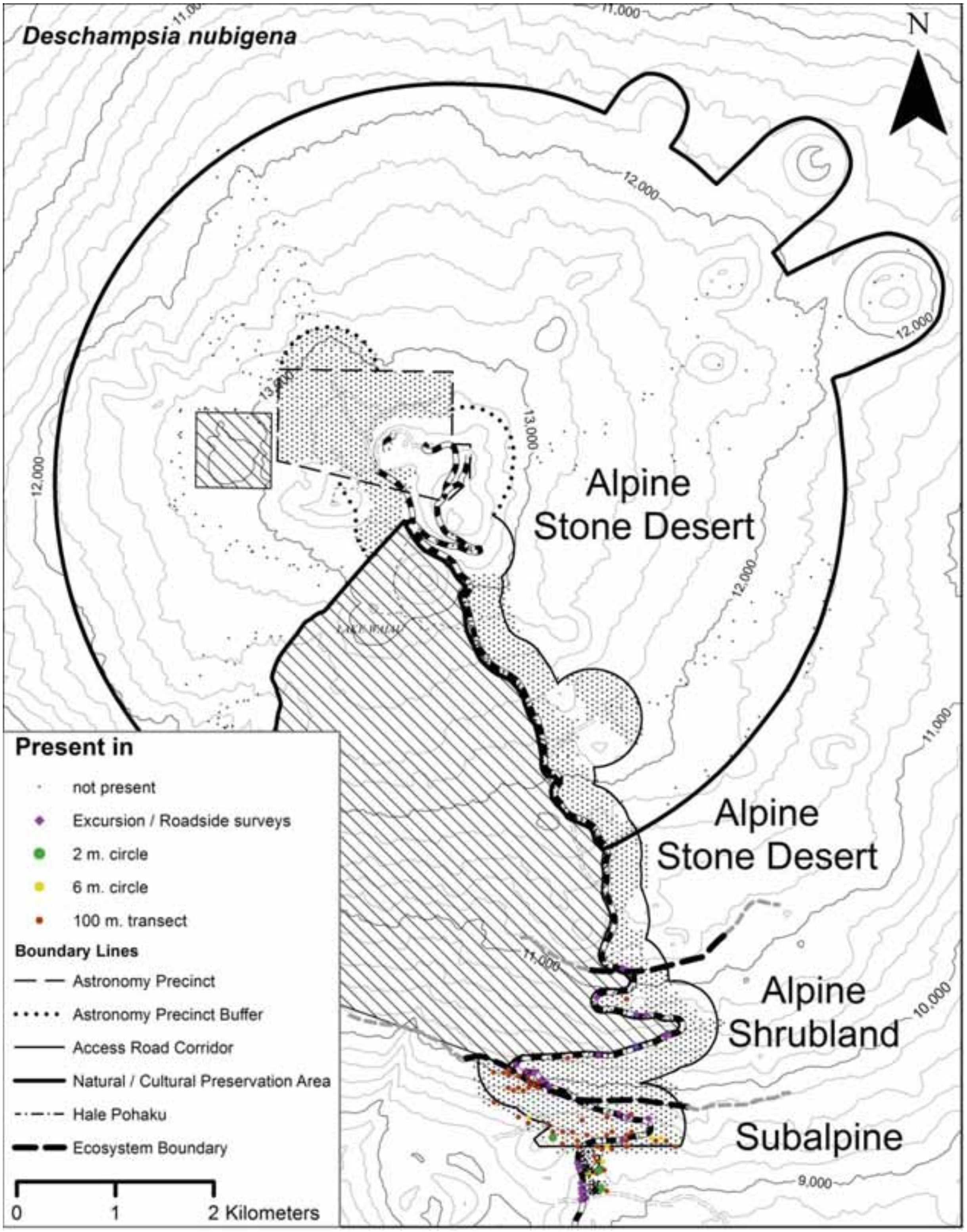


Figure APP-C19. *Deschampsia nubigena* or alpine hair grass (Poaceae).

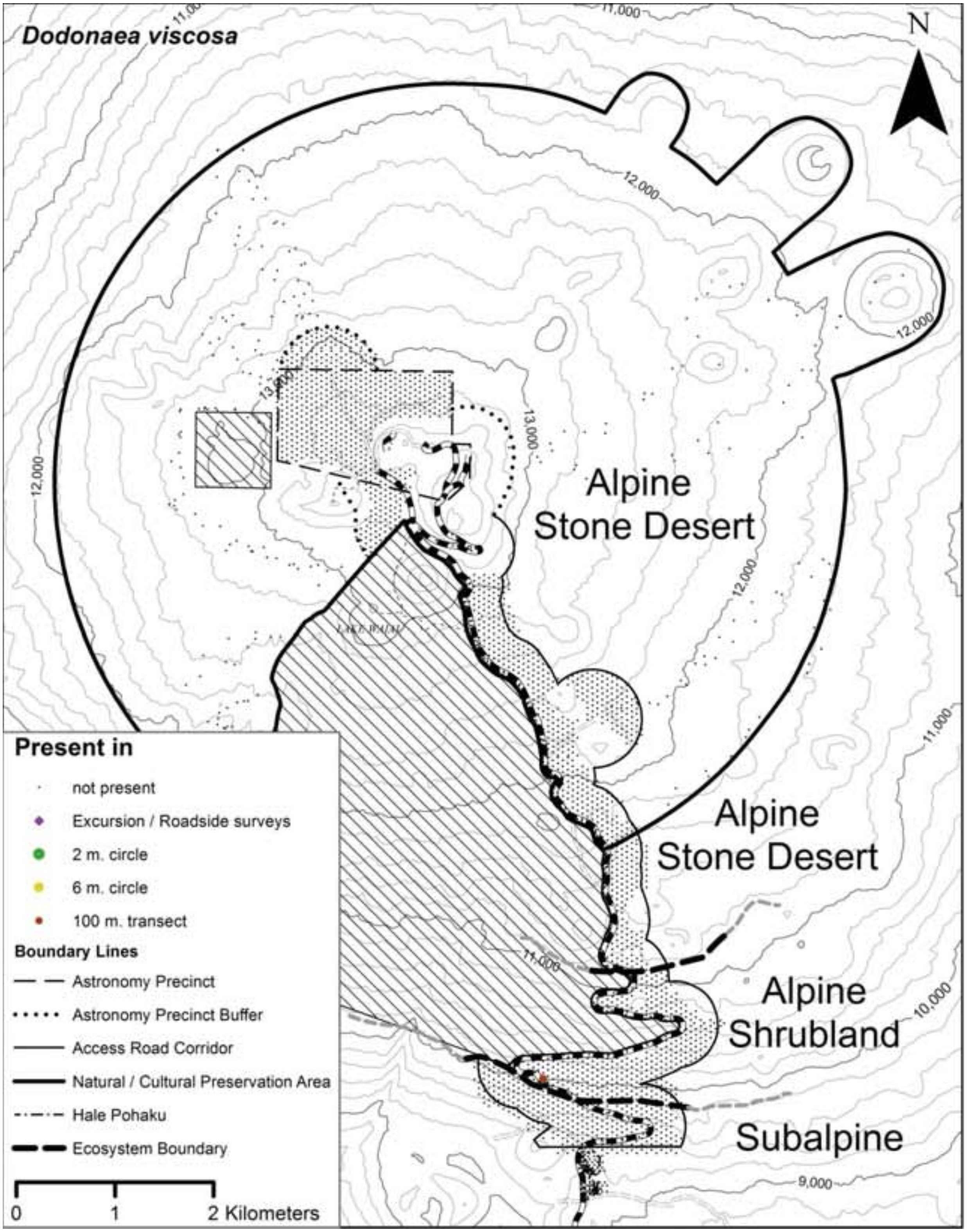


Figure APP-C20. *Dodonaea viscosa* or *`a`ali`i* (Sapindaceae).

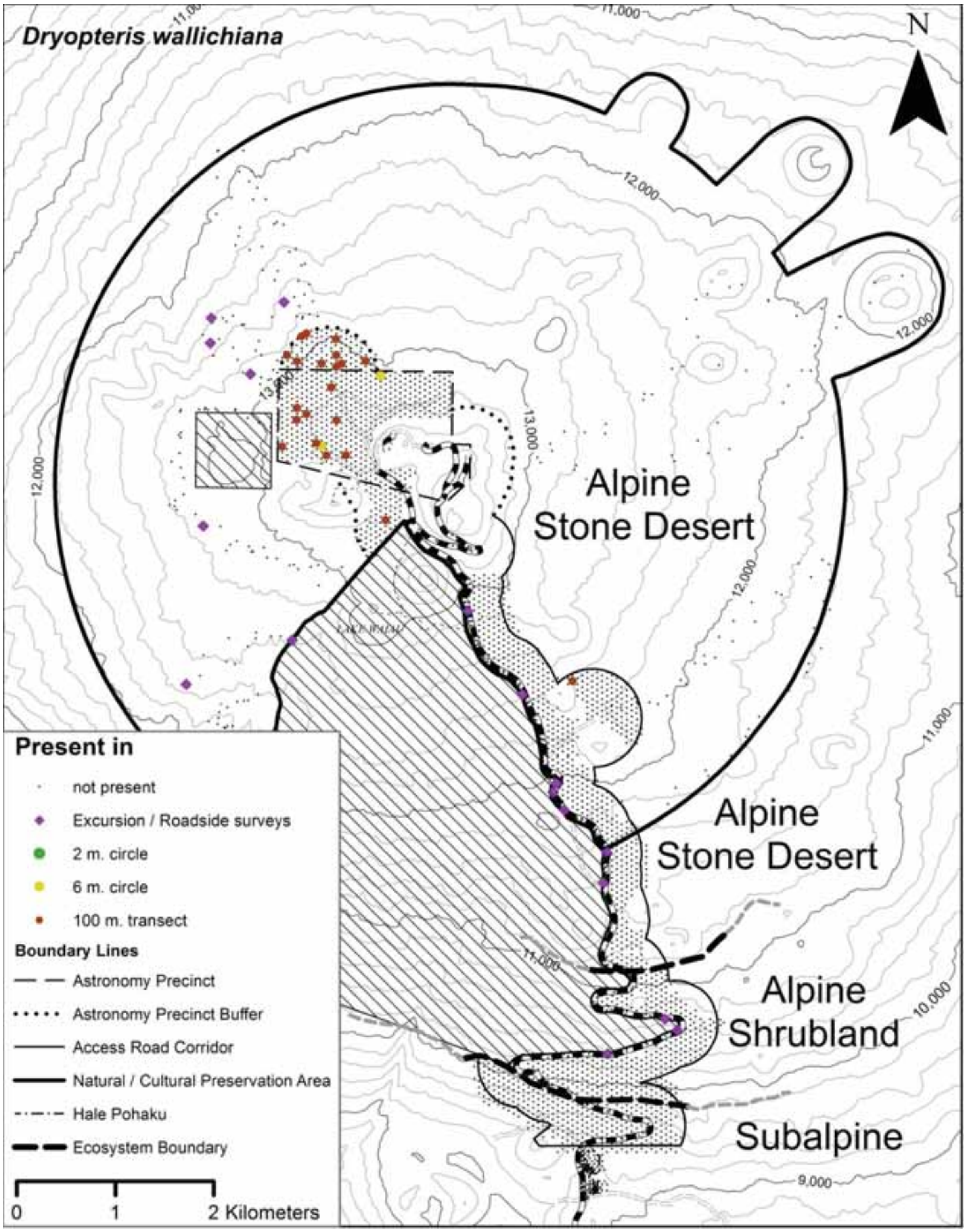


Figure APP-C21. *Dryopteris wallichiana* or alpine wood fern (Dryopteridaceae, Pteridophyta).

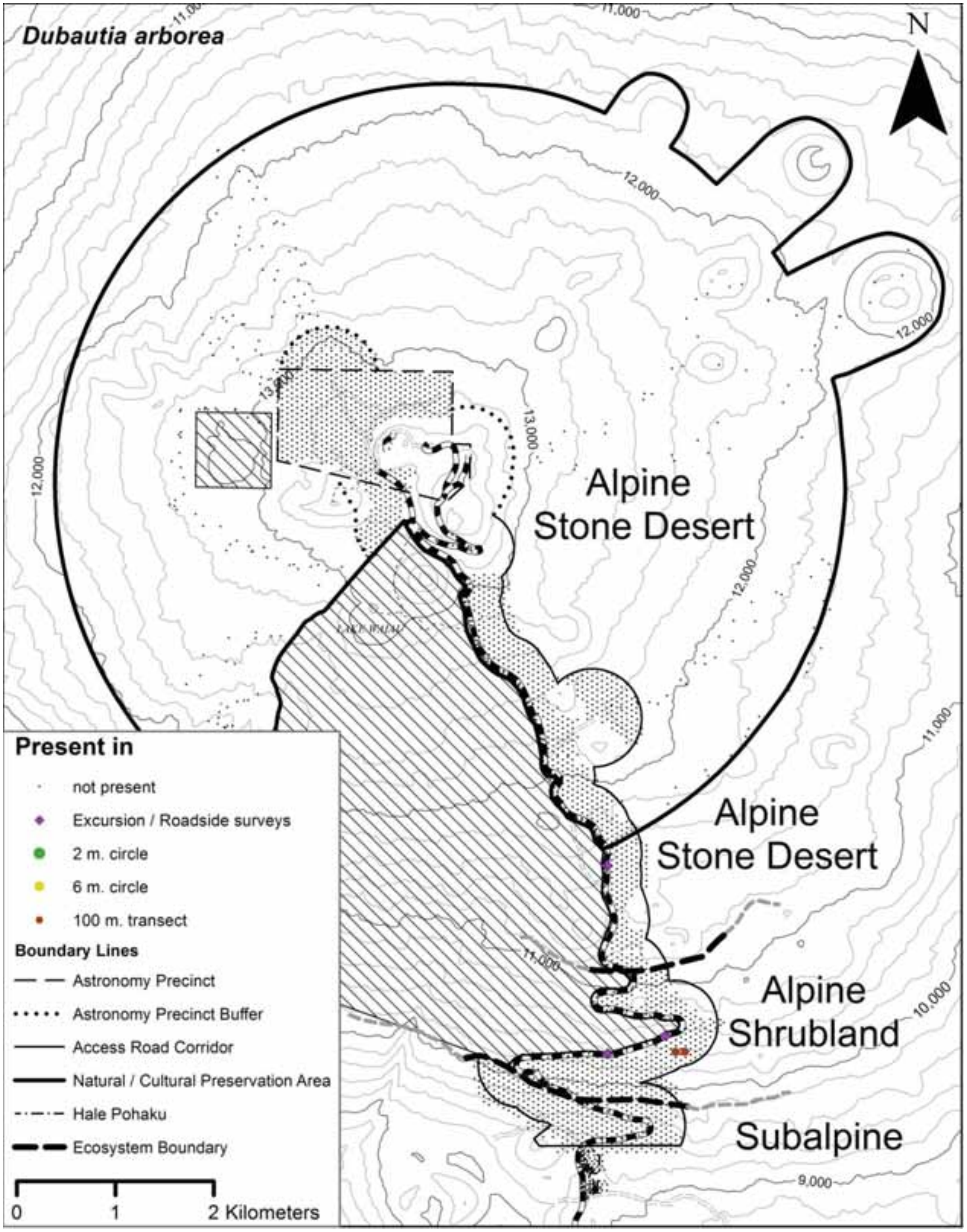


Figure APP-C22. *Dubautia arborea* or *na`ena`*e or Mauna Kea dubautia (Asteraceae).

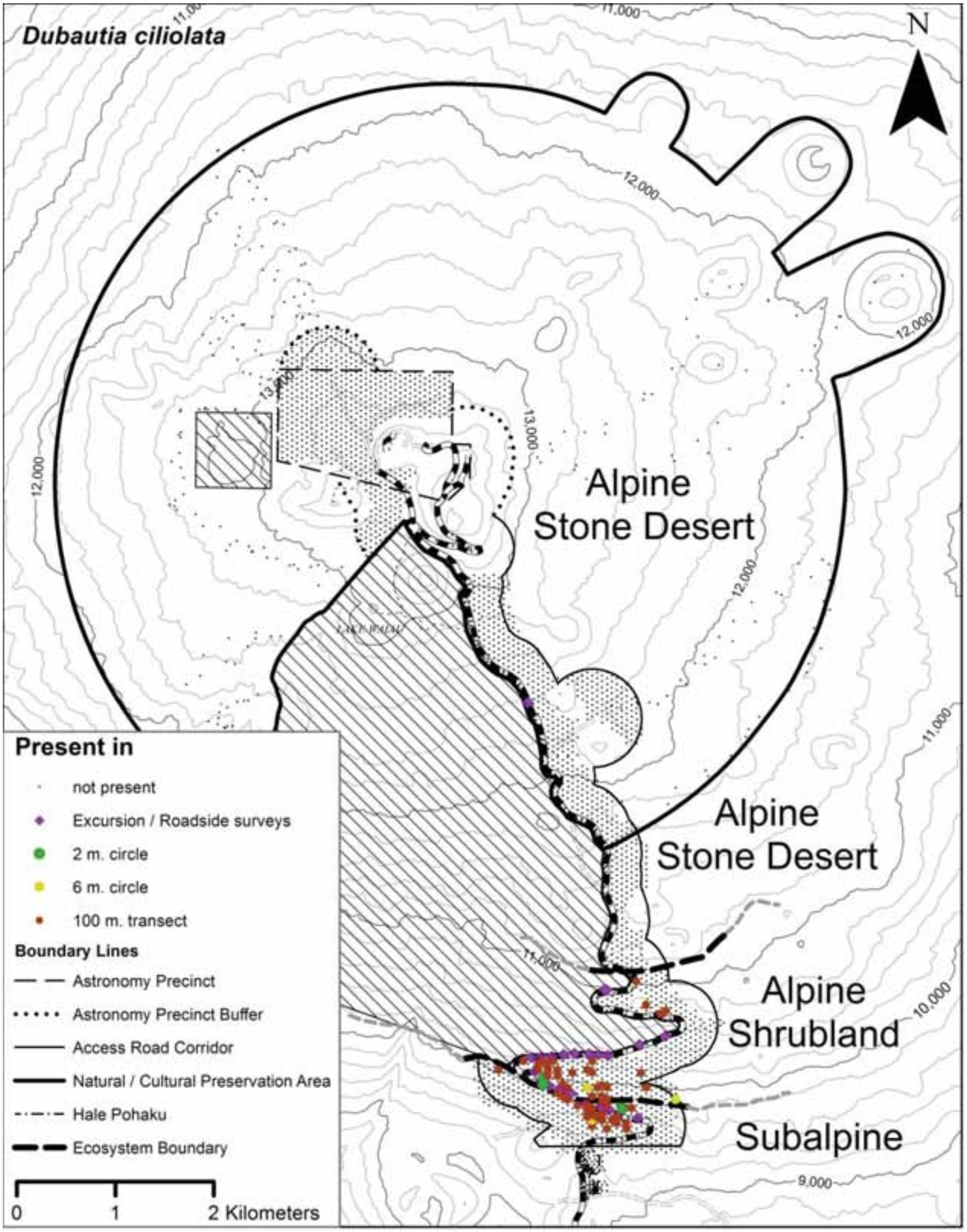


Figure APP-C23. *Dubautia ciliolata* or *na`ena`*e (Asteraceae).

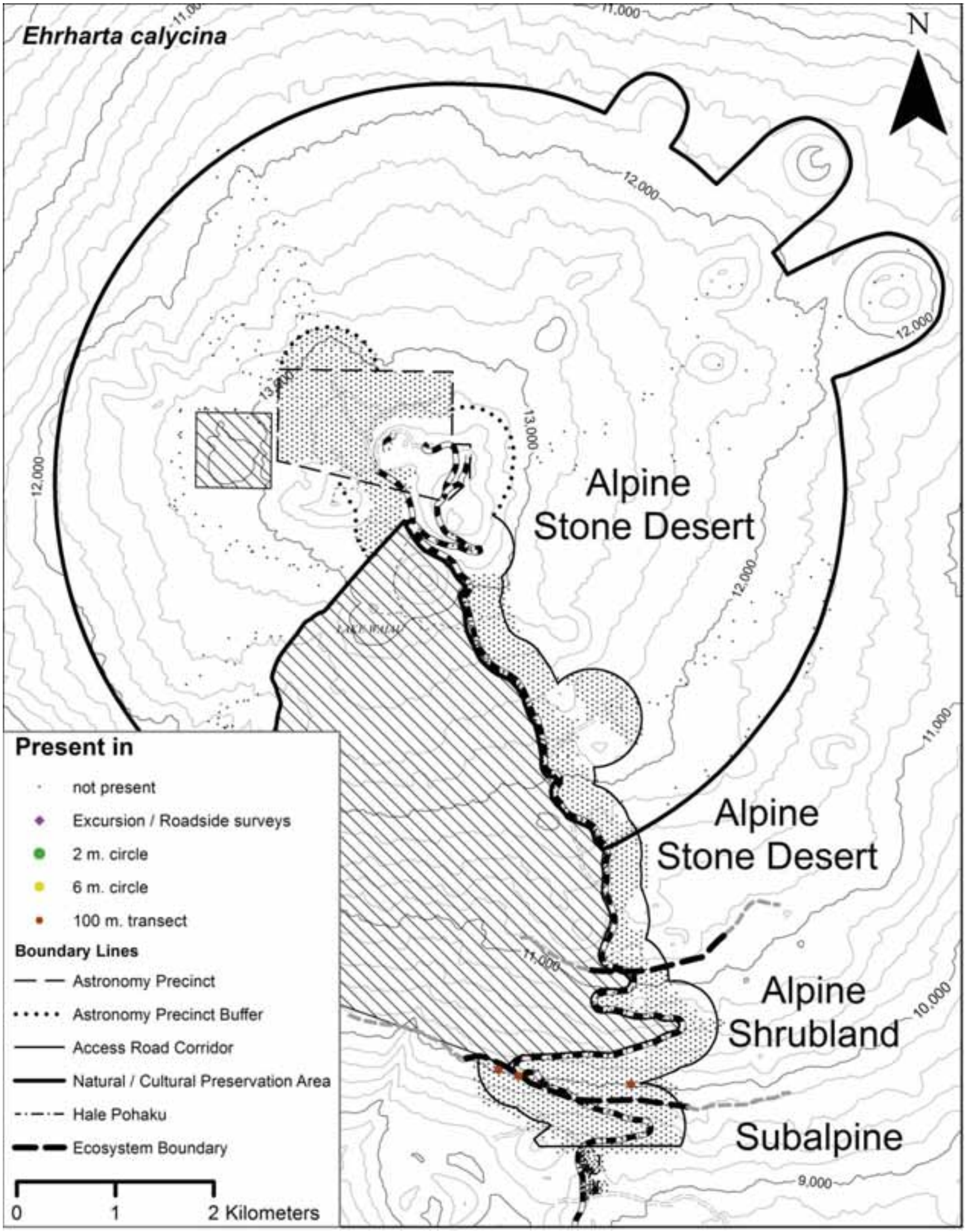


Figure APP-C24. *Ehrharta calycina* or perennial veldtgrass (Poaceae).

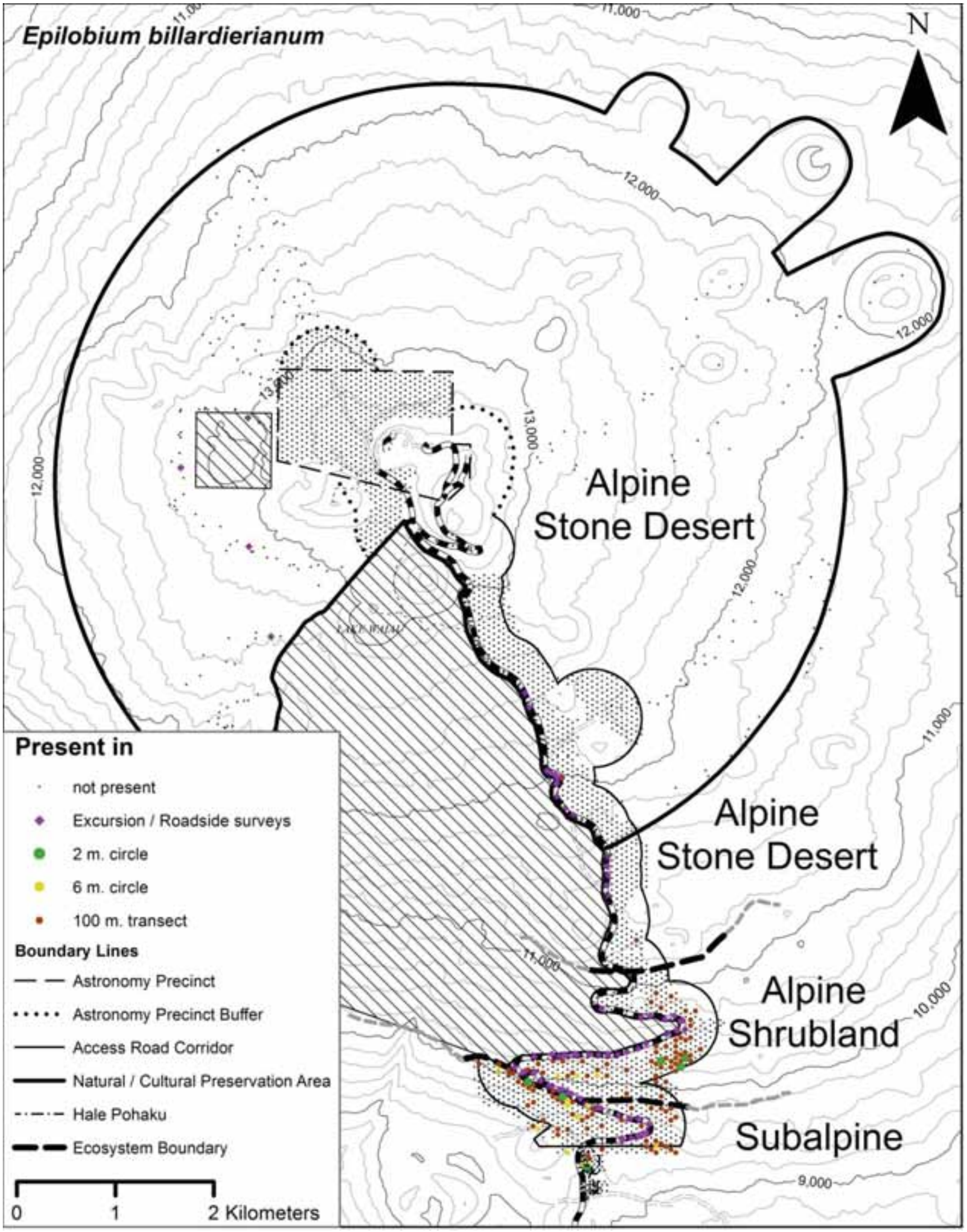


Figure APP-C25. *Epilobium billardierianum* **subsp.** *cinereum* or willow herb (Onagraceae).

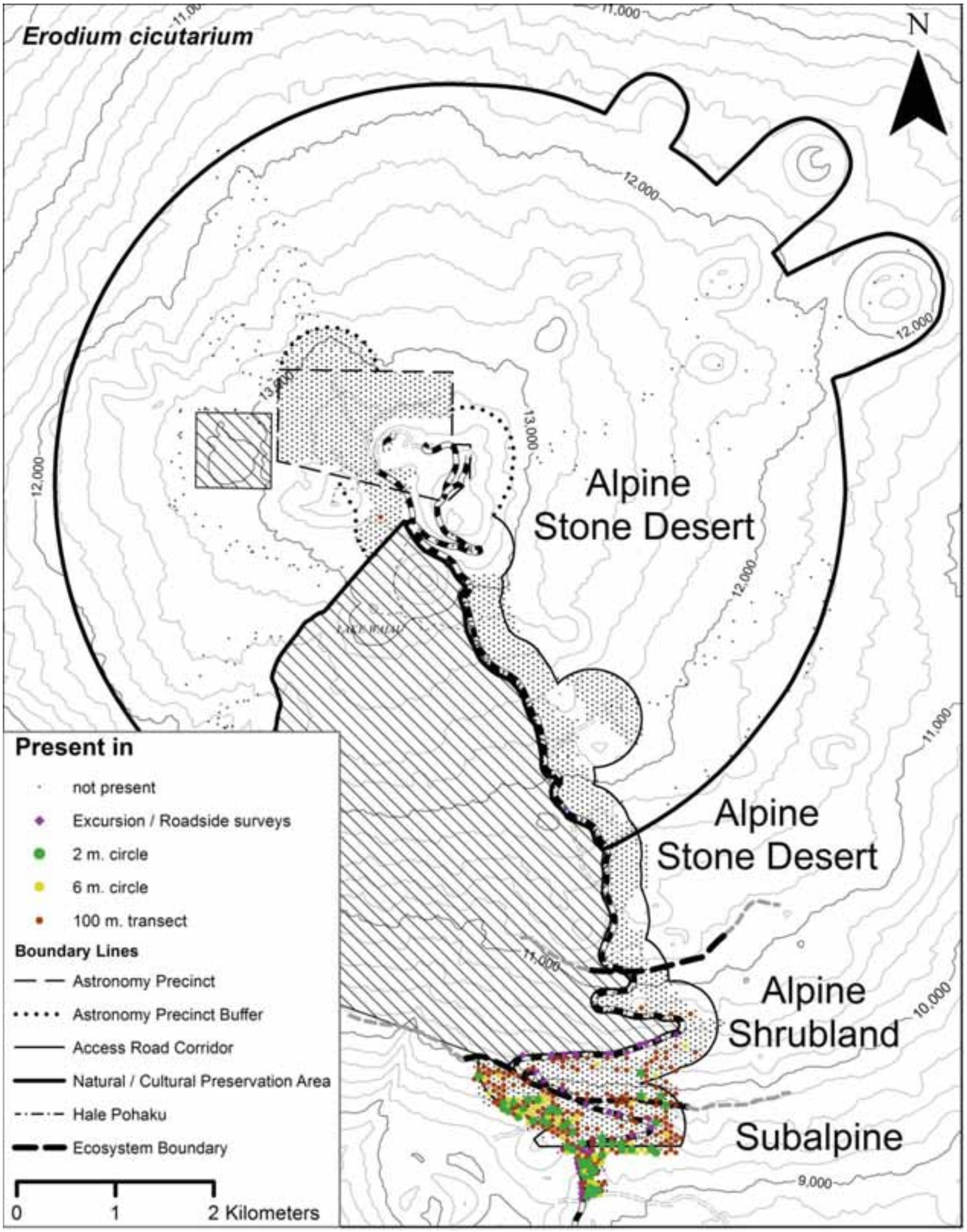
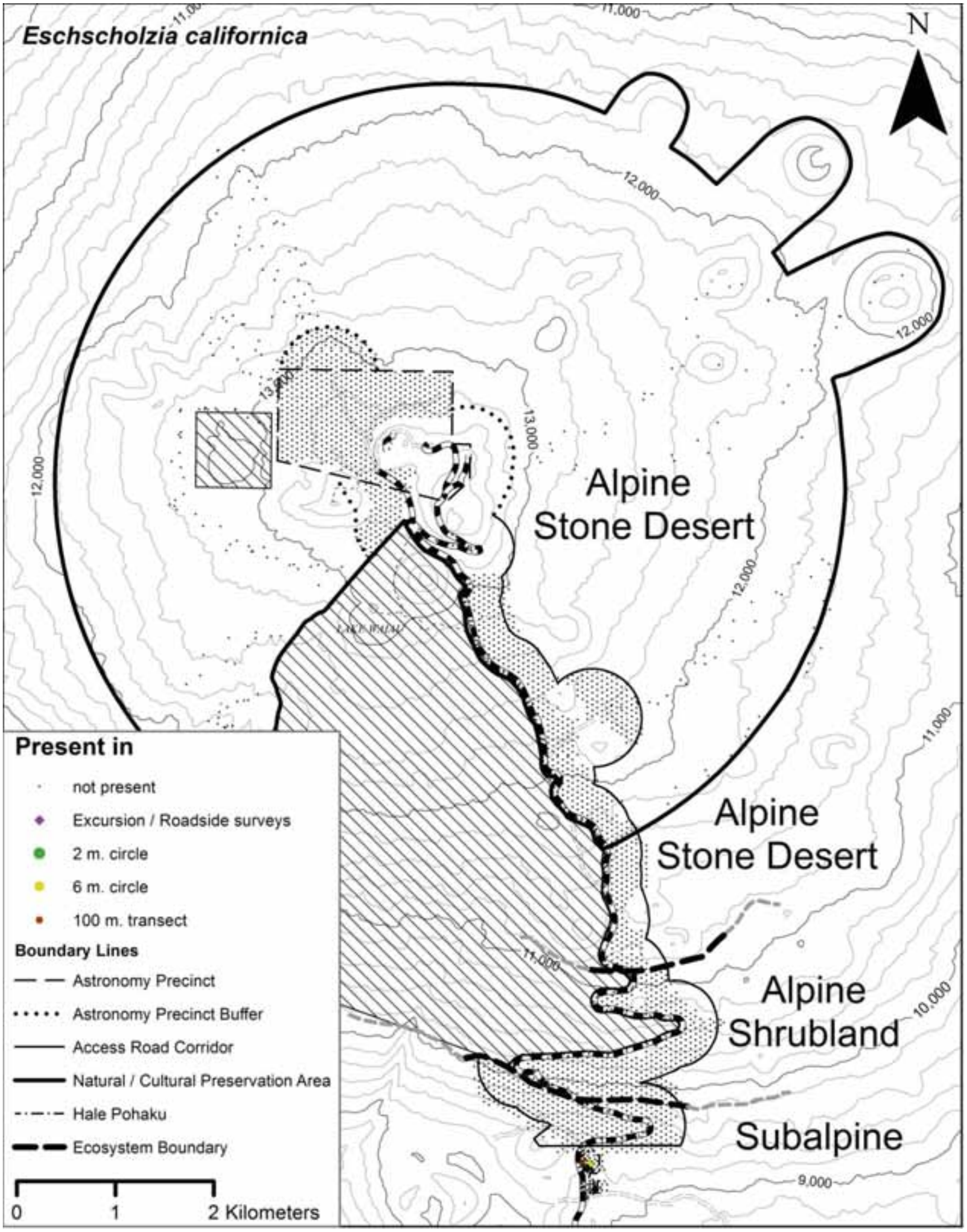


Figure APP-C26. *Erodium cicutarium* or alfilaria (Geraniaceae).



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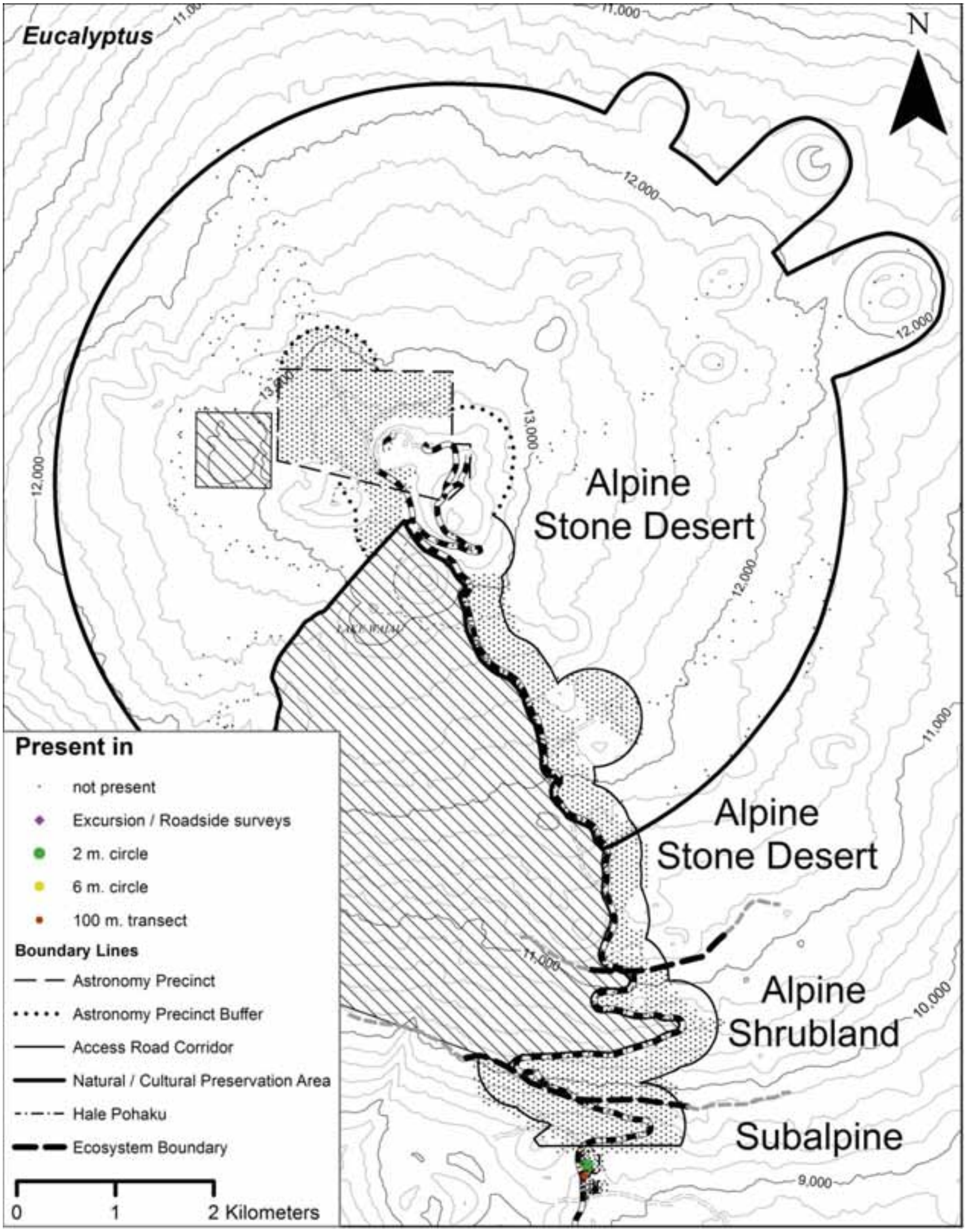

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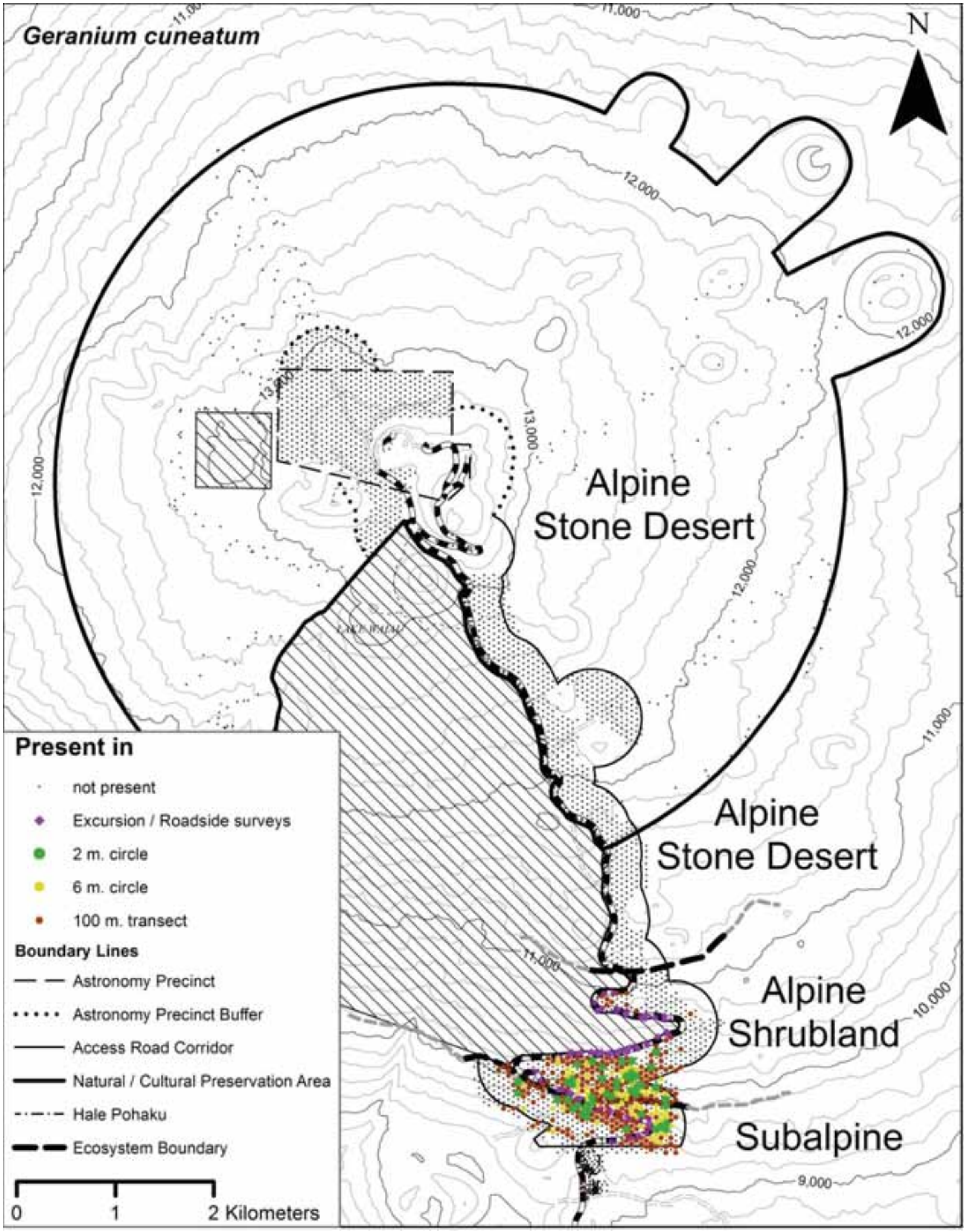


Figure APP-C29. *Geranium cuneatum* **subsp.** *hololeucum* or *hinahina* (Geraniaceae).

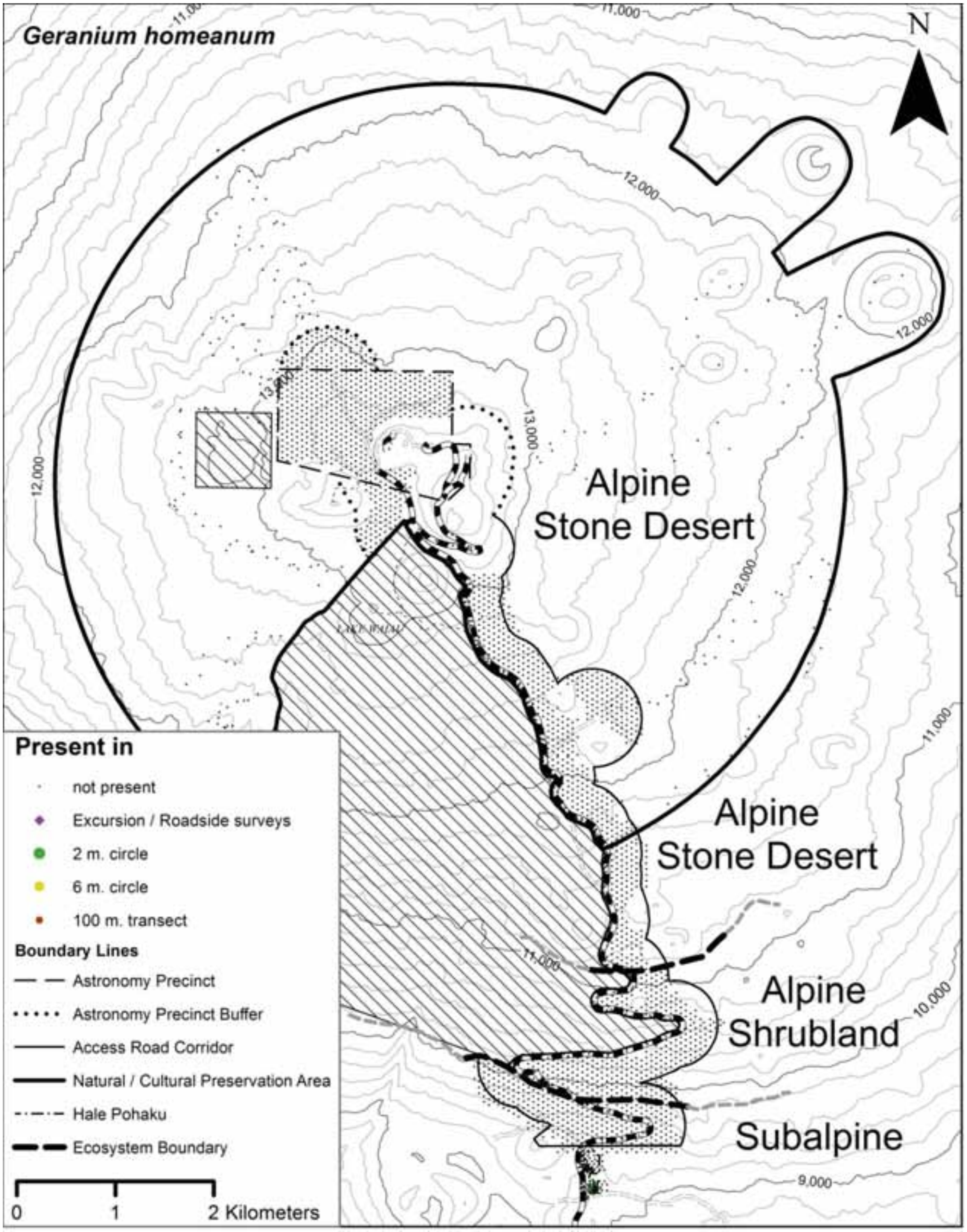


Figure APP-C30. *Geranium homeanum* or cranesbill (Geraniaceae).

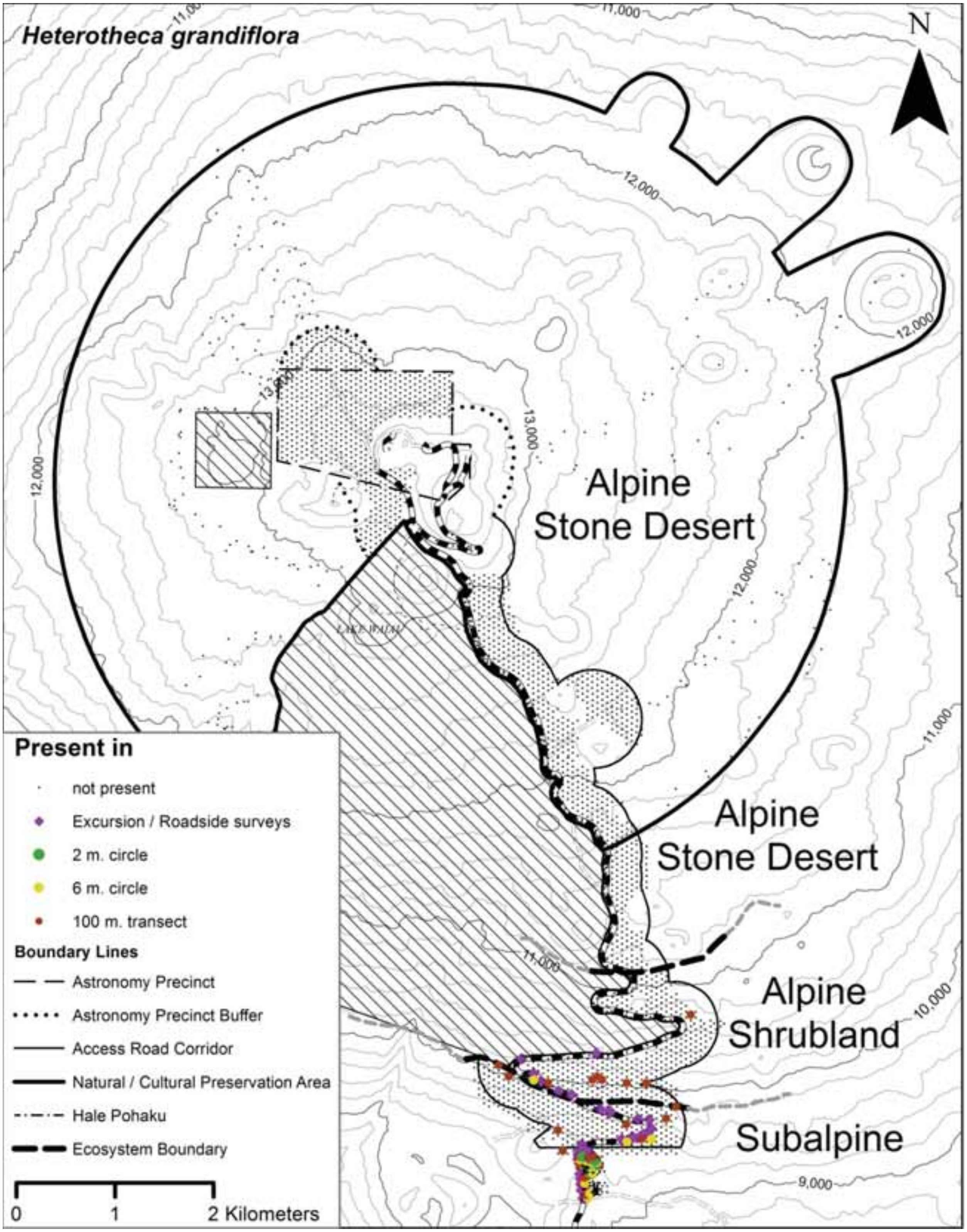
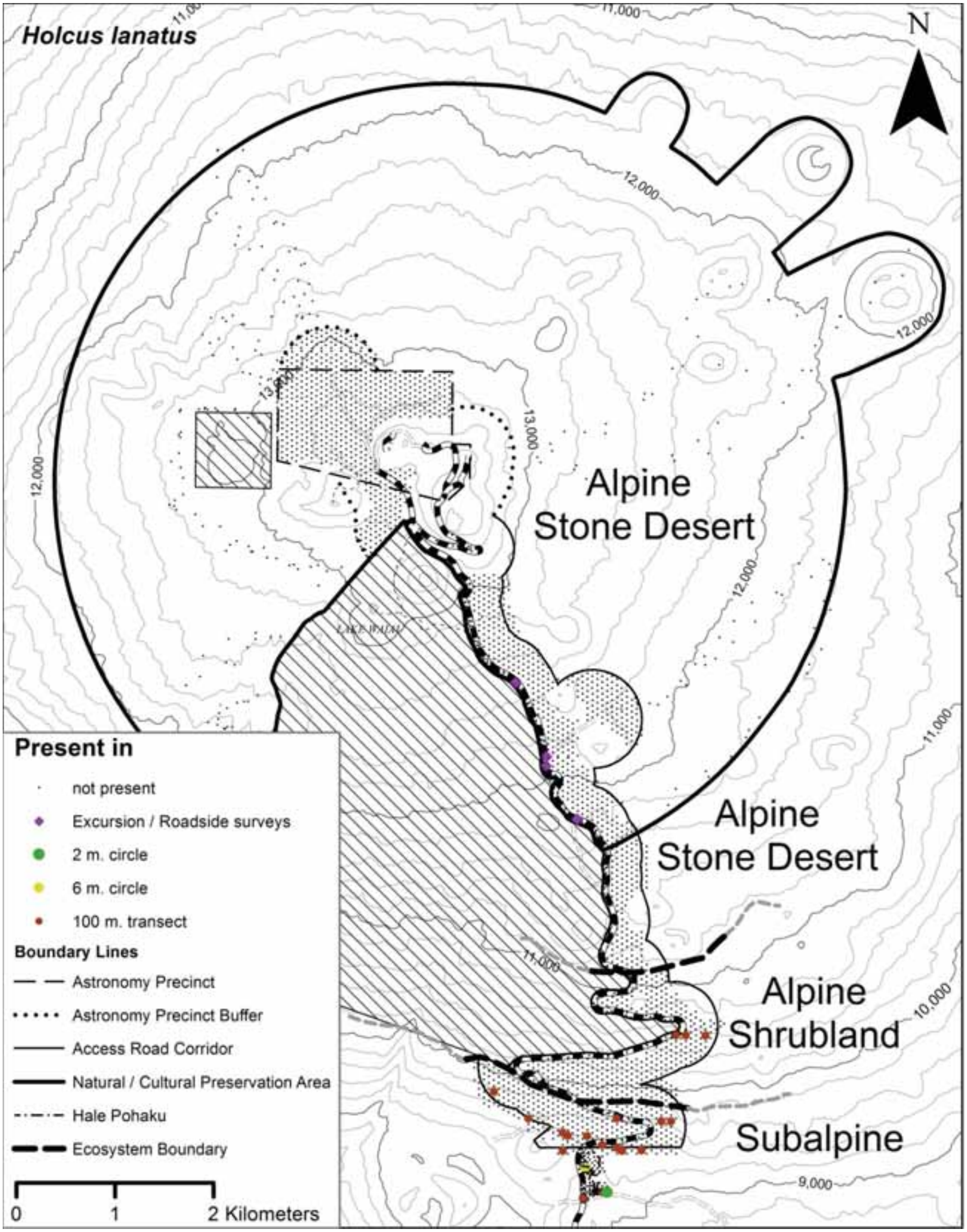


Figure APP-C31. *Heterotheca grandiflora* or telegraph plant (Asteraceae).



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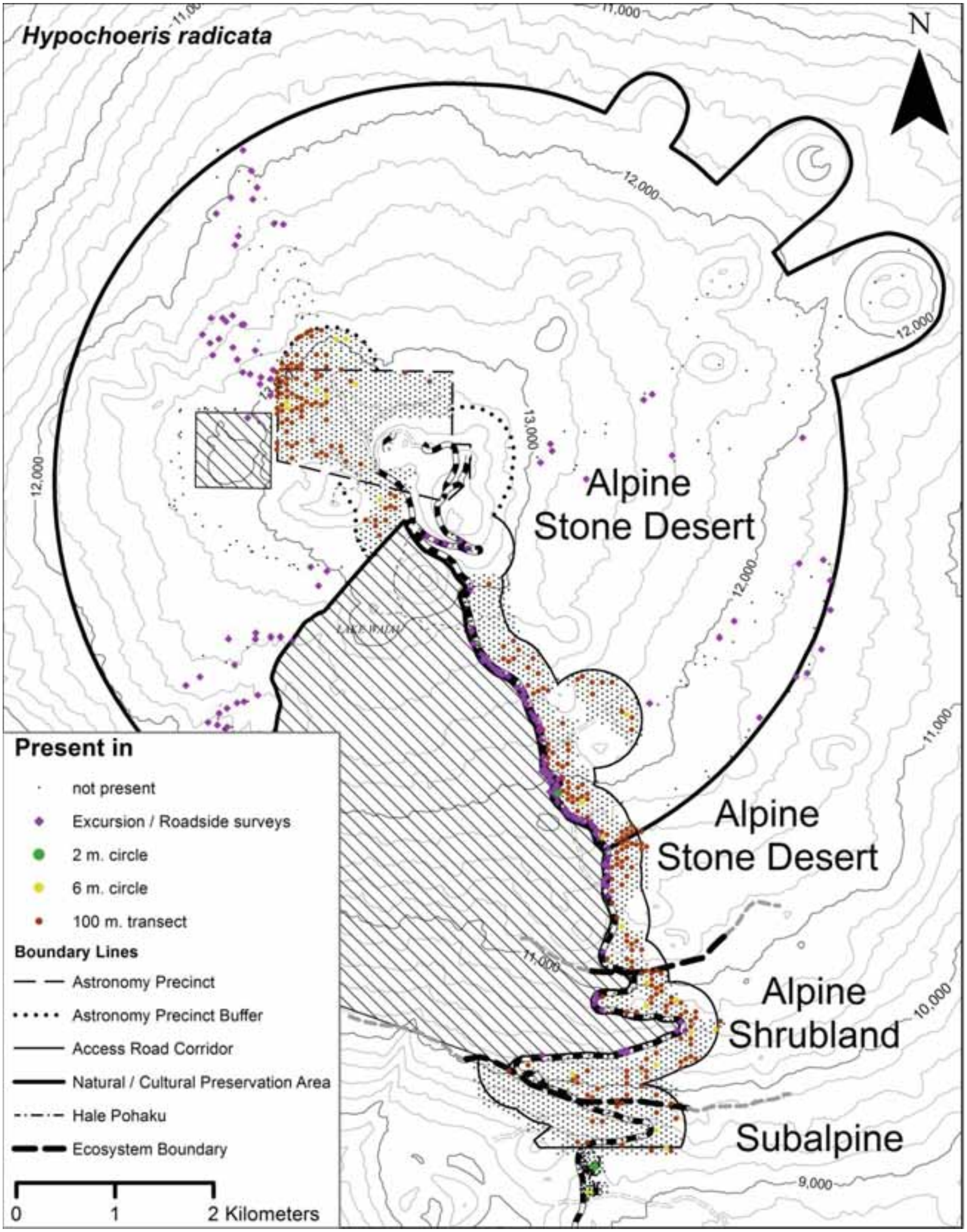

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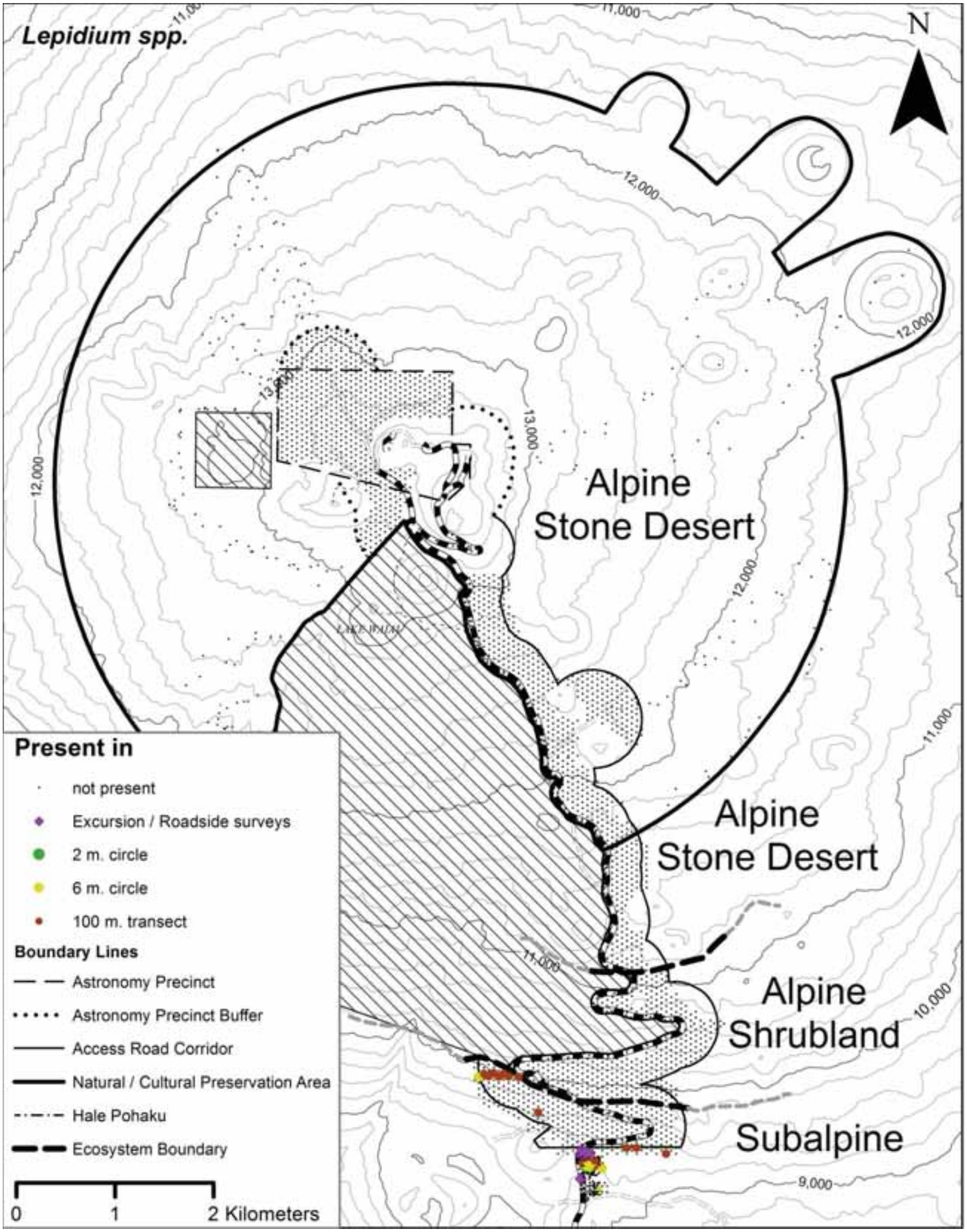

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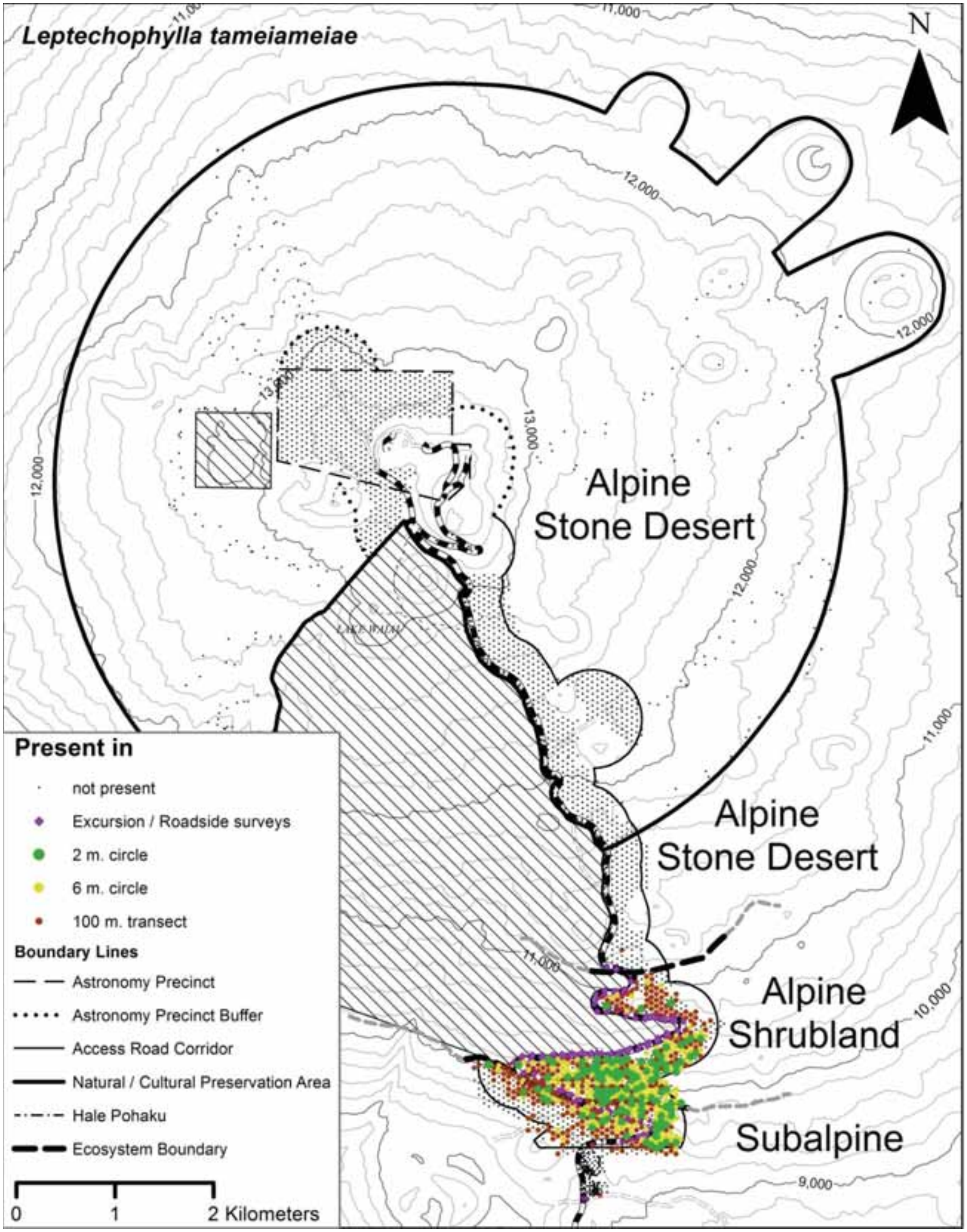

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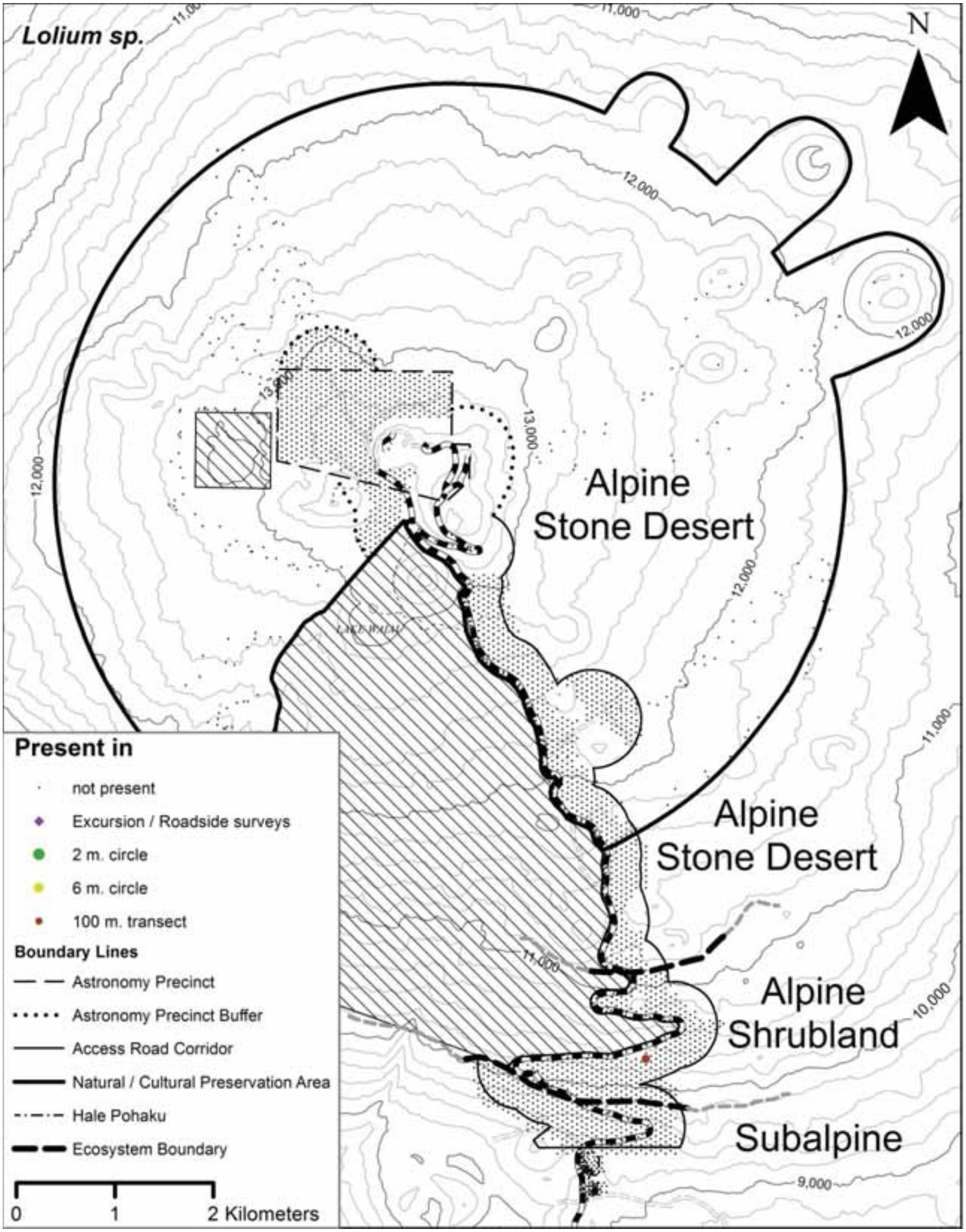


Figure APP-C36. *Lolium sp.* or rye grass (Poaceae).

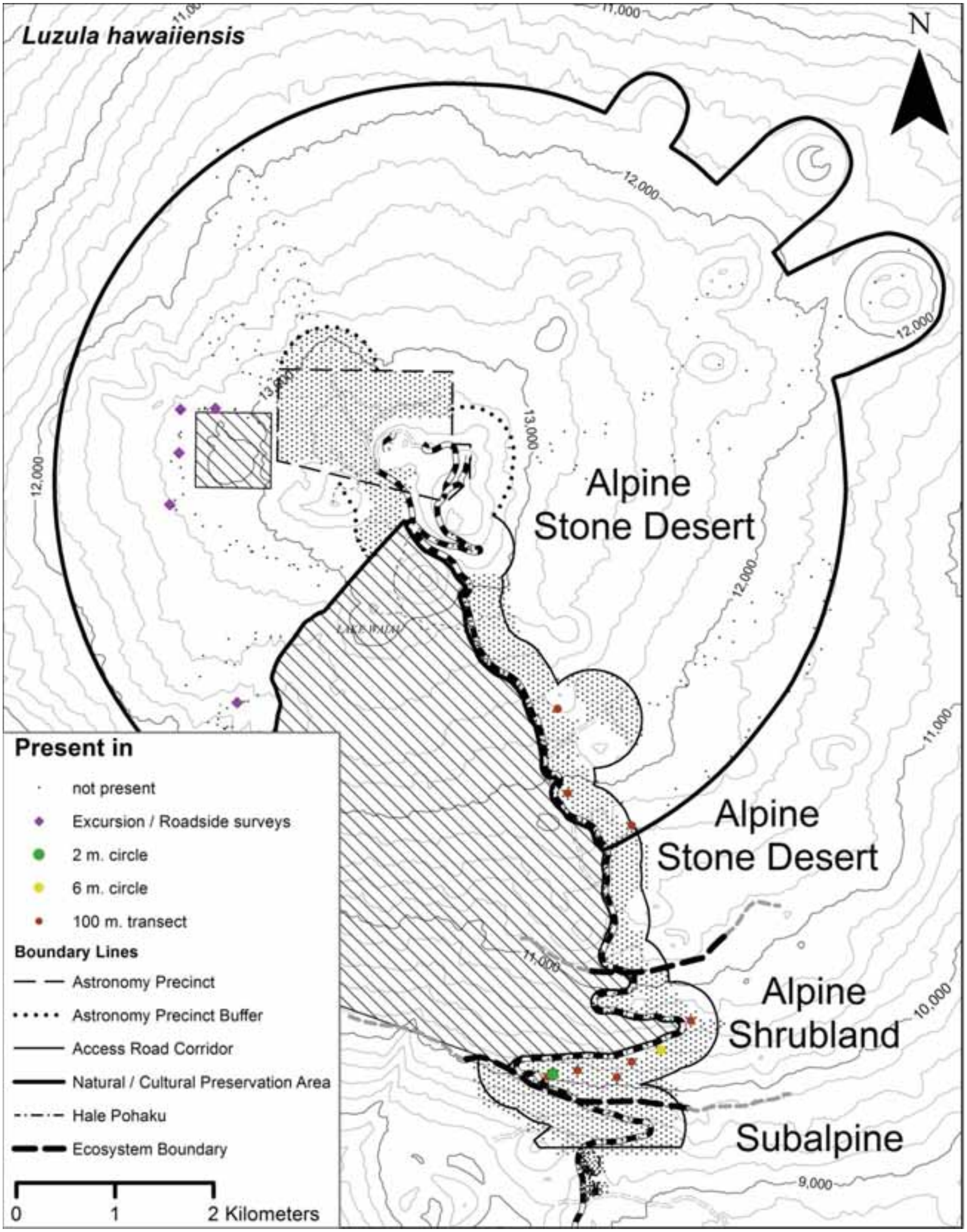
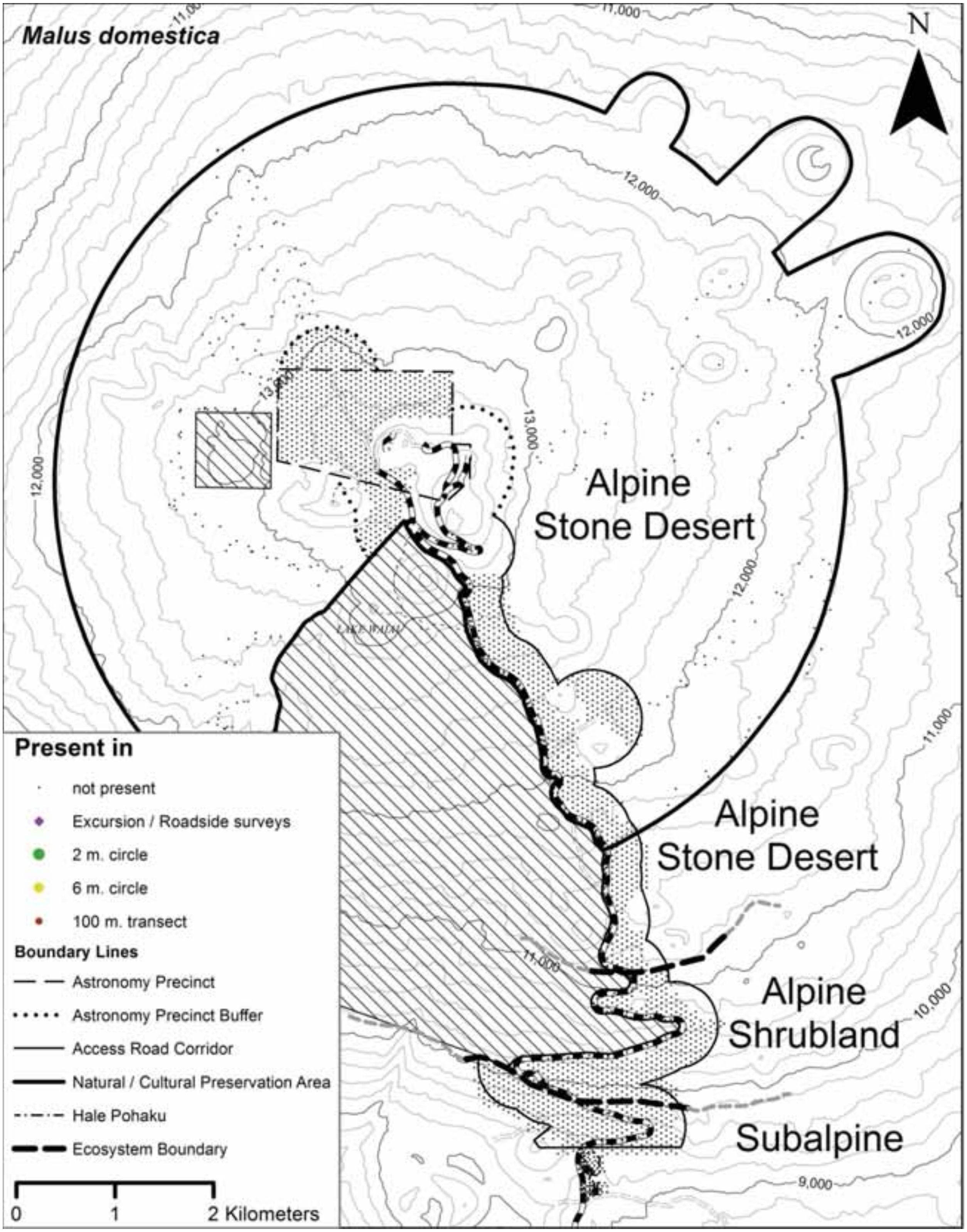


Figure APP-C37. *Luzula hawaiiensis* **var** *hawaiiensis* or Hawaii wood rush (Cyperaceae).



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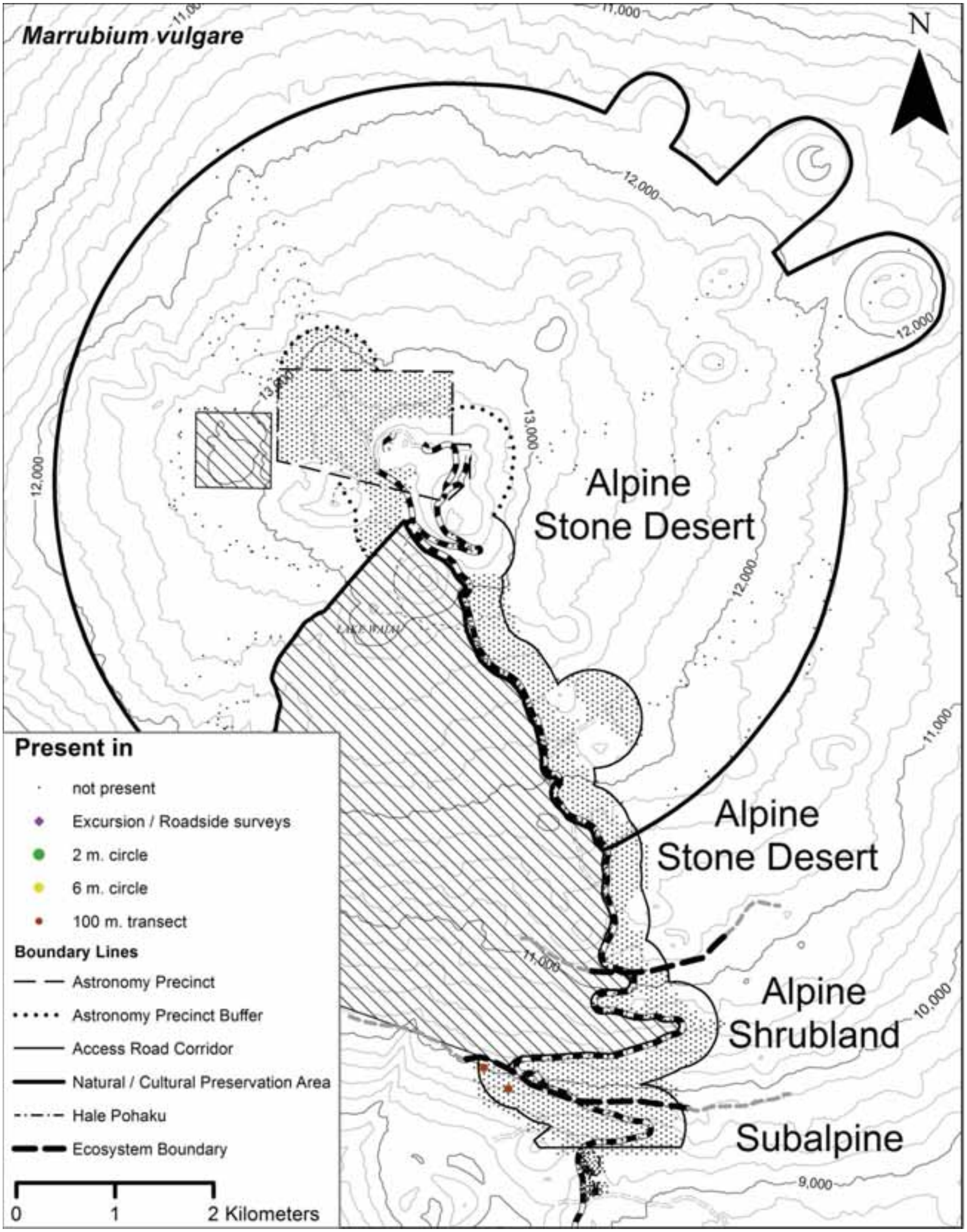


Figure APP-C39. *Marrubium vulgare* or horehound (Lamiaceae).

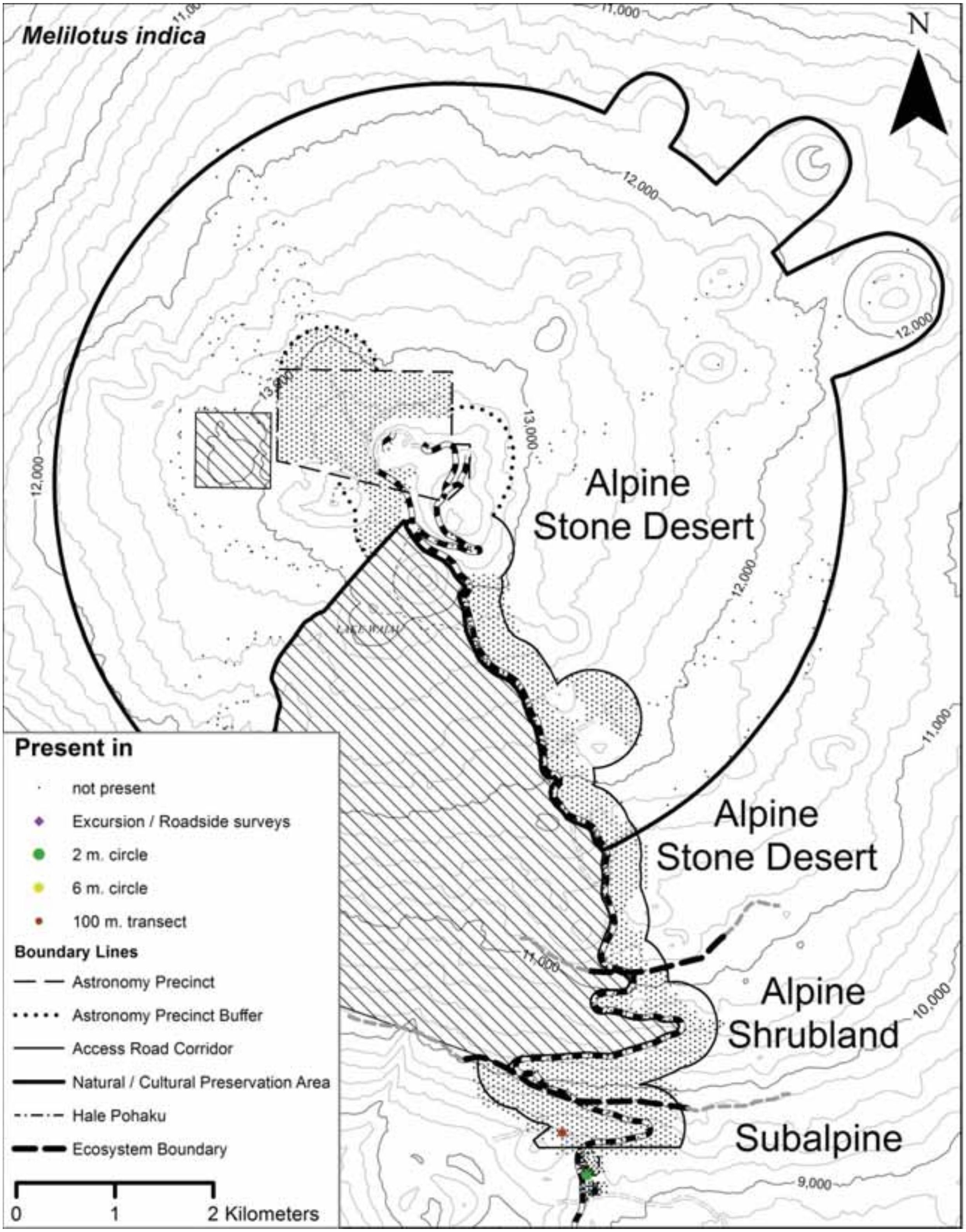


Figure APP-C40. *Melilotus indica* or sweet clover (Fabaceae).

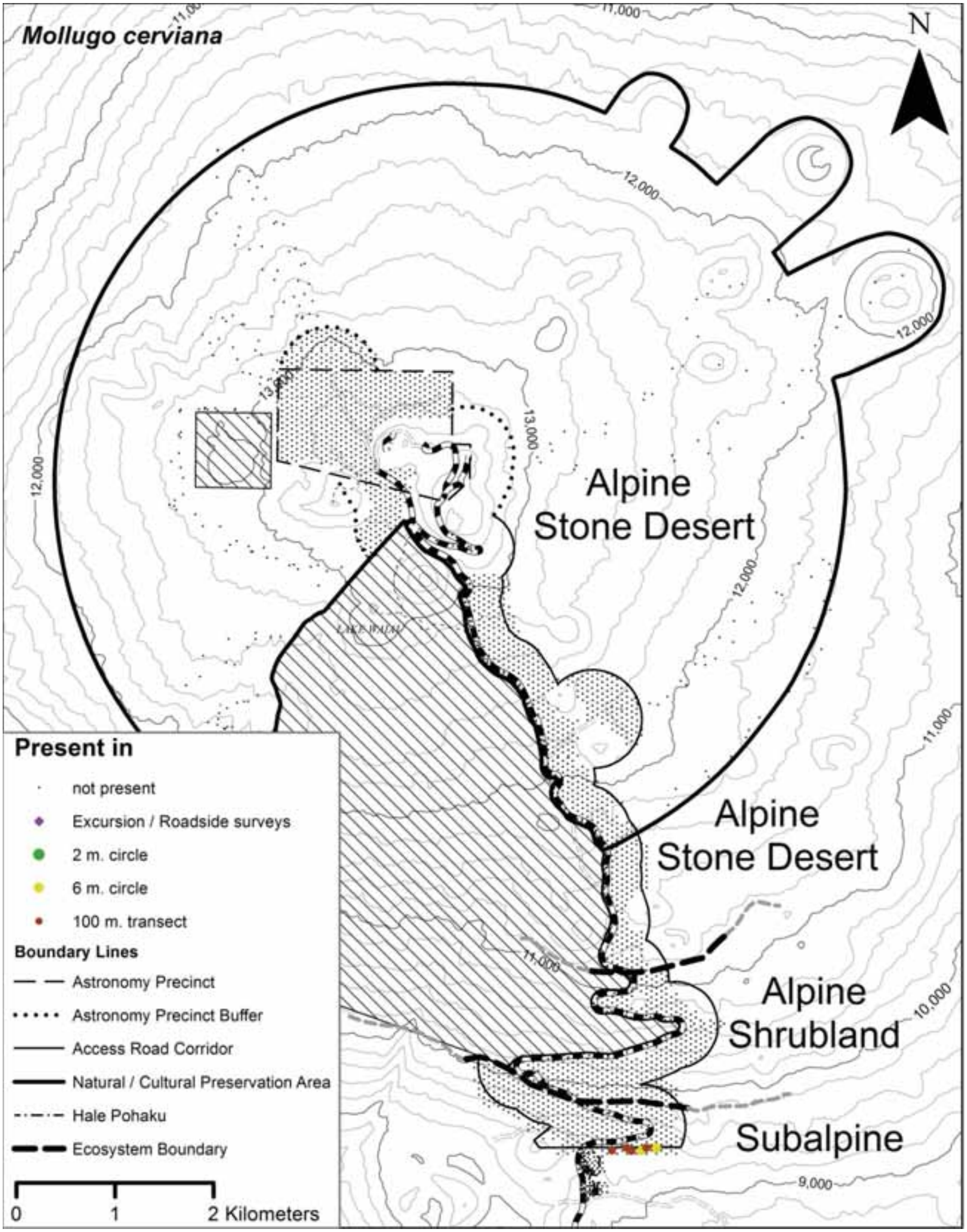


Figure APP-C41. *Mollugo cerviana* or carpetweed (Molluginaceae).

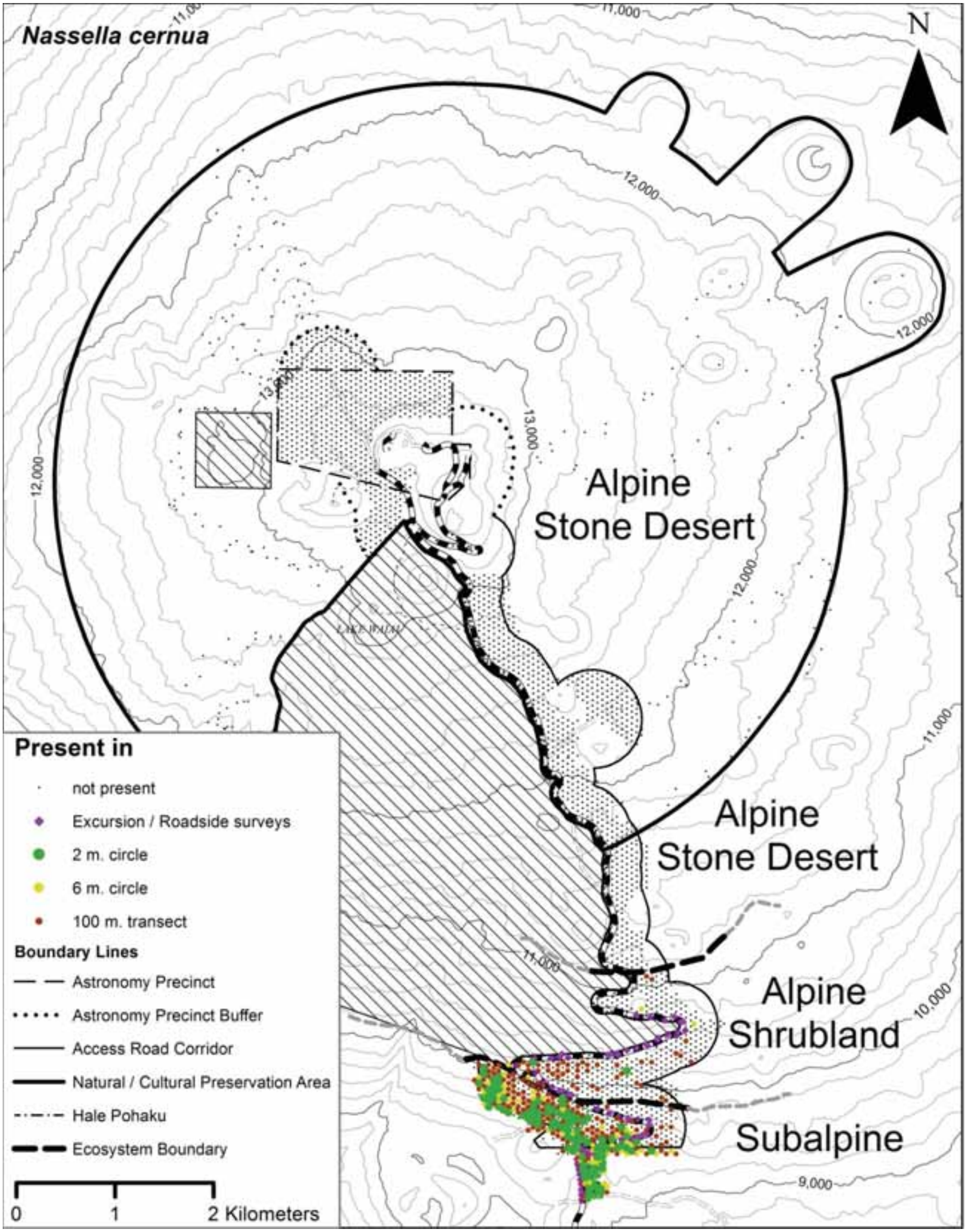


Figure APP-C42. *Nassella cernua* or needlegrass (Poaceae).

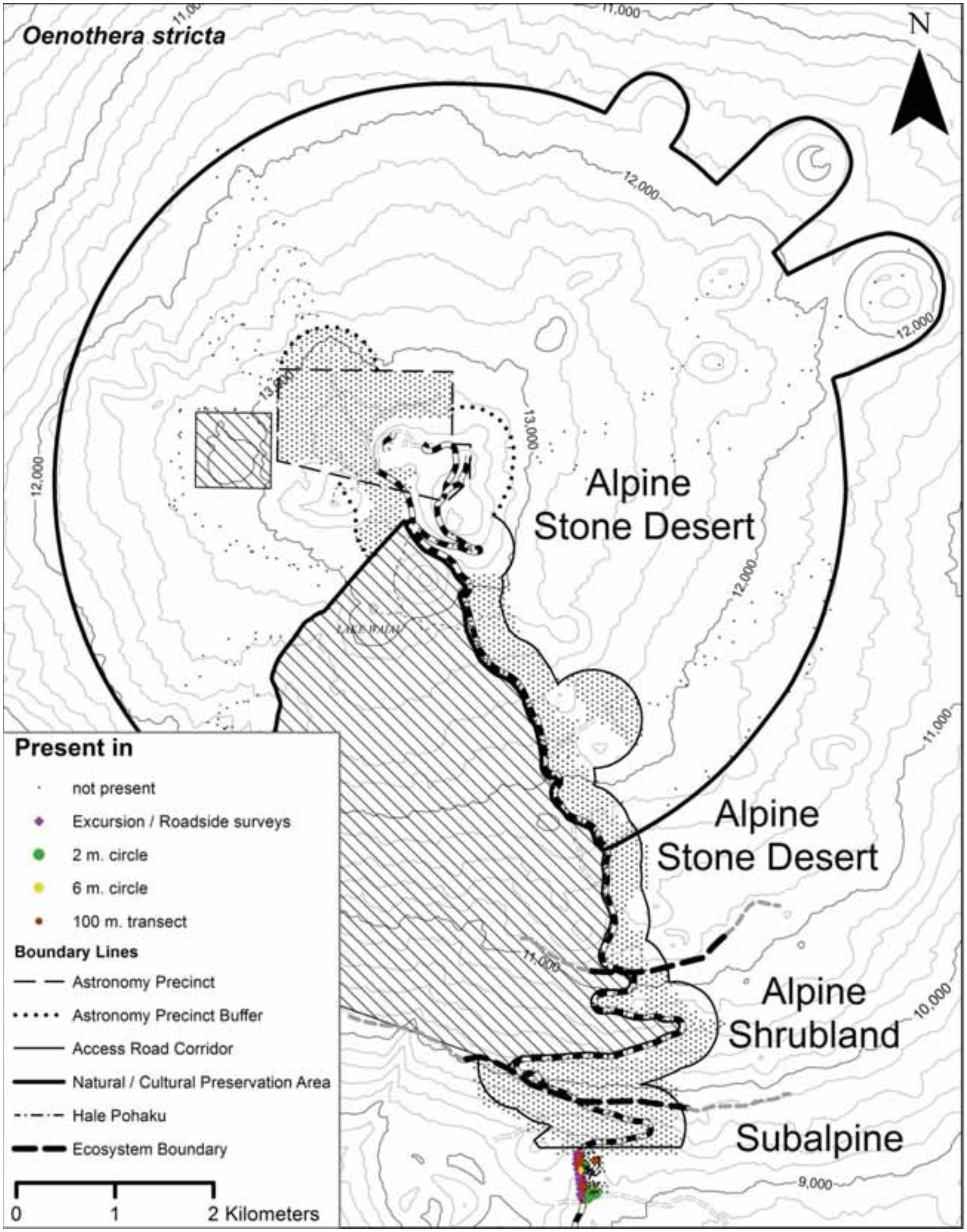


Figure APP-C43. *Oenothera stricta* or Chilean evening primrose (Onagraceae).

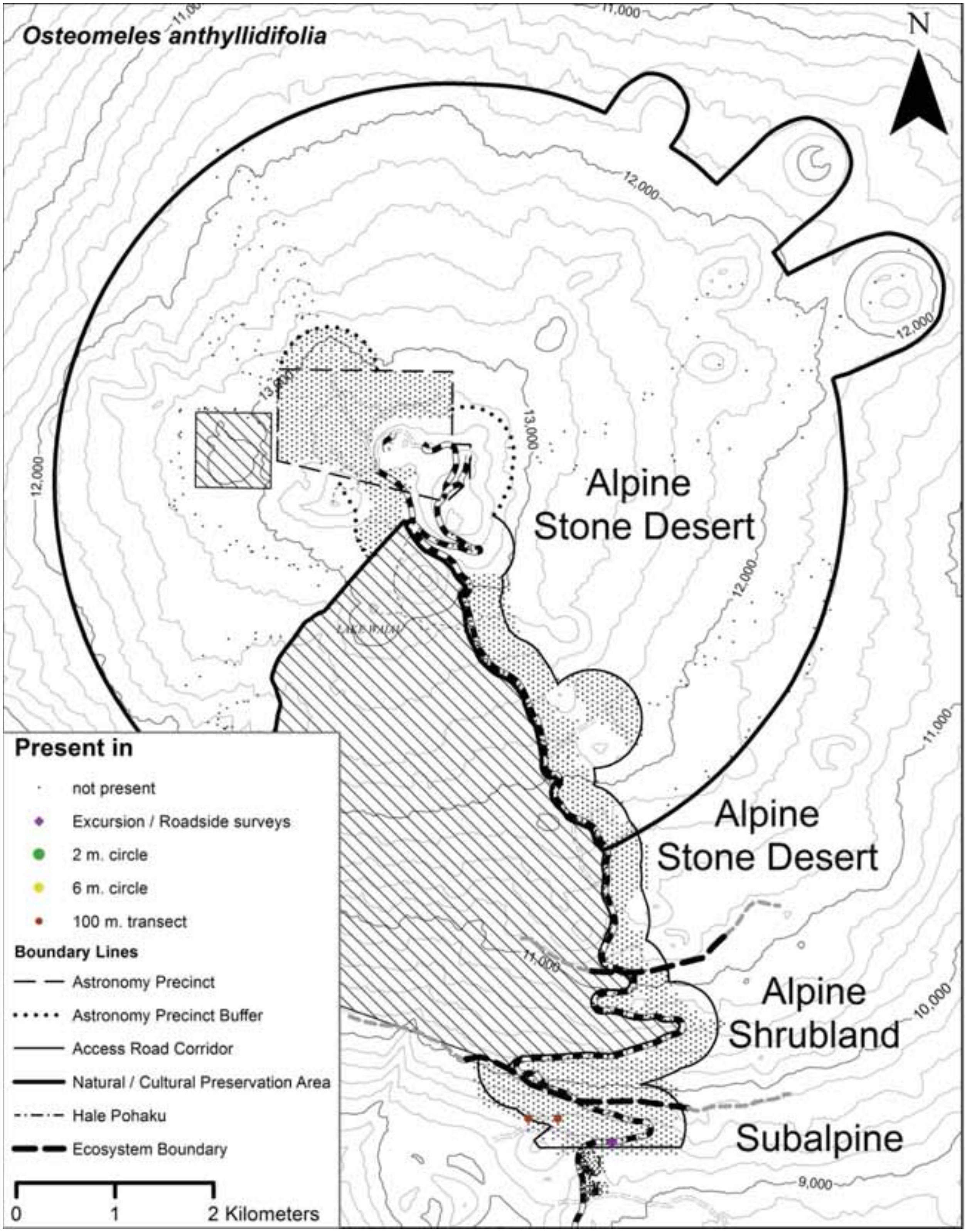


Figure APP-C44. *Osteomeles anthyllidifolia* or *'ūlei* (Rosaceae).

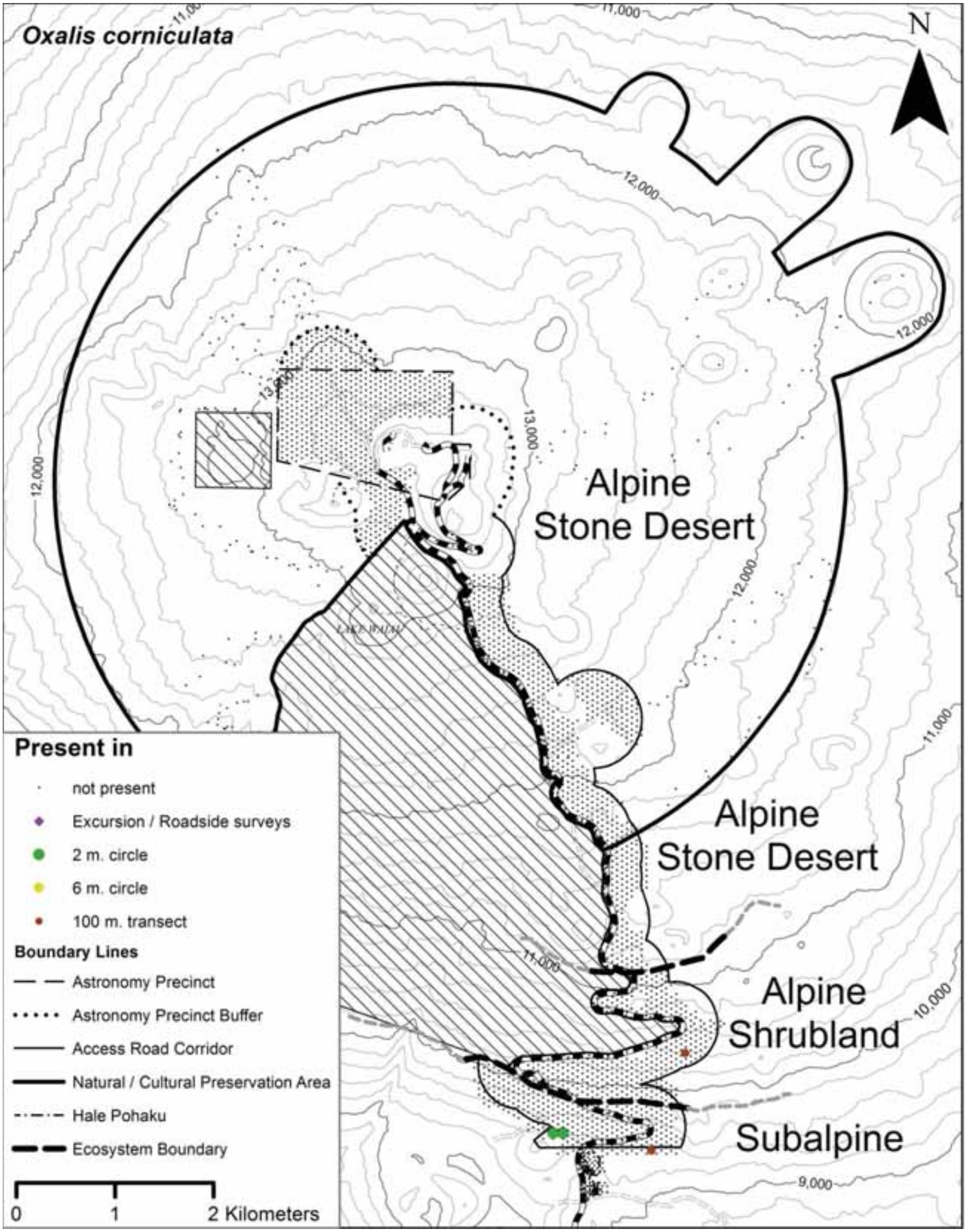
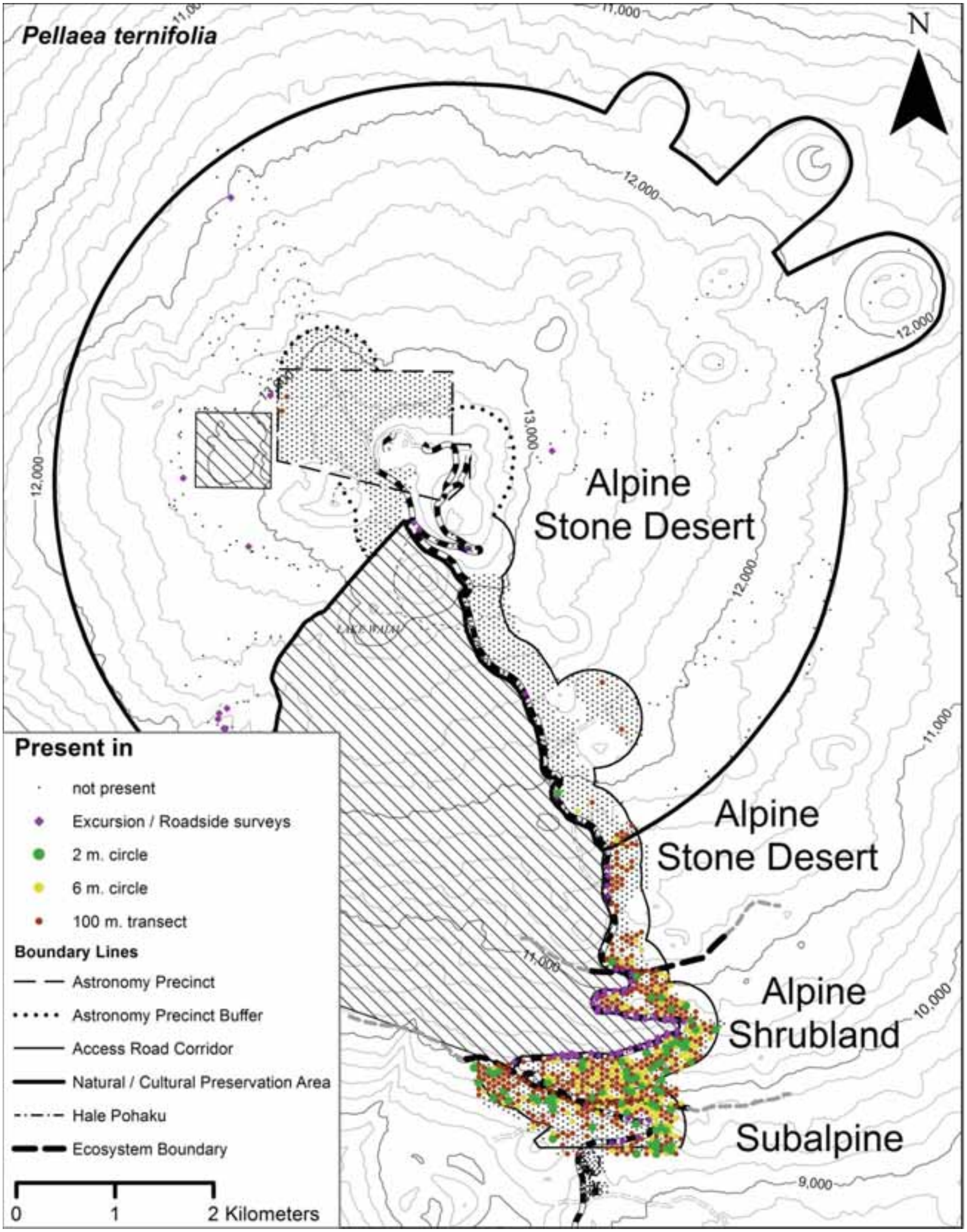


Figure APP-C45. *Oxalis corniculata* or *'ūlei* (Oxalidaceae).



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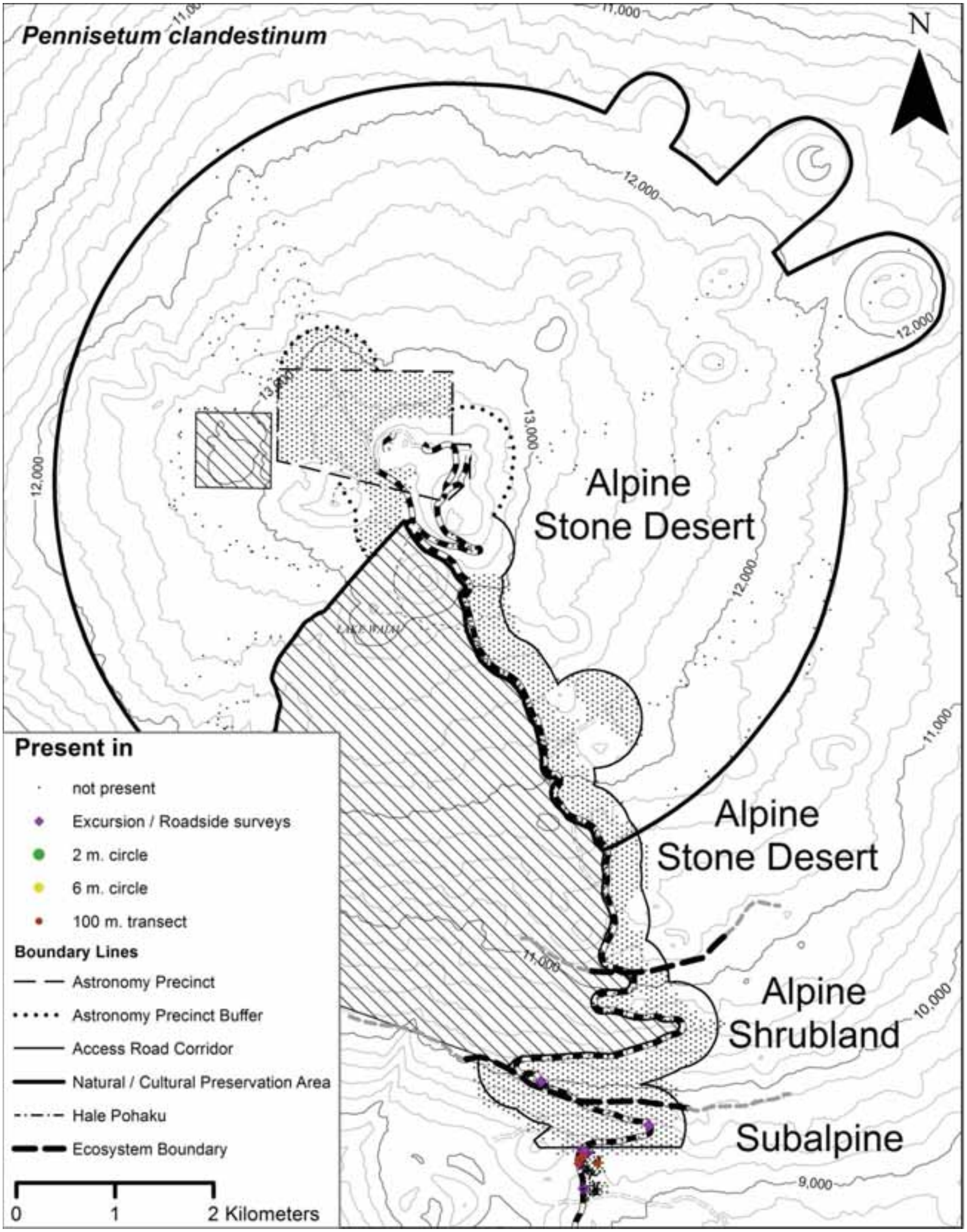

Figure APP-C47. *Pennisetum clandestinum* or kikuyu grass (Poaceae).

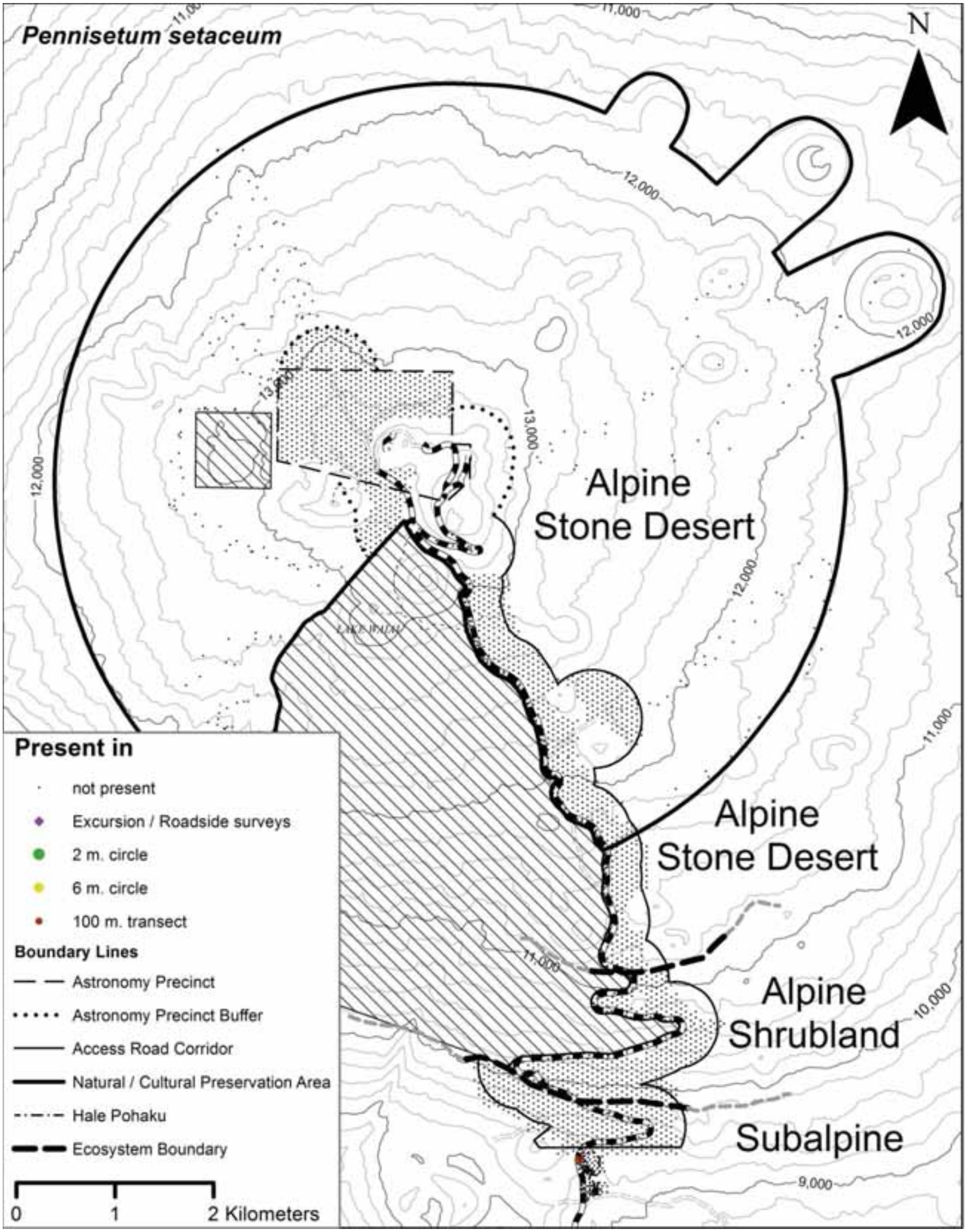

Figure APP-C48. *Pennisetum setaceum* or fountain grass (Poaceae).

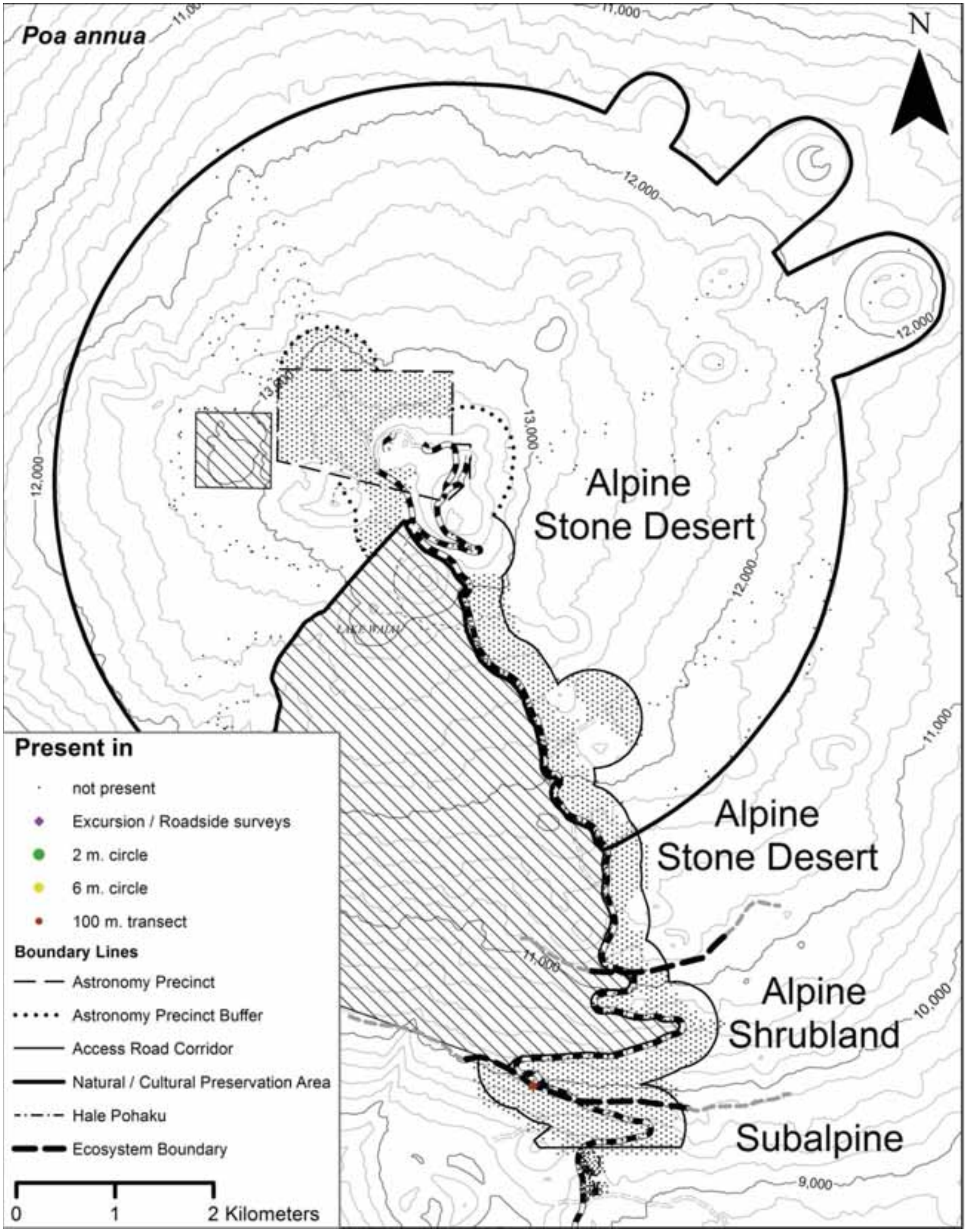

Figure APP-C49. *Poa annua* or annual bluegrass (Poaceae).

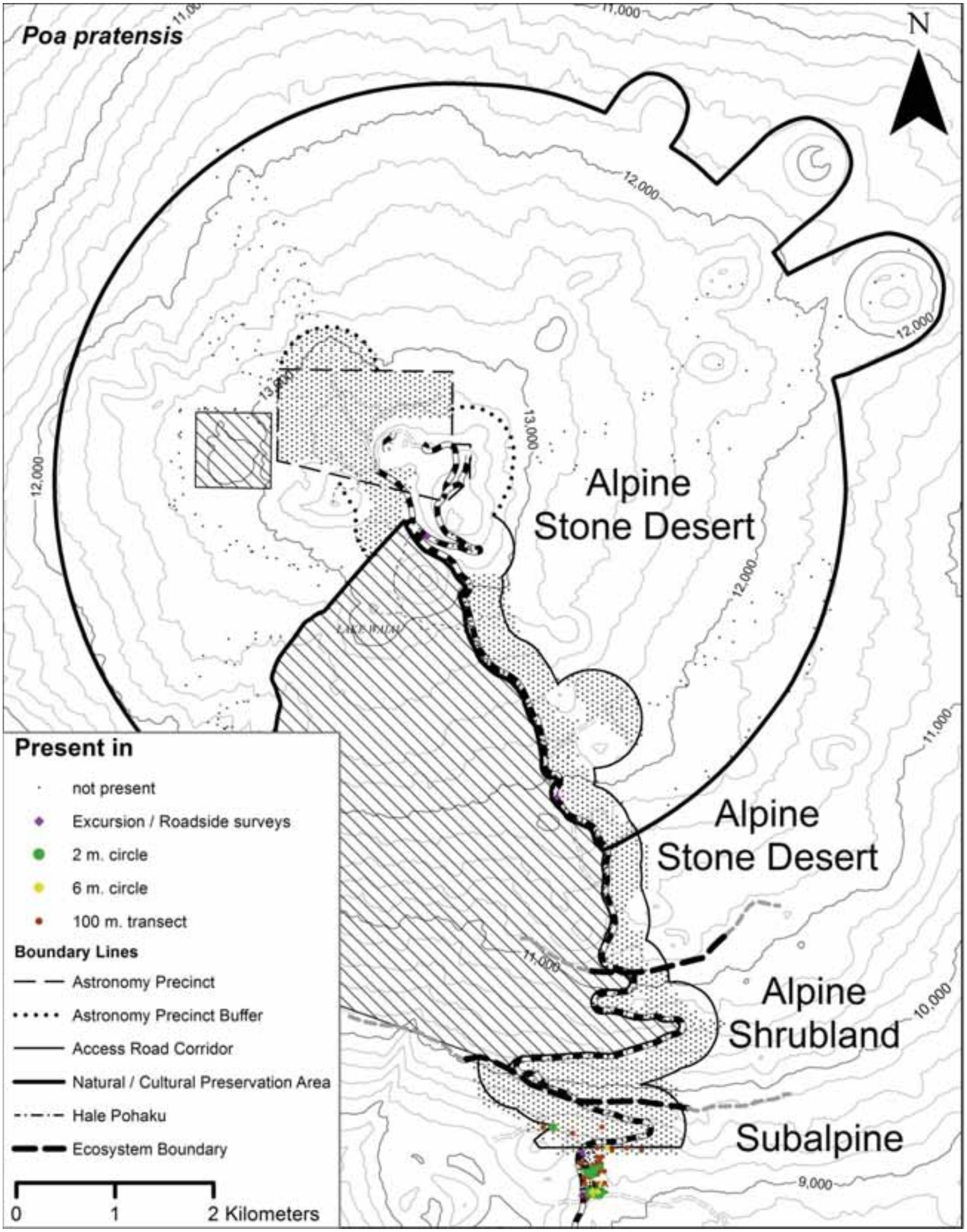

Figure APP-C50. *Poa pratensis* or Kentucky bluegrass (Poaceae).

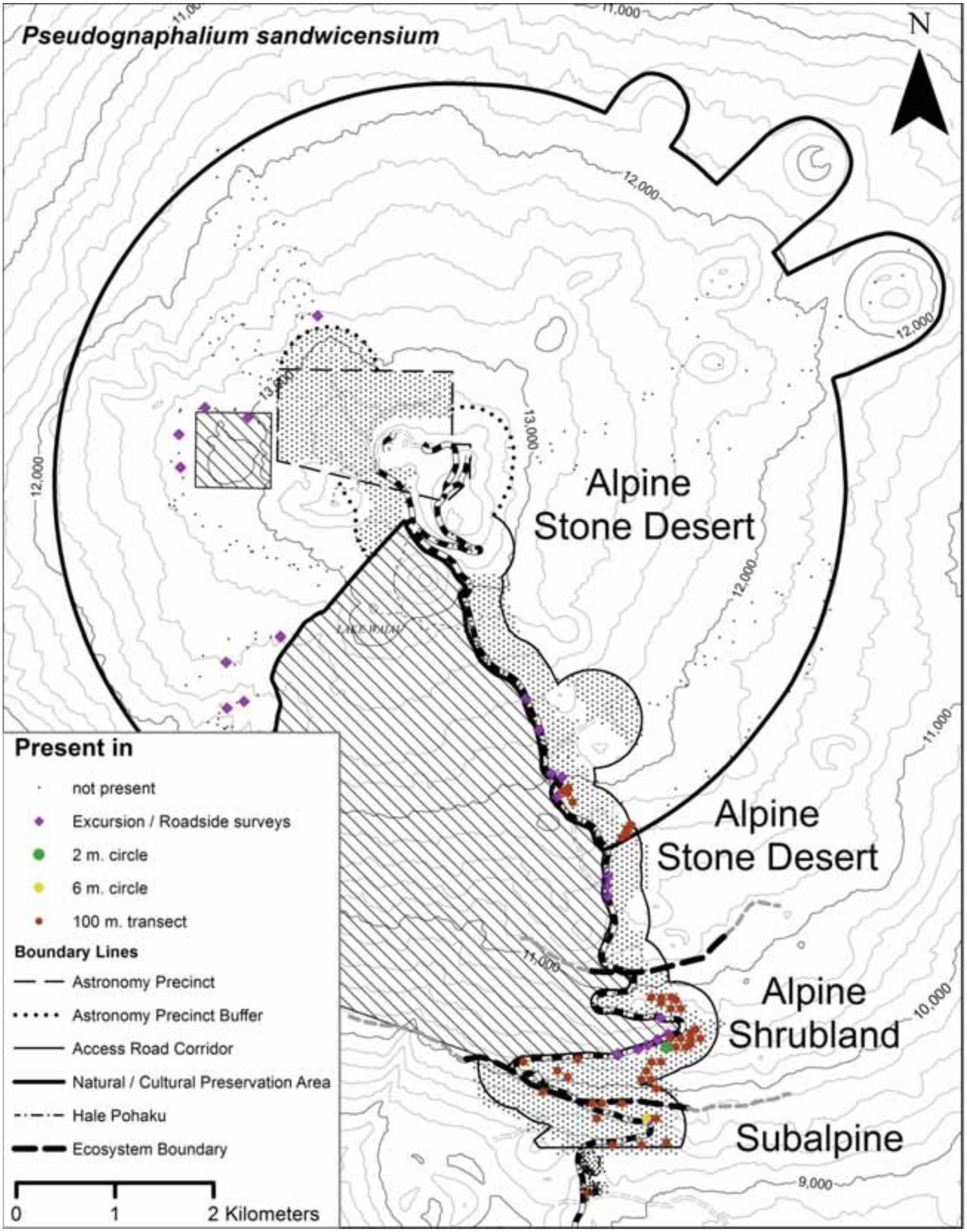

Figure APP-C51. *Pseudognaphalium sandwicensium* or *'ena 'ena* (Asteraceae).

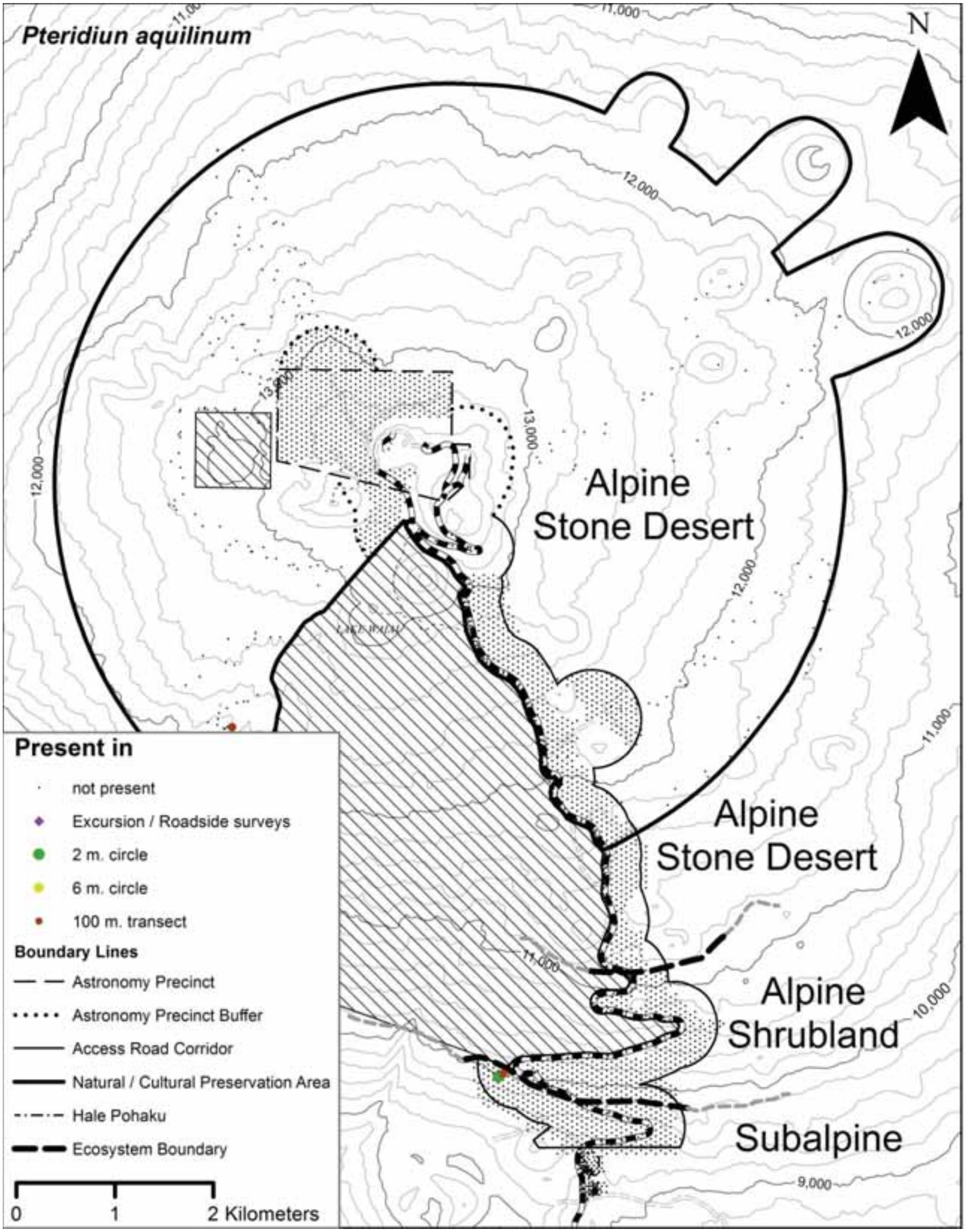

Figure APP-C52. *Pteridium aquilinum* or bracken (Dennstaedtiaceae: Pteridophyta).

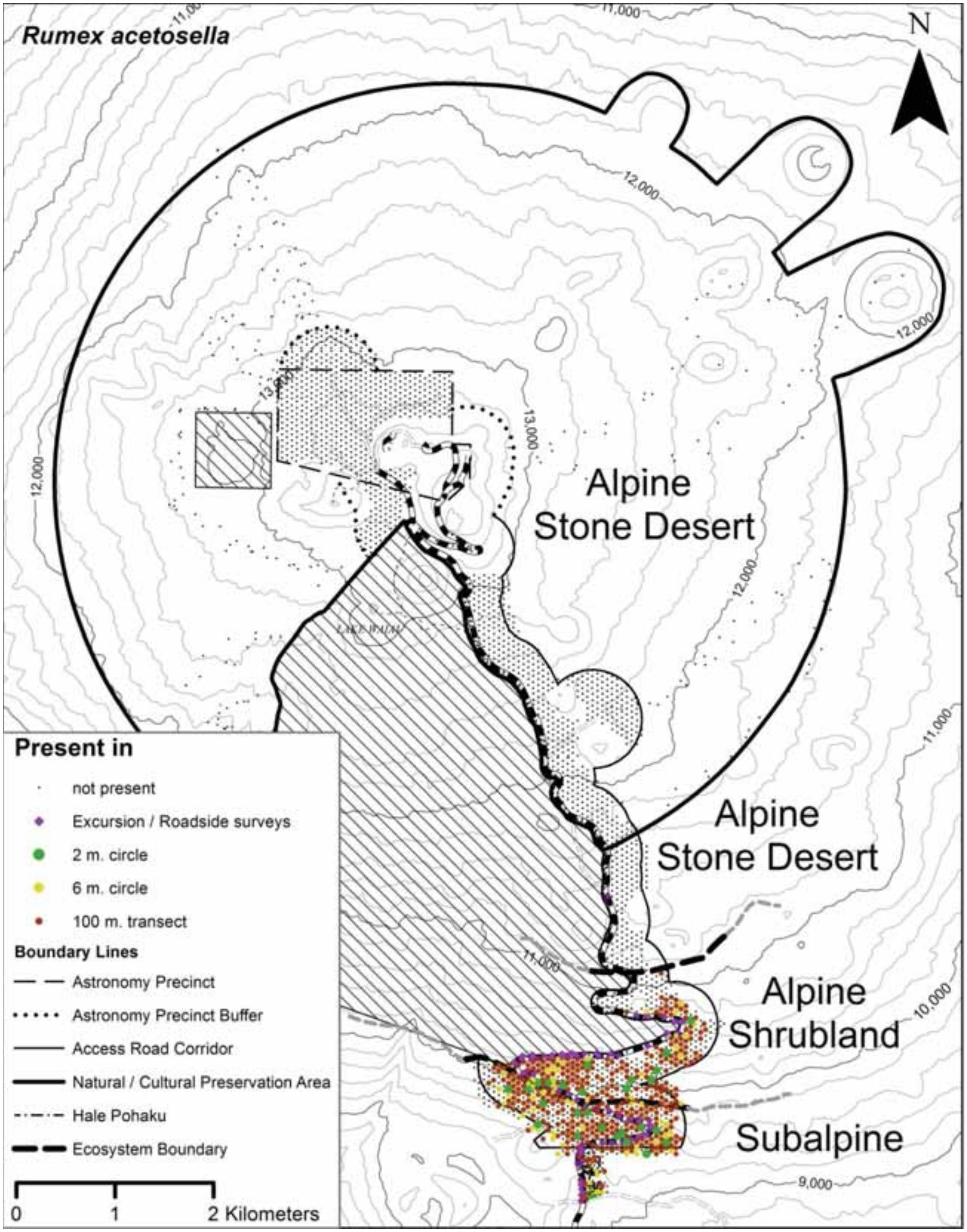

Figure APP-C53. *Rumex acetosella* or sheep sorrel (Polygonaceae).

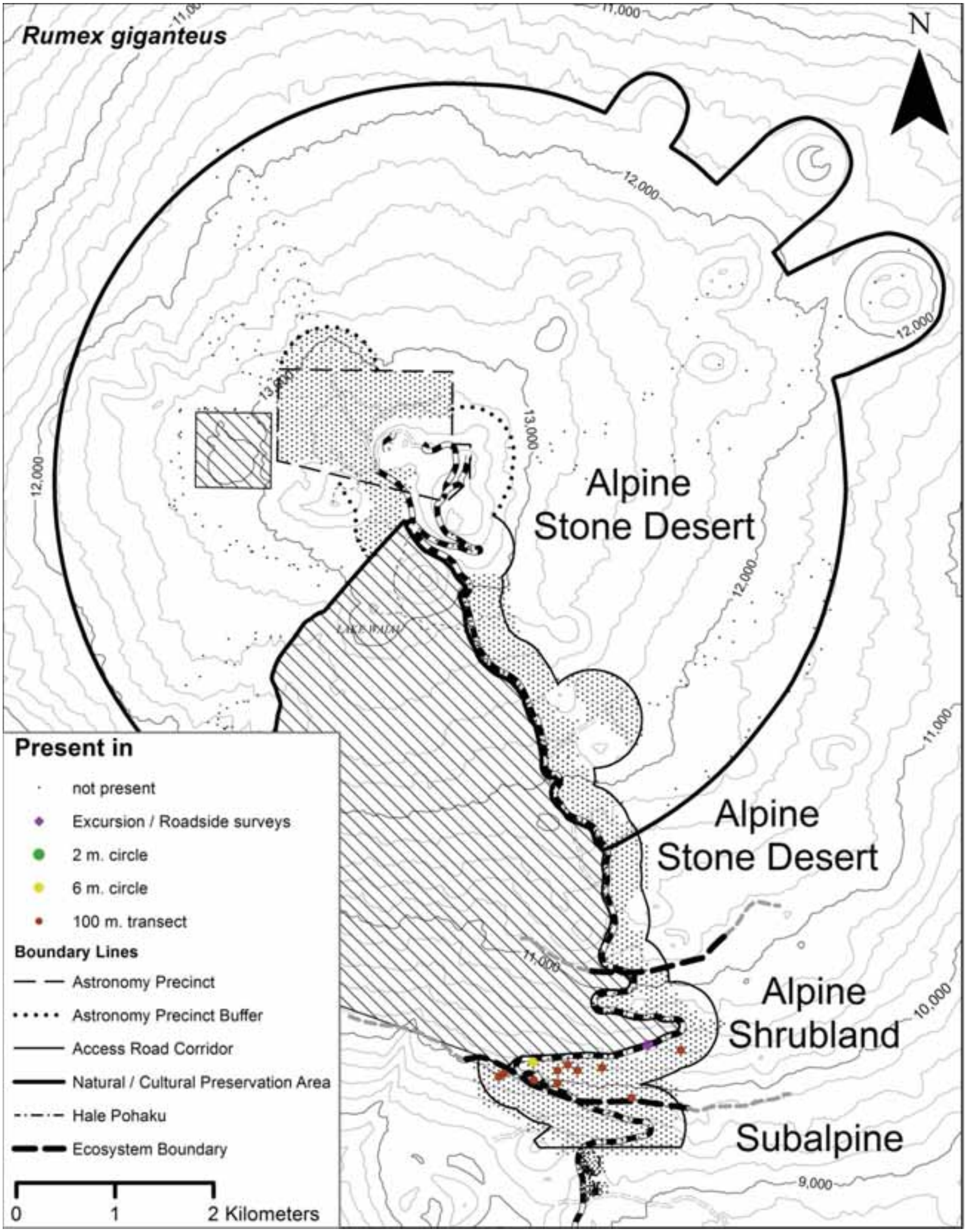

Figure APP-C54. *Rumex giganteus* or *pāwale* (Polygonaceae).

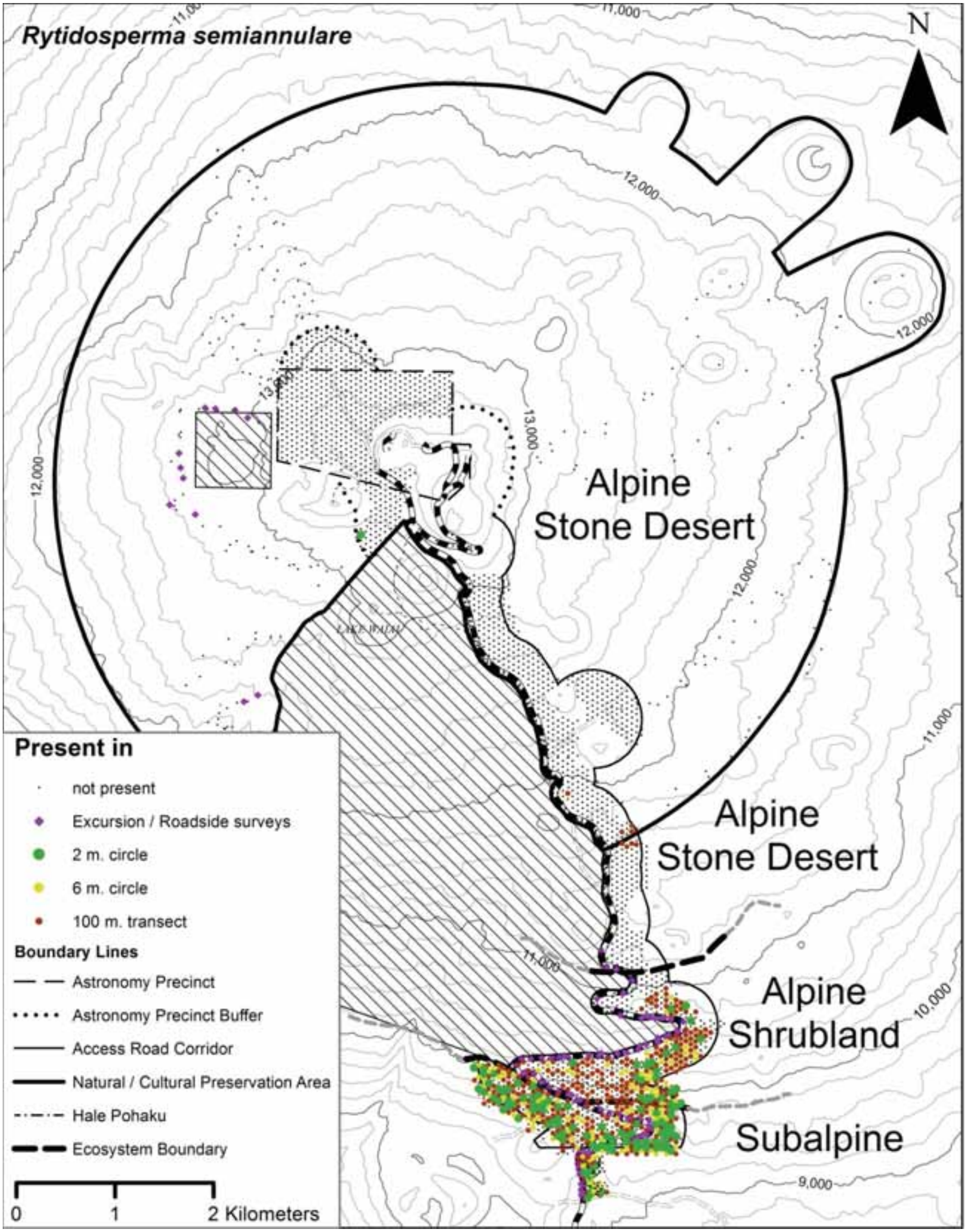

Figure APP-C55. *Rytidosperma semiannulare* or wallaby grass (Poaceae).

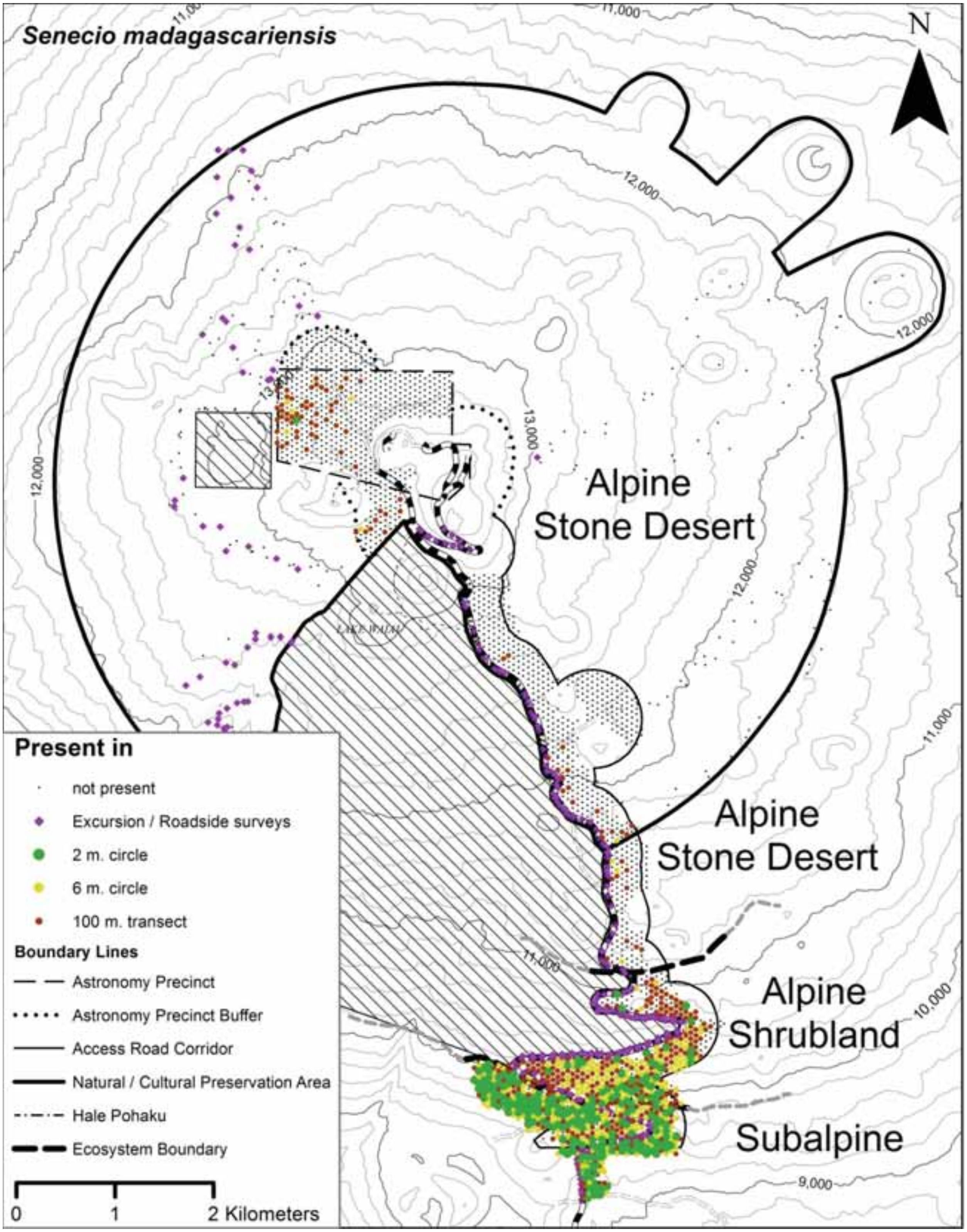

Figure APP-C56. *Senecio madagascariensis* or fireweed (Asteraceae).

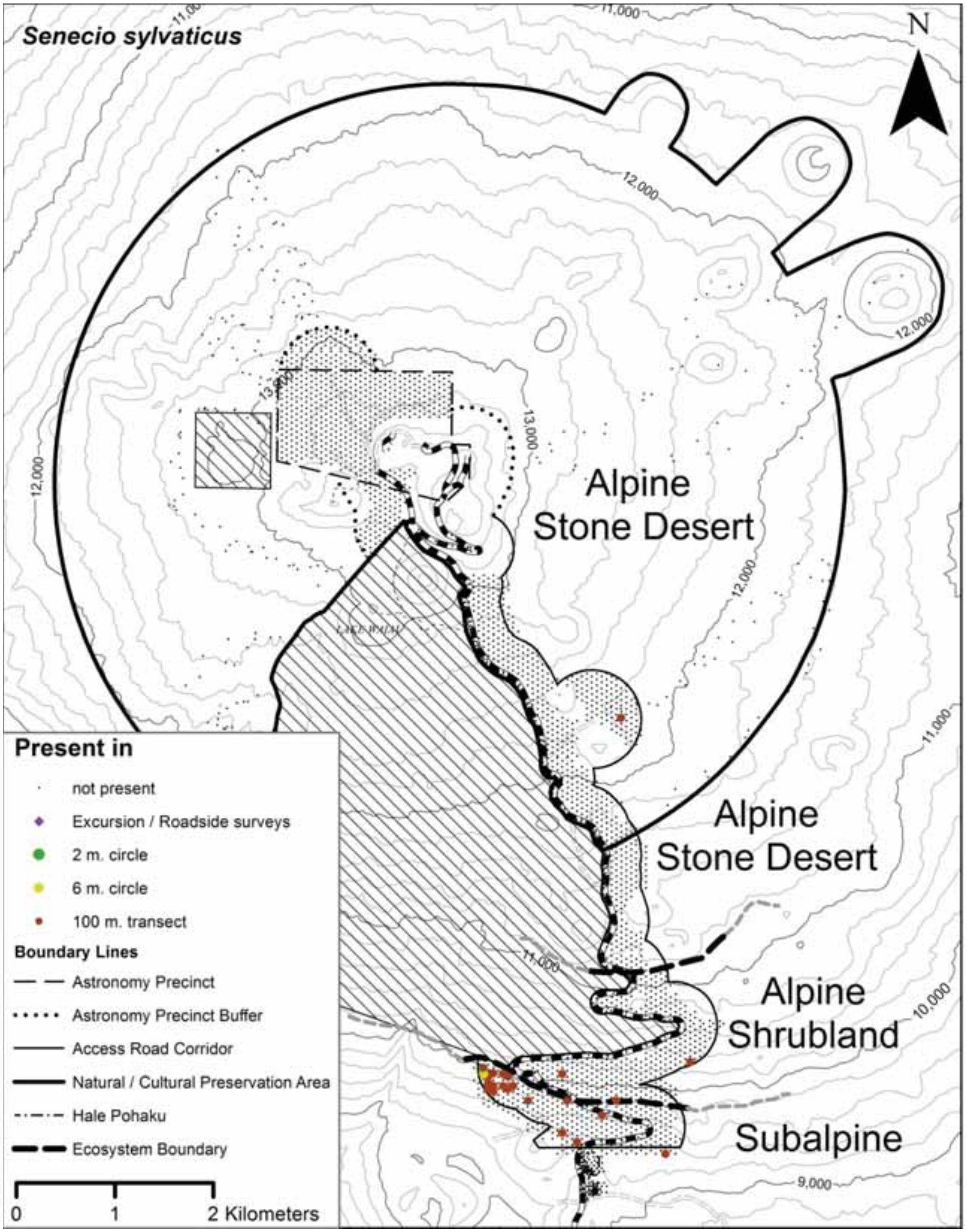

Figure APP-C57. *Senecio sylvaticus* or woodland groundsel (Asteraceae).

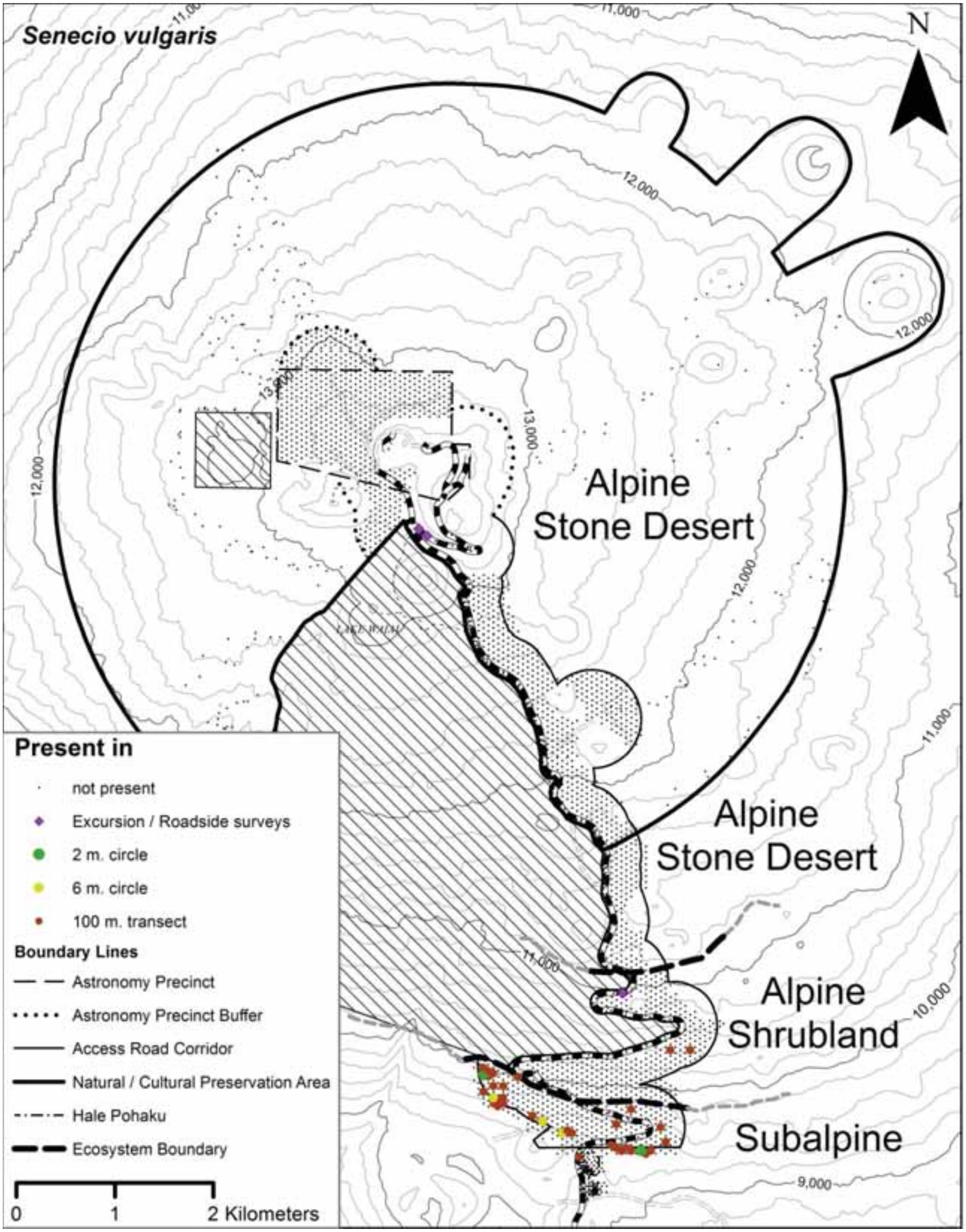

Figure APP-C58. *Senecio vulgaris* or common groundsel (Asteraceae).

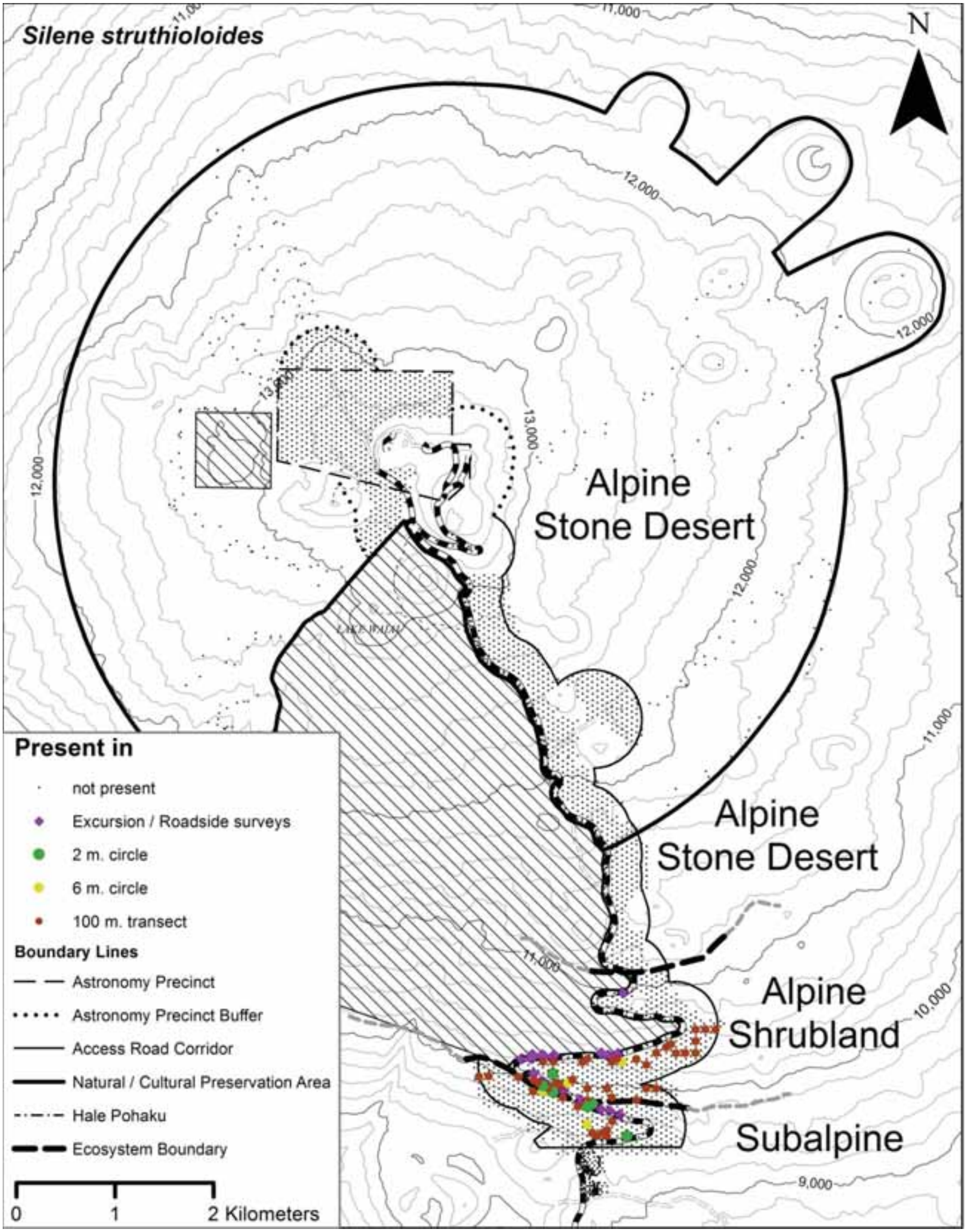

Figure APP-C59. *Silene struthioloides* or alpine catchfly (Caryophyllaceae).

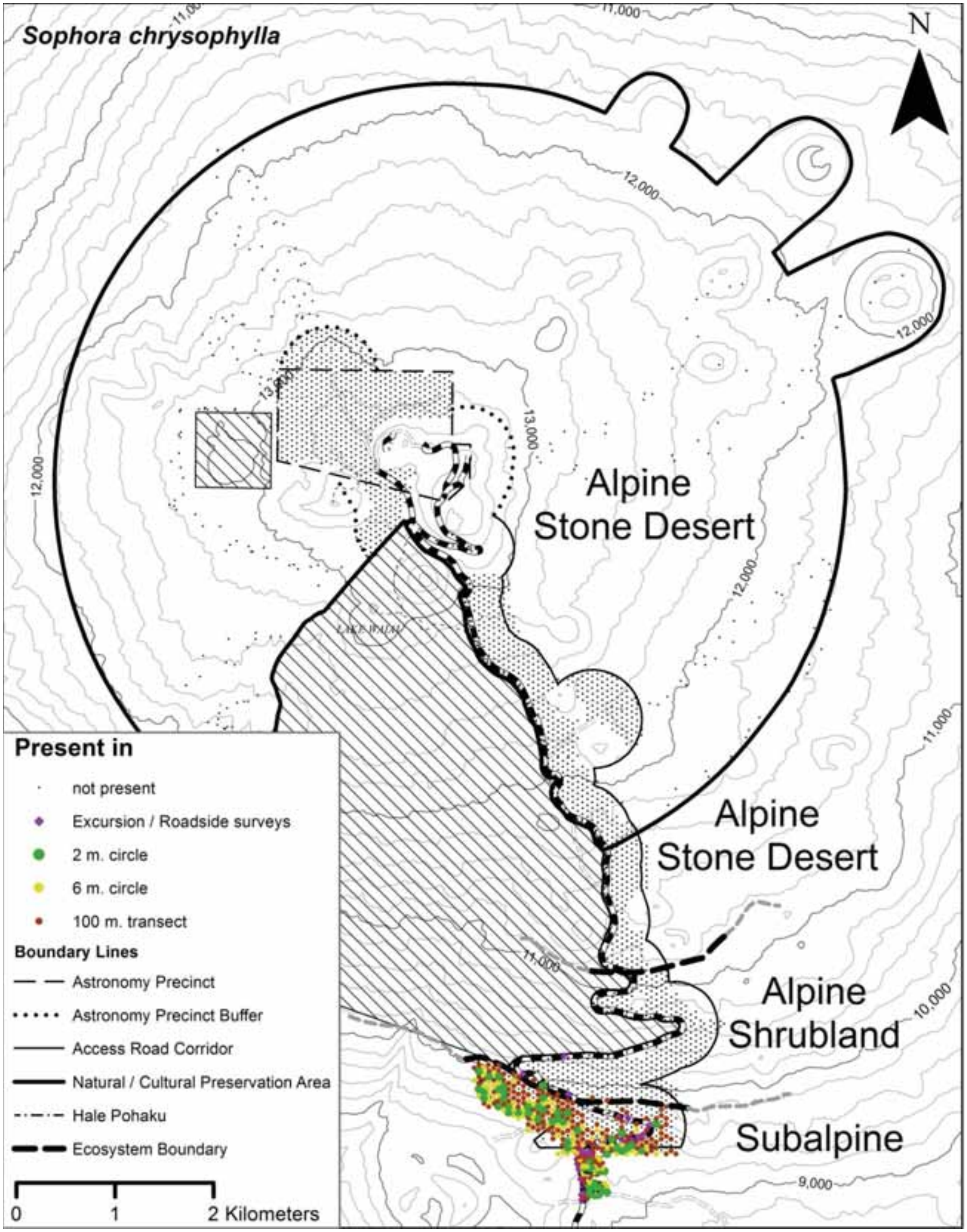

Figure APP-C60. *Sophora chrysophylla* or *māmane* (Fabaceae).

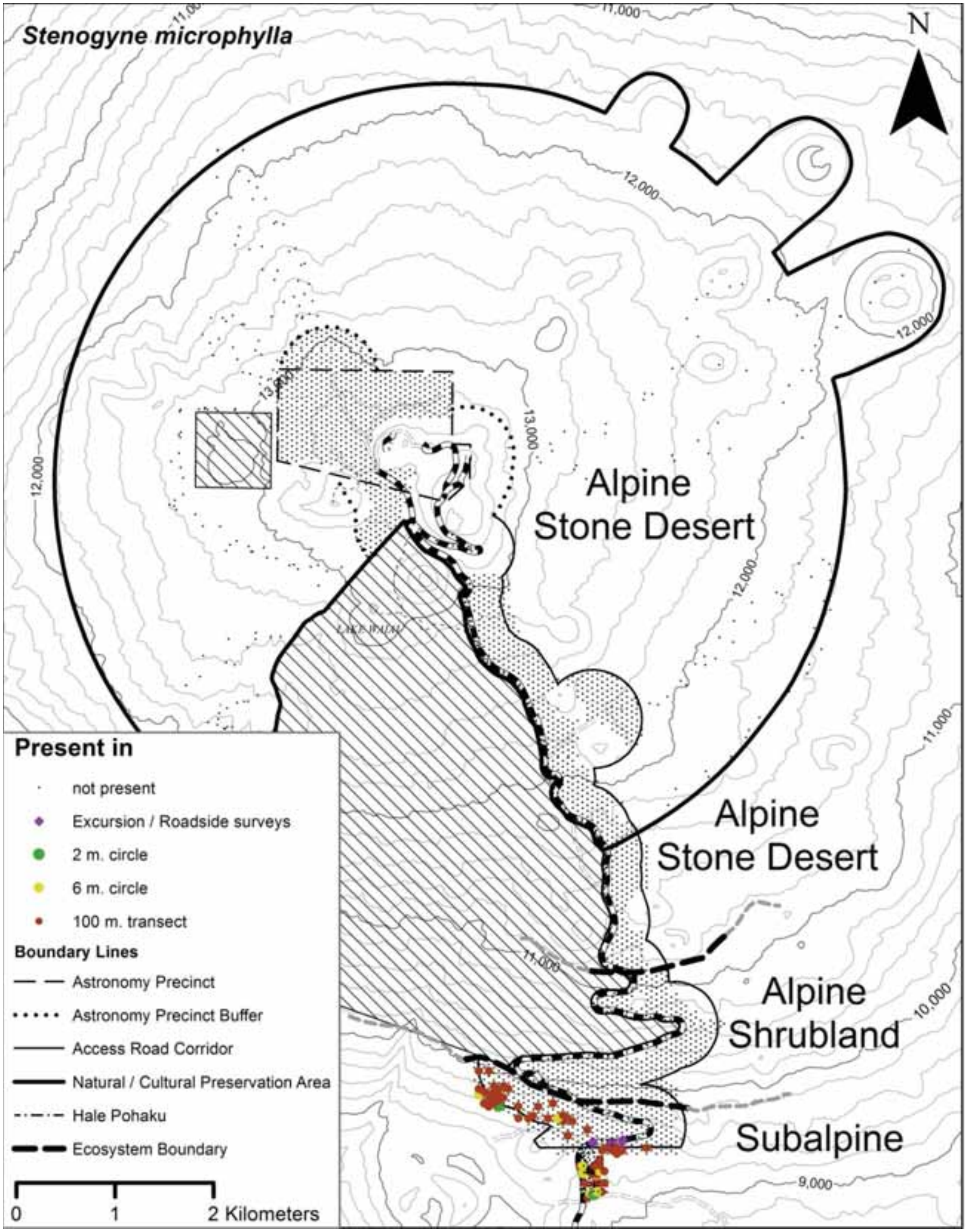

Figure APP-C61. *Stenogyne microphylla* or littleleaf stenogyne (Lamiaceae).

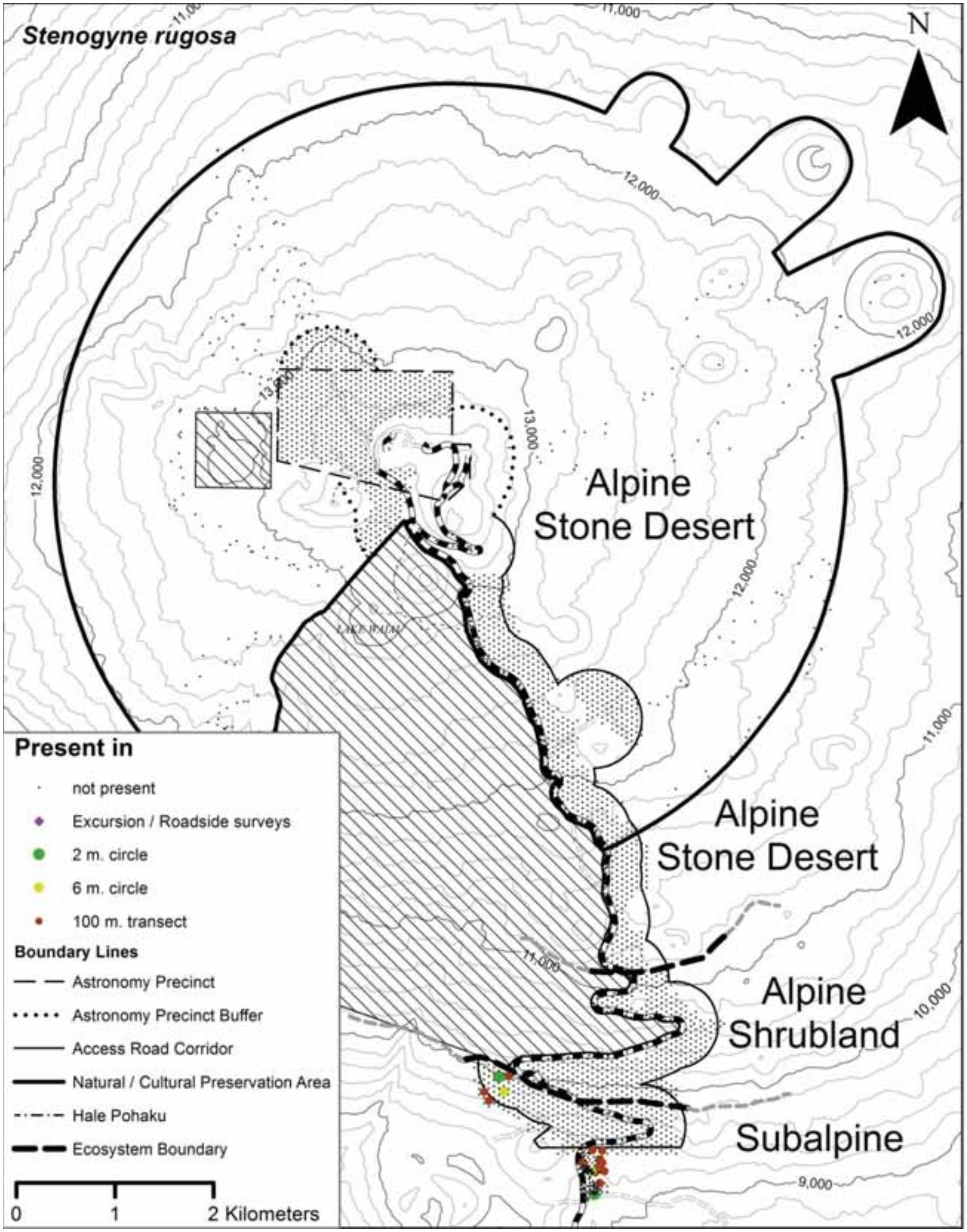

Figure APP-C62. *Stenogyne rugosa* or *mā'ohi'ohi* (Lamiaceae).

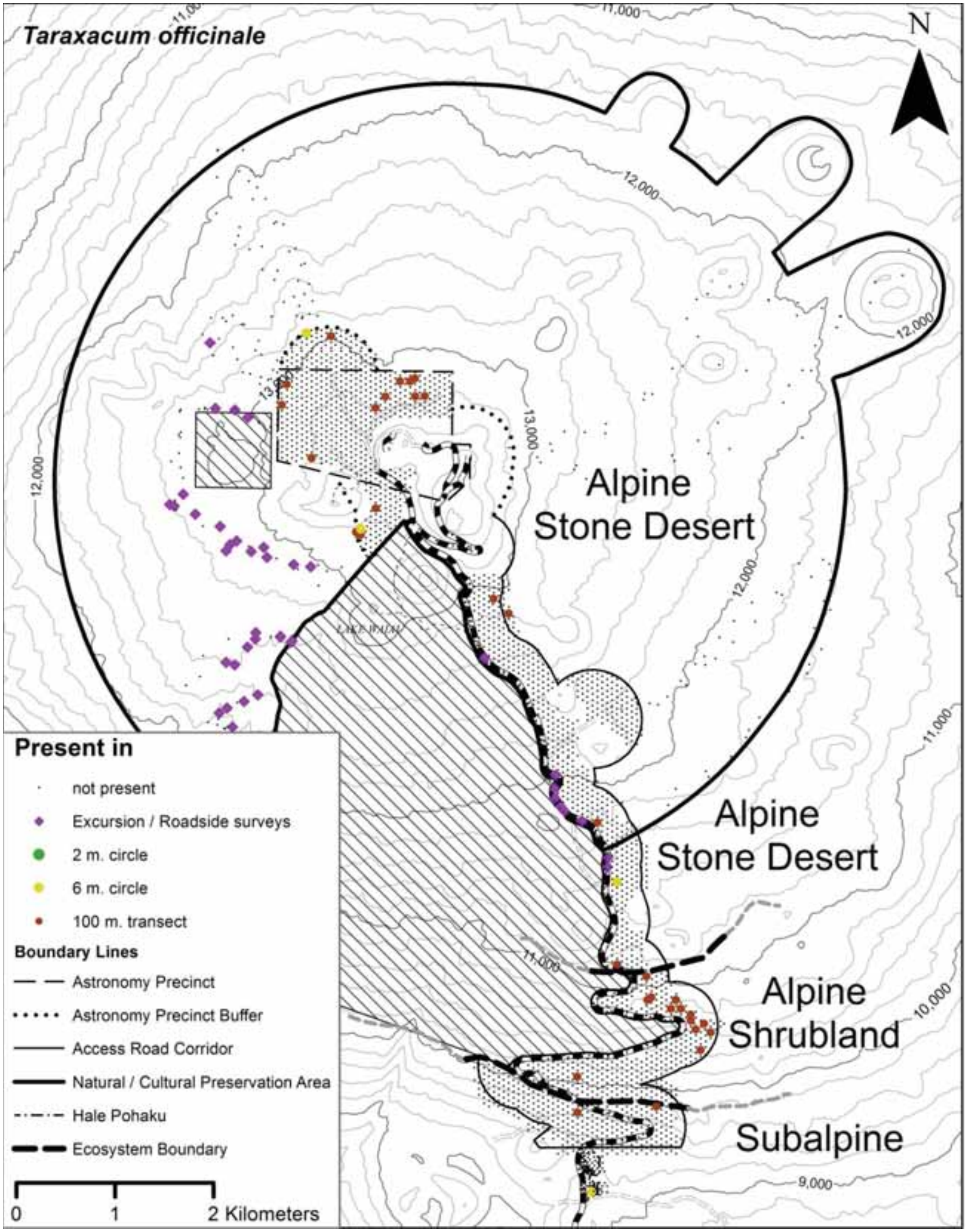

Figure APP-C63. *Taraxacum officinale* or common dandelion (Asteraceae).

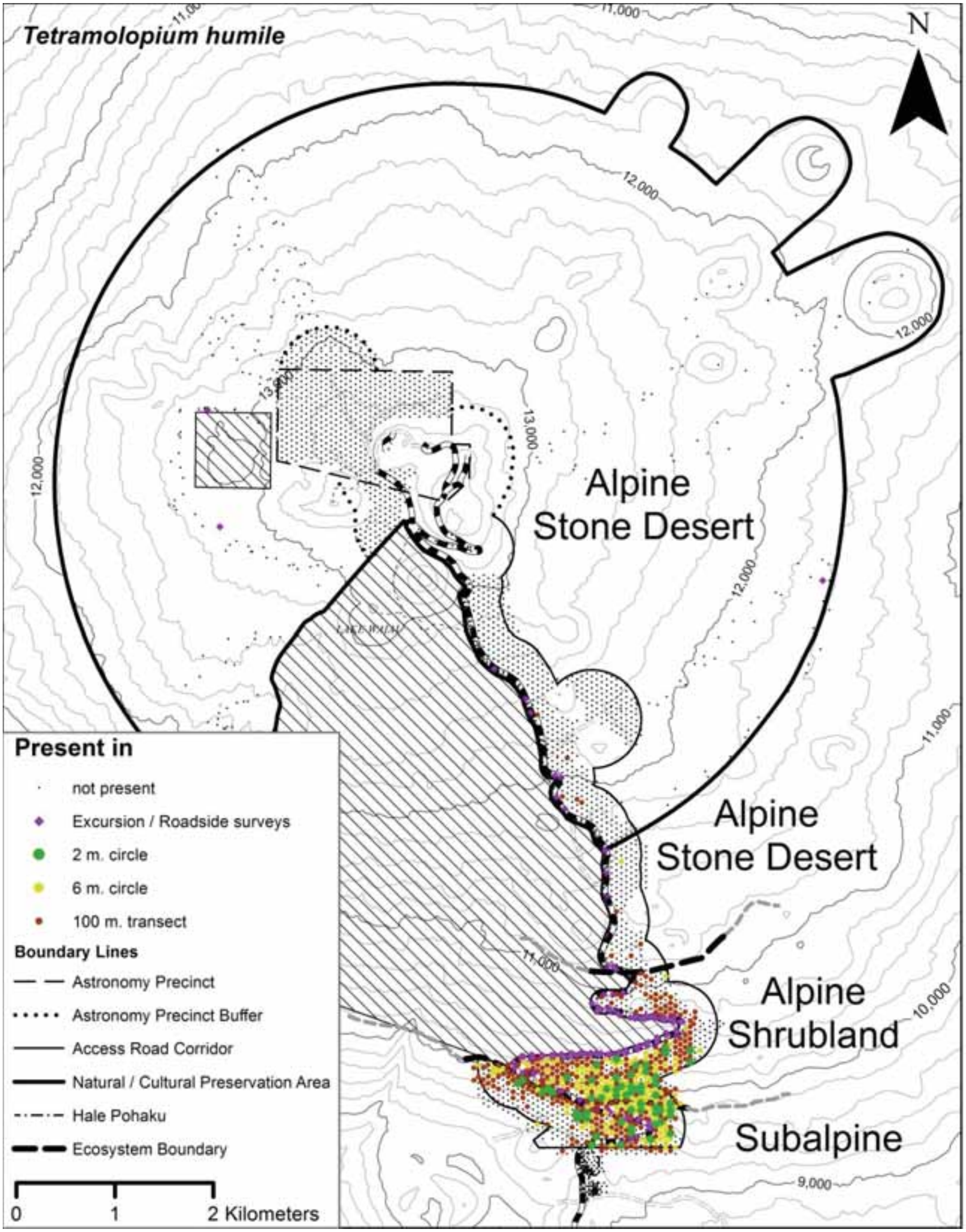

Figure APP-C64. *Tetramolopium humile***. subsp.** *humile* or alpine tetramolopium (Asteraceae).

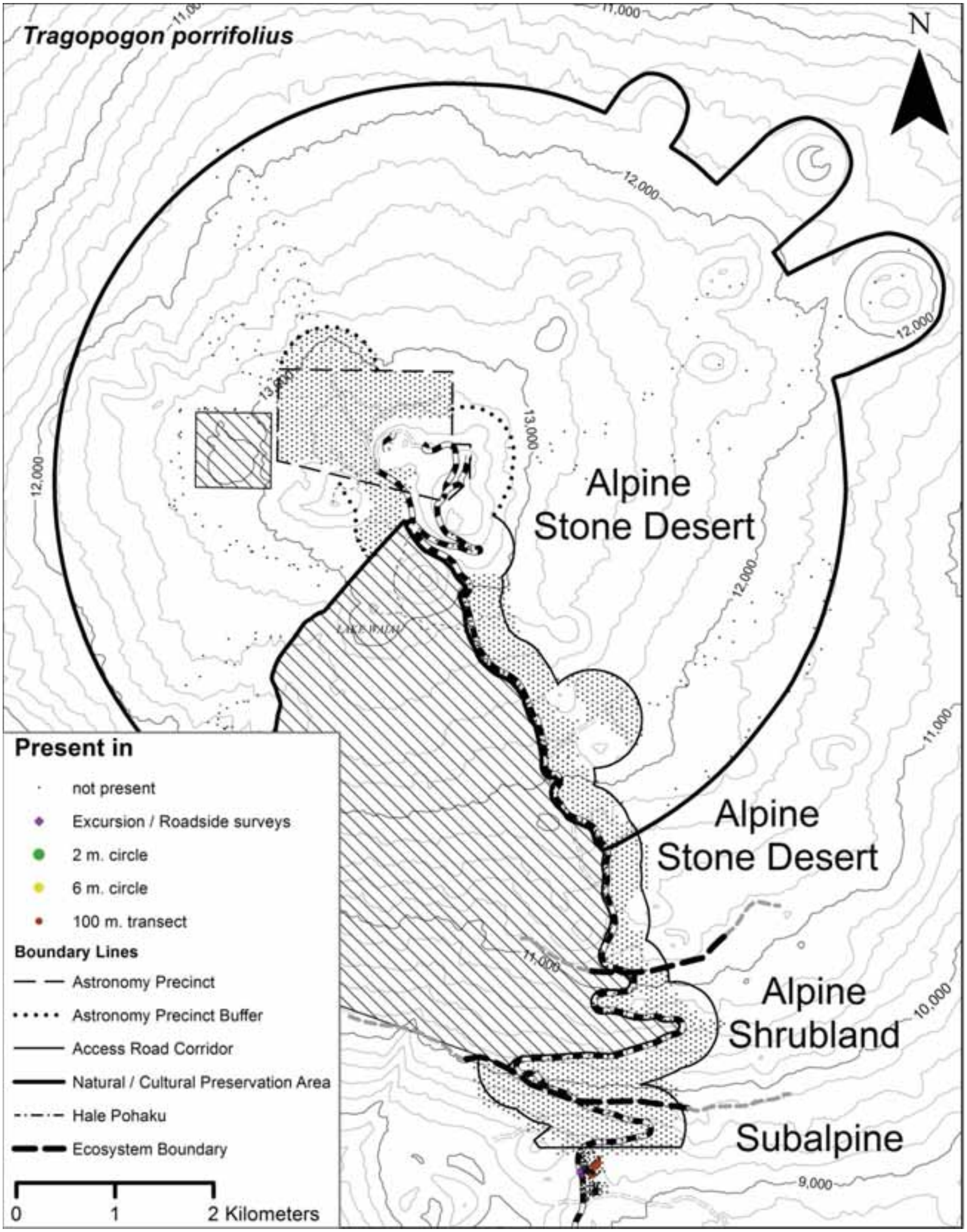

Figure APP-C65. *Tragopogon porrifolius* or salsify (Asteraceae).

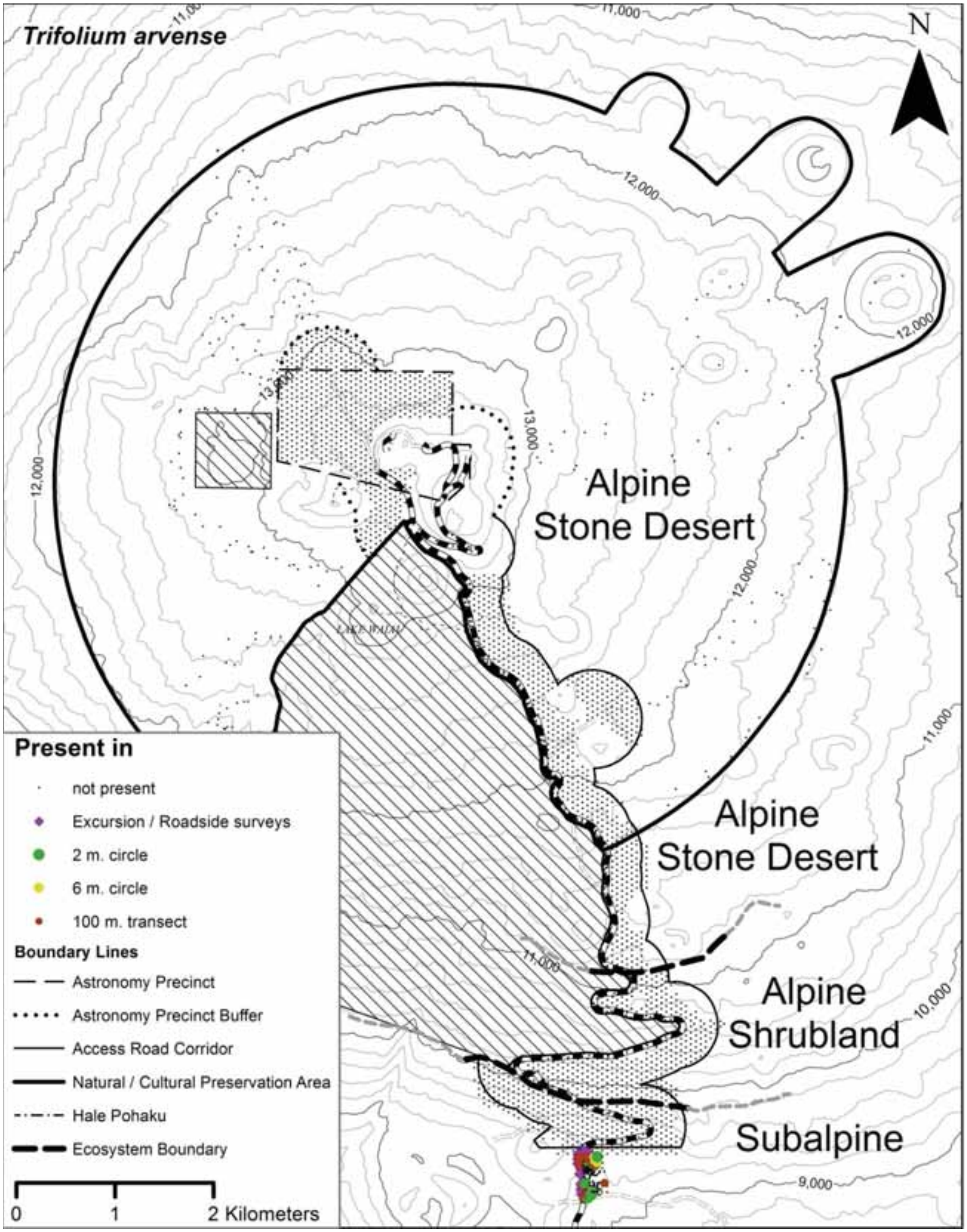

Figure APP-C66. *Trifolium arvense* **var** *arvense* or lance clover (Fabaceae).

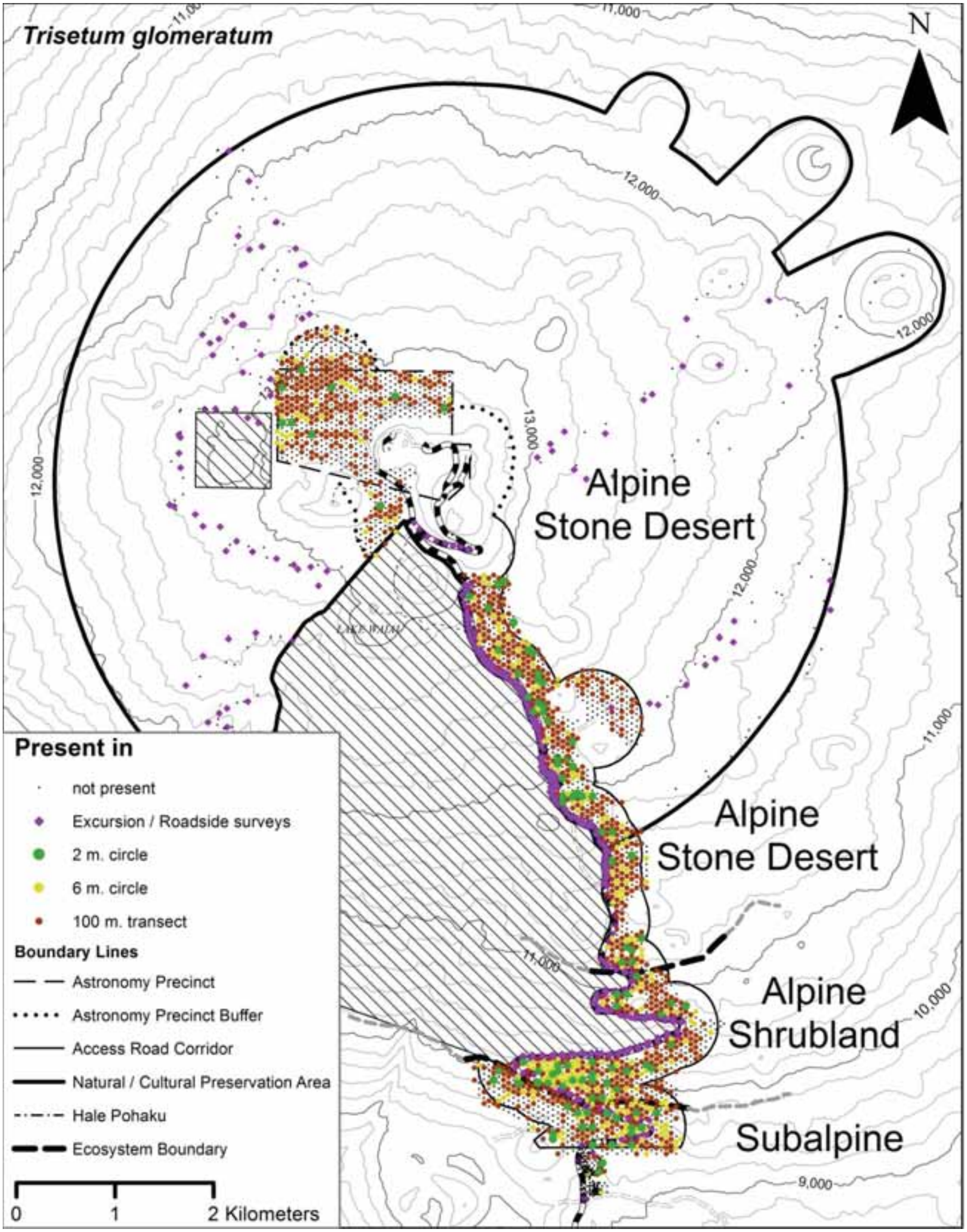

Figure APP-C67. *Trisetum glomeratum* or *pili uka* (Poaceae).

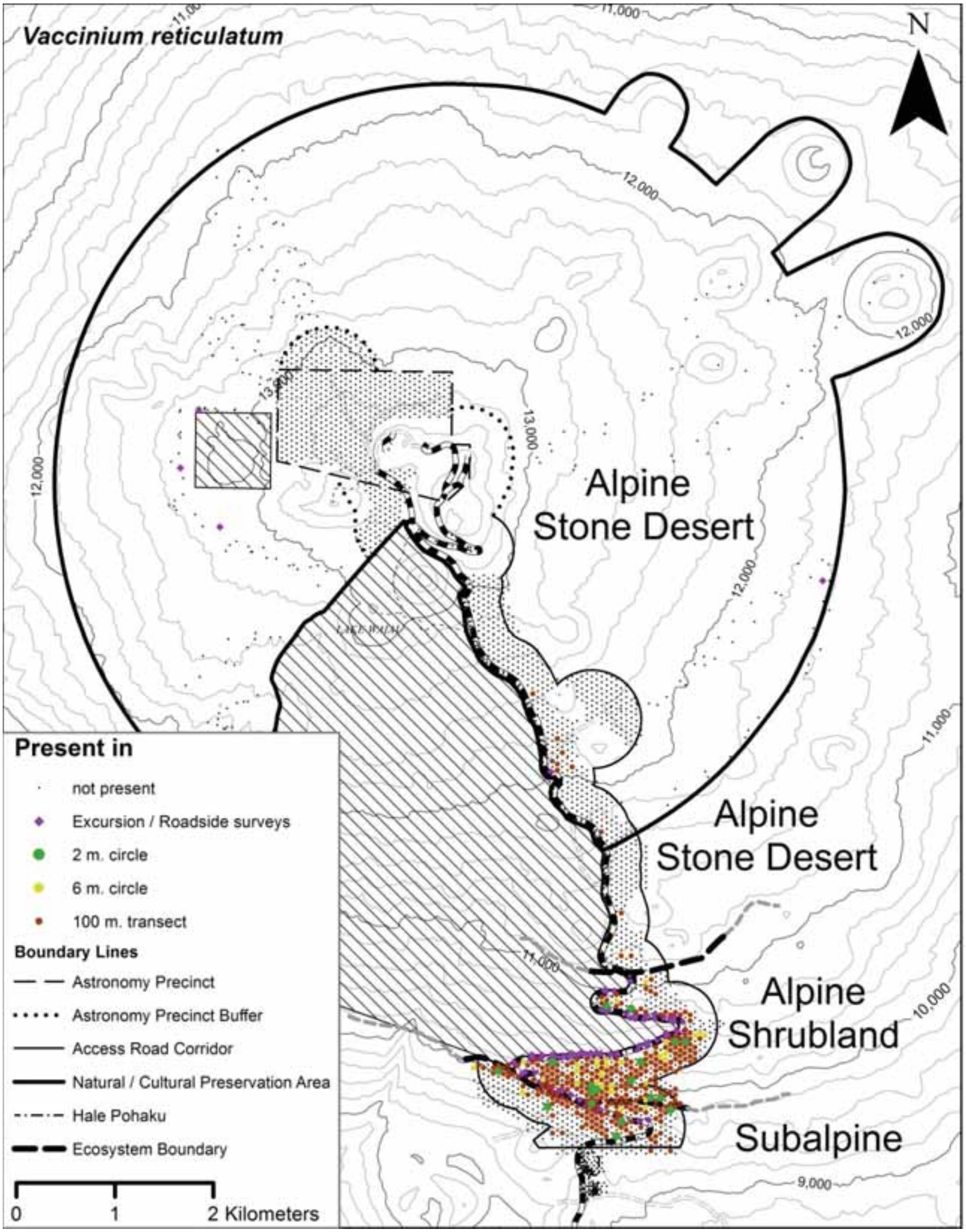

Figure APP-C68. *Vaccinium reticulatum* or *ohelo* (Ericaceae).

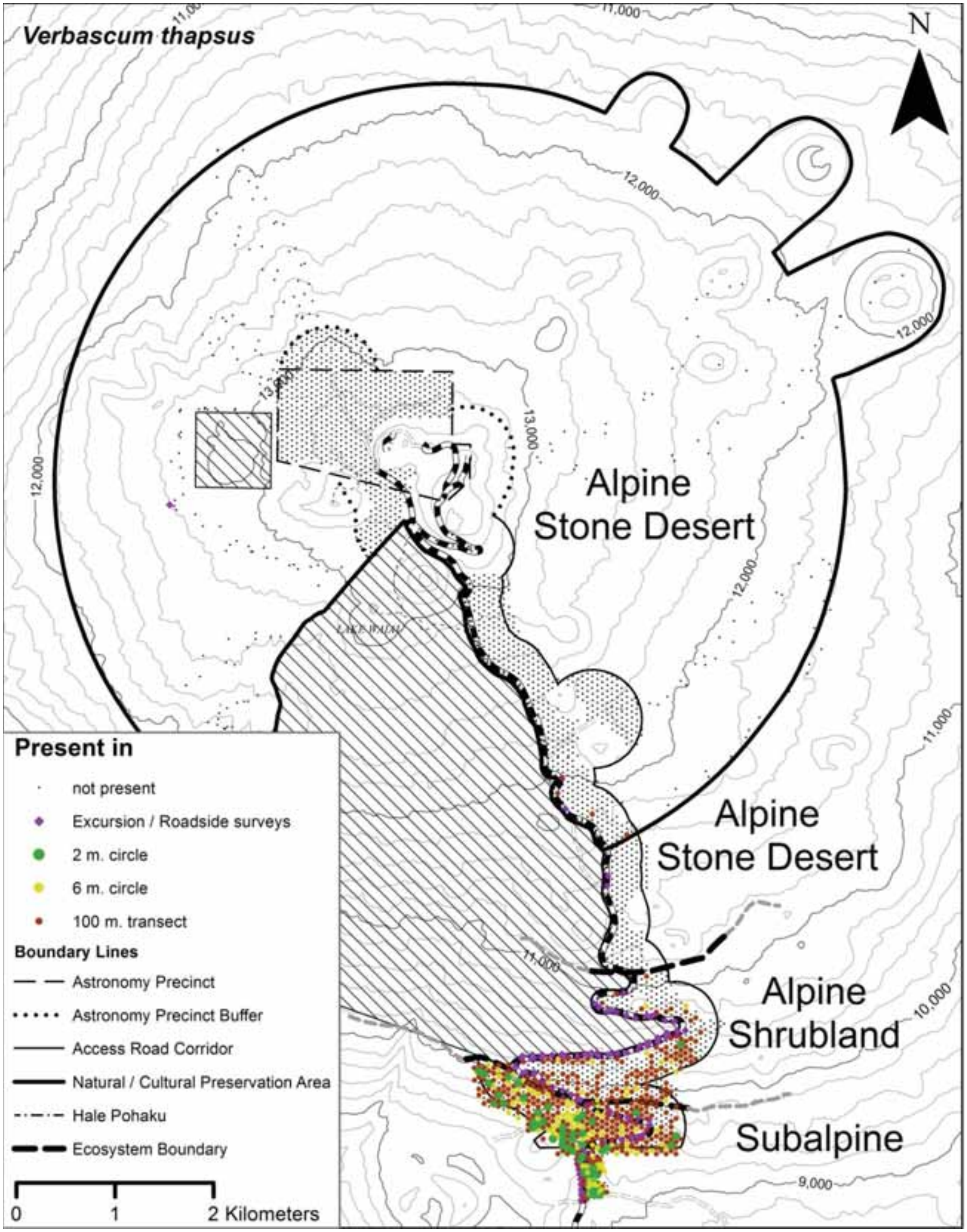

Figure APP-C69. *Verbascum thapsus* or common mullein (Scrophulariaceae).

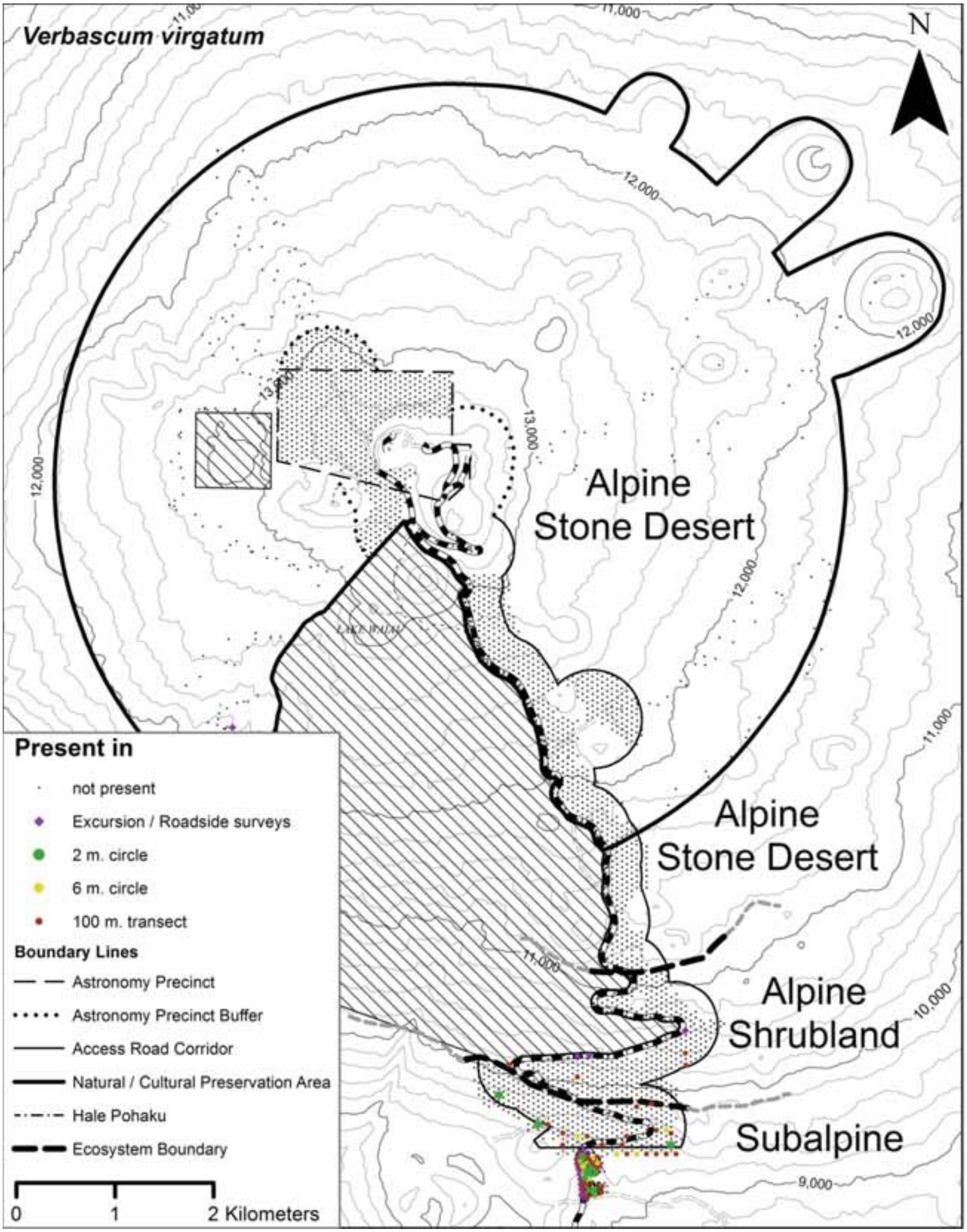

Figure APP-C70. *Verbascum virgatum* or wand mullein (Scrophulariaceae).

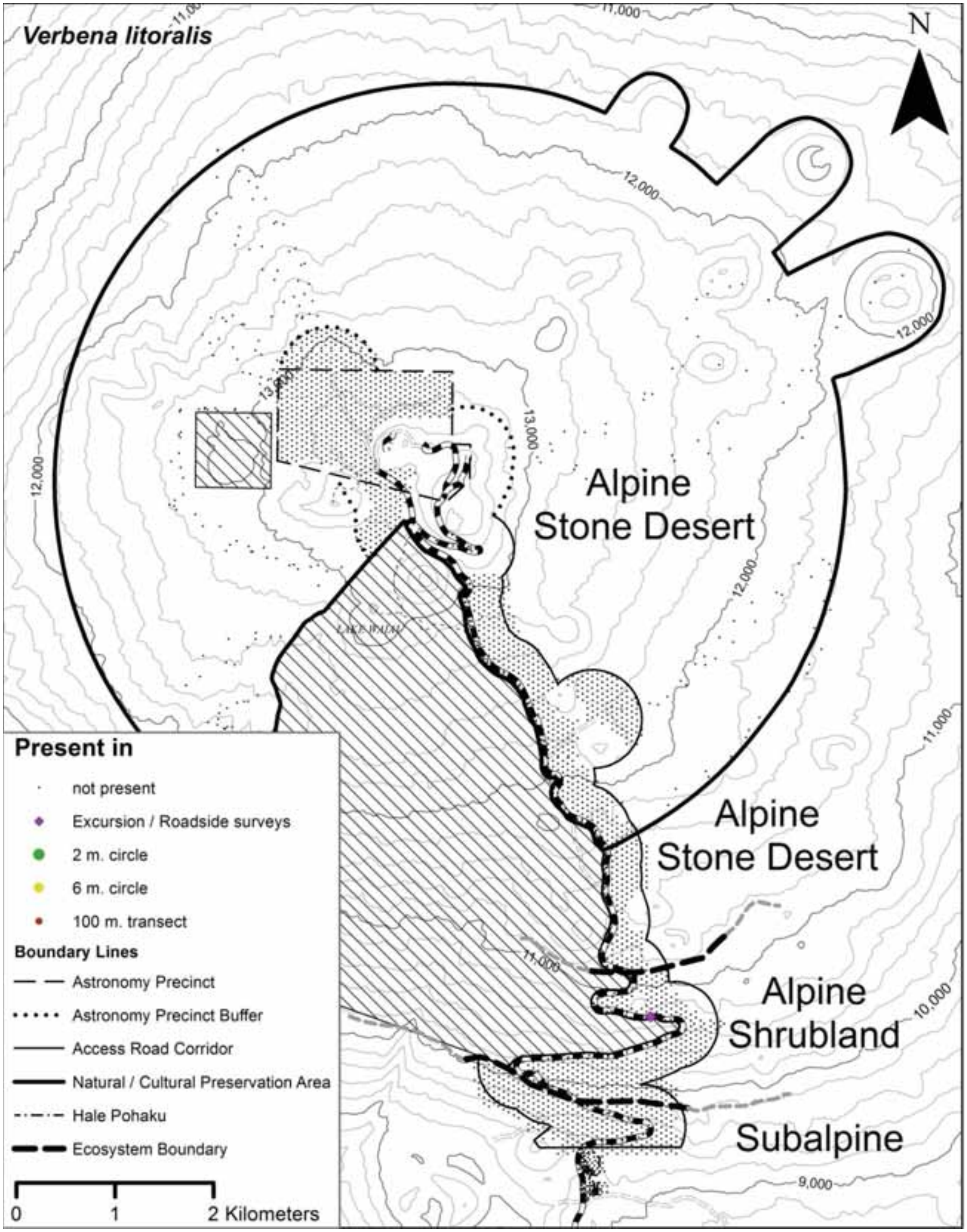

Figure APP-C71. *Verbena litoralis* or vervain (Verbenaceae).

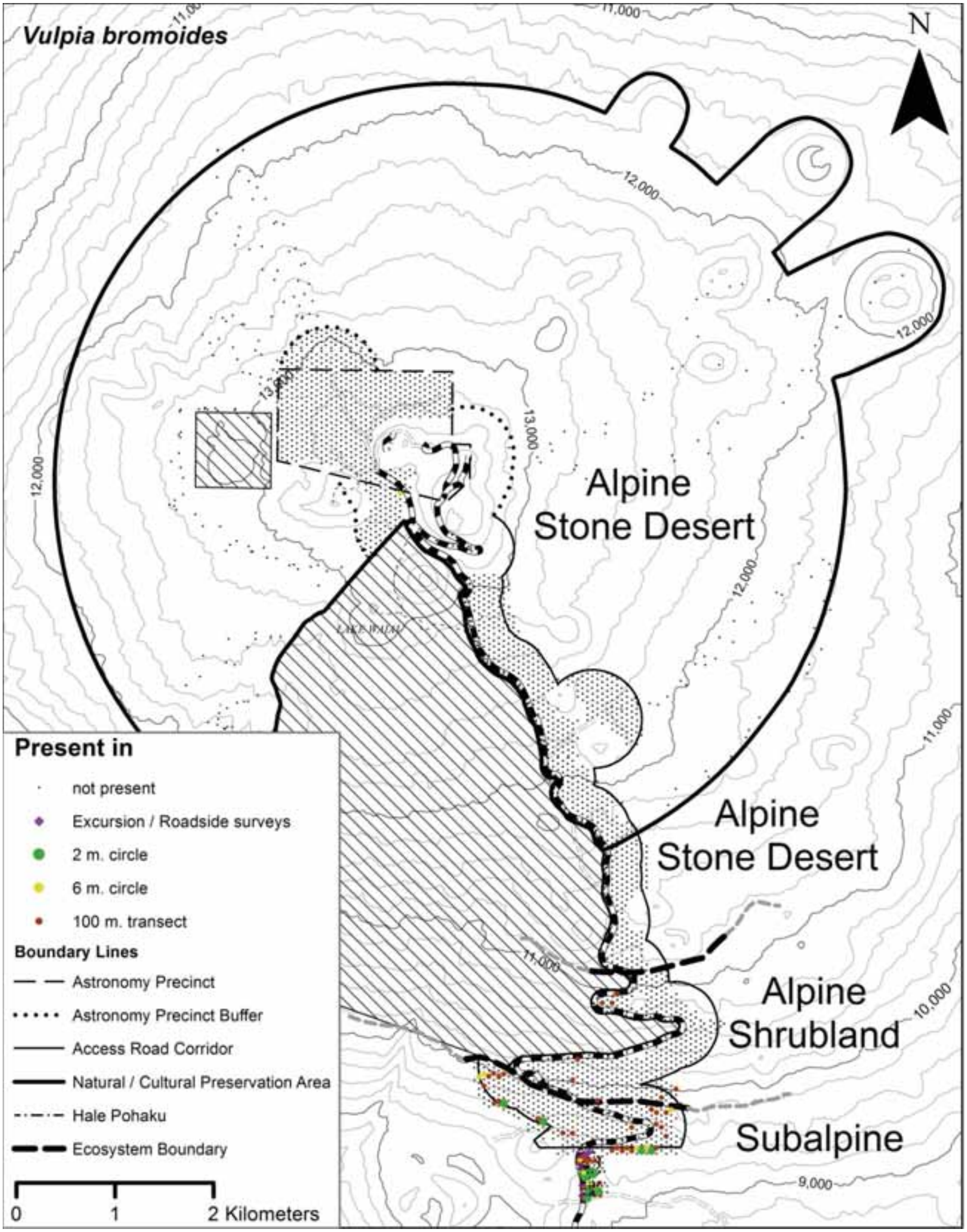

Figure APP-C72. *Vulpia bromoides* or brome fescue (Poaceae).

Appendix D: Lichen Reports, Checklists and Data

Contents of Appendix D

Appendix D1: Berryman and Smith (2011).

Full Text of Berryman, S. and C. W. Smith. 2011. “Lichens and Bryophytes of Mauna Kea within the TMT Footprint and Impact Area, Summit of Mauna Kea,” to be included as “Appendix A” in “Buffer Zone Lichen, Arthropod and Botanical Inventory and Assessment, Thirty Meter Telescope Project, Mauna Kea Science Reserve, Northern Plateau and Hale Pohaku, Hamakua district, Island of Hawaii.” Prepared for Parsons Brinckerhoff, Honolulu; Prepared by Pacific analytics, L.L.C., Scio, Oregon. (In Preparation)

Provided by Pacific Analytics, L.L.C. of Scio, Oregon, and their subcontractors.

LICHENS AND BRYOPHYTES OF MAUNA KEA
WITHIN THE TMT FOOTPRINT AND IMPACT AREA
SUMMIT OF MAUNA KEA

December 2011

S. Berryman and C.W. Smith

The lichens at the summit of Mauna Kea are the dominant element of the vegetation even though they provide only a trace of cover in this severe, essentially unvegetated landscape. The mosses have a higher biomass in small areas where they are quite common in the small caves and in crevices but overall such habitats are extremely limited. It appears that the only limiting factor of lichen growth is the physical environment. The *Umbilicaria* communities probably support an herbivore as there are signs of abrasion which could be feeding damage. We conducted some casual observations under the thalli but did not find anything.

There are four principal environmental factors that determine the lichen and moss vegetation and species composition: substrate, moisture, temperature and the ultra-violet (UV) radiation.

SUBSTRATE

There are four principal substrate types in the summit area recognized from this and previous studies. They are:–

- andesite slabs and blocks of grey rock which rings when hit with a hammer. The rock is quite smooth with few, if any, blisters. It forms the large lava flows the edges of which are fragmented into large, frequently cubical rocks which may have been split off by ice fracturing. Water drains off the rock rapidly.
- more typical glaciated pahoehoe which does not ring noticeably when hit with a hammer. There are numerous blisters creating a surface with an uneven

microtopography creating numerous depressions where water can accumulate. The rock is generally brown in color but some is distinctly reddish and these latter areas always appear to have more lichens on them

- glacial rubble, often an assorted mix of various types of rock. The surface of this rubble rarely supports lichen growth probably due to its instability. However, rocks under the surface layer often have lichens growing on them. Ash accumulated under the rock precludes lichen growth.
- cinder and ash, generally grey or red, is present only in pockets in small areas other than the cinder cones. This substrate is too unstable to support lichen growth.

MOISTURE

Rainfall is very low at the summit of Mauna Kea (Table 1). The air is also extremely dry such that the poikilohydric (having no mechanism to prevent dehydration) organisms (e.g., mosses and lichens) dry out very rapidly. Lichens and mosses are desiccation tolerant but there is a price; when rehydrating the membranes, disrupted during desiccation, have to be repaired before normal metabolism can resume. For species growing in such a harsh environment the process probably takes longer than at lower elevations.

Another possible source of moisture is from humidity particularly as the temperature drops in the evening. Lichens with Chlorophyta algae can absorb water from the air when the RH exceeds about 70% so there is the possibility that they could become hydrated during the evening, remain hydrated through the night and be capable of photosynthesis at first light. Specimens growing in sheltered situations would be able to continue photosynthesis for longer periods. The rate of photosynthesis would be low because of the low temperatures in such situations.

The vesiculate and porous rocks and ash retain water for longer periods of time and could provide sufficient water to the lichens and mosses to enable them to photosynthesize longer.

Table 1. Average Precipitation (1971-2000) at the summit of Mauna Kea (NOAA 2008).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total annual.
(in.)	0.85	0.15	1.07	0.48	0.97	0.12	0.20	0.75	0.62	0.53	1.26	0.42	7.41
(mm)	216	38	272	122	246	30	51	190	157	135	320	107	1882

TEMPERATURE

Temperature has a profound effect on the rate at which organisms metabolize and grow because of its effect on enzyme kinetics. Metabolic activity is negligible at $0^{o}C$ increasing to a maximum at around 40^{o}C. The activity of most enzymes increases by 50 to 100% with every 10^{o}C rise in temperature. Though the average temperature rarely rises above 10^{o}C, the temperature of rock surfaces certainly rises above this temperature. The blacker rocks can be hot to touch at midday; thus the air temperature is not a reliable measure of the temperature to which exposed lichens and mosses are exposed. However, plants growing in the shade of rocks do experience lower temperatures akin to the weather station data.

The average monthly temperatures at the summit range from -5 to 13^{o}C (NOAA 2008).

Table 2. Average temperatures (1971-2000) at the summit of Mauna Kea (NOAA 2008).

Average Maximum Temperature

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average annual.
(˚F)	42.0	42.5	40.3	41.4	47.5	49.3	50.9	49.9	50.5	48.3	45.1	42.7	46.0
(˚C)	5.6	5.8	4.6	5.2	8.6	9.6	10.5	9.9	10.3	9.1	7.3	5.9	7.8

Average Minimum Temperature

(˚F)	26.3	26.1	24.9	26.2	29.0	29.4	30.3	30.9	31.3	29.5	27.8	27.6	28.4
(˚C)	-3.2	-3.3	-3.9	-3.2	-1.7	-1.4	-0.9	-0.6	-0.4	-1.4	-2.3	-2.4	-2.0

There is a notable, as yet unmeasured, difference in the temperature of exposed (hot) and shaded (cold) areas of rock faces. The difference is quite abrupt particularly where the aspect of the rock face changes abruptly.

UV

The ultraviolet index is an international standard of the strength of UV. It is a linear scale where higher values represent an increasing risk of skin damage. An index of 0 corresponds to zero UV irradiation and values over 10 pose extreme risk to unprotected skin. The numbers are essentially related to the spectrum of UV radiation at that point. However, the more damaging effects of shorter wavelengths may be underrepresented in the indices from Hawaiian mountaintops. Suffice it to say that the largest value of UV index at the NOAA station on Mauna Loa was 51.3 ± 3.1 μW cm^{-2}, which is putatively the highest recorded anywhere at the Earth's surface (Bodhaine et al. 1997).

Photosynthetic organisms are particularly sensitive to UV radiation high levels of which result in chlorophyll degradation and thereby a reduction in photosynthetic activity. Numerous studies have demonstrated decreases in biomass of lichen communities and the success or rate of colonization of lichens. Most established lichens can overcome, if only partially, the effects of

UV by screening out the radiation. Many lichens at the summit are naturally very dark (e.g. *Umbilicaria decussata, Psuedephebe miniscula*) or turn black in exposed areas (*Lecidea baileyi*). The orange color of the more normally paler yellow *Candelariella vitellina* is almost certainly a response to the intense radiation. An alternative method of obscuring incoming radiation is the production or increase of a necral layer above the upper cortex, a layer of dead cells over the surface of the thallus. The air between the dead cells reflects the light so that it appears white. I am not sure if it also reflects the UV light as in a snowscape.
Ozone, produced in high quantities in response to high UV irradiation, is a potent oxidizing agent but several lichen acids act as free radical scavengers.

THE LICHEN/BRYOPHYTE VEGETATION

The lichen and bryophyte vegetation of the summit of Mauna Kea within the study area consists of lichens and mosses. There are no liverworts or hornworts. There are 22 species, plus one commensal, of lichens and four moss species, all of which have a cover value of much less than one percent over the study area. There is only one community, a macrolichen community dominated by the foliose *Umbilicaria decussate*. The community has a significant cover but the community is restricted to very limited, specific situations. Where it occurs, the community generally covers over 50% of the essentially vertical surface of andesite rock faces with a north to north-east aspect. However, suitable rock faces are few and far between. The remainder of the lichen flora consists of crustose species scattered throughout the study area on various substrates other than the shifting ash and cinder.

The most common species in the Mauna Kea crustose flora are *Lecanora polytropa*, *Lecidea baileyi* and *Candelariella vitellina* which are widely dispersed throughout the study area. Other common species include an unknown species of *Acarospora* and *Buellia*, and *Lecanora* cf. *subaurea*. A number of species are present which cannot be determined beyond the genus level and four species cannot even be placed in a genus with certainty. The uncertainty is because reproductive structures are either absent or not in adequate condition for determination. Vegetative characters are unreliable due to modifications to protect against the severe environmental conditions of the summit area. The nature of the flora will only be understood after studying the flora at lower elevations on the mountain where lichens can be found in conditions of less environmental stress.

Mosses are the only bryophytes present in the study area occurring at 71% of the study sites. *Pohlia nutans* is the most common species and is present throughout the area. The mosses are most well developed in the small caves and over ash deposits in crevices where drainage is impeded. None of the mosses found bore sporophytes.

Though most of the lichens and mosses are on the surface of rocks or in protected situations, four species (*Acarospora* sp 3, *Buellia* sp. 1, *Lecanora* cf. s*ubaurea*, *L. polytropa*) are found on the undersurface of loose rocks (generally under rocks 10-20 cm diam.) or on the surface of rocks underlying other rocks up to depths of approximately 10 cm. The *Buellia* was only found at Site 1. These subsurface occurrences were recorded in 22 (76%) of the study sites. Though some lichens are known to prefer crevices and receded habitats, it is unusual that the species recorded here would occur in such a situation. However, in this very severe environment, the increased humidity under the rocks and protection from sun and wind provides a suitable habitat for survival. In the case of *Umbilicaria decussata*, the rocks on which the lichens were found had probably been disturbed since this species requires full exposure for growth.

The checklist of the lichens in this survey notes 23 species, twelve more than observed during the 2008 study (Smith 2008) (Appendix 1) and two more than the study in 1982 (Smith et al., 1982). The difference between the two recent studies is due to expanding the studying area down to 13,000 ft, a recommendation of the 2008 study, as well as including three sites on the western boundary of the area around Puu Poliahu. The three western sites were somewhat richer in species (at least three species were unique to this region of the study area) or had better developed thalli which better linked the depauperate specimens in the TMT area with species found at Hale Pohaku, e.g., *Physcia dubia*. Some of the uncertainties in previous studies were therefore resolved. The reason for the richness of the flora in these areas around Puu Poliahu is not known but during the field trip in May/June 2011 thunderstorms along the Kona Coast reached up to the summit and covered the western sides of the summit in cloud and occasionally snow, hail or rain.

The only substantive lichen community in the study area near the summit of Mauna Kea is dominated by *Umbilicaria decussata* which is nearly always accompanied by *Pseudephebe minuscula* and generally *Rhizocarpon geographicum* and *Lecidea baileyi*. Where the community occurs it is substantial but its cover was not captured in the report because the intercept for cover classification is a point vertical to the surface of the ground not the individual rock face. The community is confined to the exposed north to north-east facing vertical faces of andesite blocks which suggests that special conditions allow growth there but not elsewhere. Since the community is only found in this position, conditions on flat rock surfaces and other aspects are probably too severe (e.g., inimicable daily temperatures) to allow establishment or growth since the community does not spread onto other more exposed surfaces and there are no isolated thalli elsewhere. The most notable distinction about the aspect of the habitat is that it is shielded from direct insolation for much of the year.

Elsewhere the macrolichens are not found on the top of rocks but are either under overhangs, in crevices and other protected areas. Lower down the mountain *Umbilicaria* species can be found on eastern facing situations. The summit of the mountain is well known for its dry air, the high number of cloud-free nights, and the stability of the atmosphere all of which suggest that climatic factors do not account for the very notable distinction in the distribution of the *Umbilicaria* community. However, there are topographical differences in the exposure of the andesite rock faces. Since lava flows down the mountain, the flow fronts face in the direction of the aspect of the mountain. It is the fronts and sides of the flows that appear to be the most fragmented such that on the northern side of the mountain most of the fragmented sections face north and on the southern side of the mountain they face southward. The upper area of the flow is protected by the mass of the flow around it and does not collapse. Since there are very few south-facing faces on the northern side of the mountain there is no opportunity for the *Umbilicaria* community to develop there. But even on the southern side of the mountain the south-facing faces are generally free of lichens possibly due to the effects of insolation because crevices and vertical faces with a more northerly aspect are covered with lichen particularly where shaded to some degree. This type of distribution can be seen around the Batch Area and on flows along the road to the VLBA telescope. This hypothesis needs further study.

A wet surface may be important for the initial establishment of a community because it is unlikely that the process could be effected by a propagule absorbing water from the air. However, it is unlikely that such luxurious colonies (up to 100% cover in patches within the study area) could be maintained by the very infrequent precipitation events as the thalli would rapidly dry out in such a dry environment without further wetting even though shaded from direct sunlight. The absence of all cyanolichens (lichens with a cyanobacterium as the photosynthetic symbiont) which require full saturation of their thalli for growth also suggests that continuous wet conditions are rare. The humidity of the air probably exceeds the dew point every evening as the temperature rapidly drops. The three-dimensional structure of fruticose and foliose lichen thalli would be good sites to intercept such moisture. There is probably enough air movement caused by temperature changes during the evening hours sufficient to facilitate such absorption. This could be verified by visiting the colonies at dawn and checking whether or not the thalli are brittle.

Once a thallus, particularly a foliose or fruticose form, becomes established it will create its own microclimate around the thallus or within the branches. The establishment of its own propagules could be possible as well as enabling other species to establish. However, casual observations suggest that there is no close physical association of one species with another. Rather there are pockets of other species such as *Pseudephebe* in the same community but isolated from the dense *Umbilicaria*. The *Umbilicaria* probably overgrows all other species thus limiting the other species to peripheral situations. The initial colonization events would be few and far between. Most of the communities are large occupying much of the available habitat suggesting considerable antiquity, the result of their very slow colonization and growth. There are smaller, possibly younger, communities but they are quite rare.

The small cave communities are dominated by mosses, principally *Pohlia nutans* with a relatively higher cover than outside the cave of *Lecanora polytropa* and *Candelariella vitellina* frequently on the moss clumps and *Lepraria* in the deeper recesses. The moss clumps are often damp and ash deeper within is visibly damp. During the day the temperature is noticeably lower inside these small caves. The water may come from percolation from above or snow, hail or rain blown in during storms but protection from the elements also contributes by limiting evaporation. The porosity and water holding capacity of the lava above the caves is not known.

The occasional lichens and moss elsewhere occur predominantly on rough lava rocks or surfaces or in small cracks and crevices. Iron rich rocks (the redder rock) support the highest number of lichens in these situations. The cinder cones do not support any lichens other than on the occasional larger rocks but even they host few thalli of *Lecanora polytropa* and *Candelariella vitellina*. The substrate is too unstable to allow any colonizing lichen to become established.

STATUS

Whereas in 1982 it was noted that there was a high level of endemism (33%) in the summit flora of Mauna Kea, monographs and taxonomic revisions since then have drastically reduced the level of endemism. In this current summary, of the 23 species known to occur above 13,000 ft., 0% are endemic, 54% are indigenous but 46% are of uncertain or unknown status because the species cannot be determined to the species level. In the much smaller area of the footprint of the TMT telescope, there are 11 species (0% endemic, 63% indigenous and 37% of unknown status).

MANAGEMENT

The question regarding the stability of the lichen and moss flora at the summit of Mauna Kea revolves around three different factors: human disturbance, long-term stability and climate change.

Human disturbance. The effects of the human activities associated with recreation, astronomy and more recently tourism are fairly obvious.

Recreation. Skiing during winter was confined to the cinder cones. The disturbance due to snow compaction and cinder movement are recognizable. The impact on the lichens is small because the lichens are few and far between due to the inherent instability of the slopes. However, the possibility of erosion due to such concentration of activities is high.

Most hikers remain on the trails. The trails themselves are obvious and devoid of lichens but situations within a few centimeters appear to be unaffected.

Tourists are increasingly common at the summit for sight-seeing, visiting the observatories and increasingly for night sky observations. The traffic associated with these activities is increasing. It may be appropriate to consider some constraints on recreational vehicular activity at the summit and particularly where the participants go on their way up and down and during the night sky observations.

The trash from recreationists that I mention in the 1982 report has since been cleared up.

Astronomy. The construction of the observatories has had a permanent impact on the biological resources in the immediate area as well as the batch plant areas, roads, and associated areas. No new lichens or mosses have become established in the area as a consequence of the construction or have used the structures as their habitat. The number of calciphiles in Hawaii is small because even though the basalts are basic the pH is close to neutrality. Therefore, though there are some small areas of elevated coral or lithified dunes in the Islands there is very little habitat for calciphiles. There are a number of lichens that favor calcareous habitats lower down, e.g. *Verrucaria nigrescens, Endocarpon pusillum,* but they are not found at these high elevations. Both species are found in temperate and other alpine situations so they might be expected at the summit.

The road traffic associated with the construction of each observatory is a matter of some concern. Dust from the vehicular traffic was considerable before the upper reaches of the summit road were paved. The paving has reduced dust formation to the point and the rocks and biota demonstrate little to no dust. The fumes from vehicular traffic might be of some concern but the number of vehicles driving up to the area is very small, at least at present, though the increase in tourist activity is of some concern.

The introduction of flowering plants to the summit is of concern because they could invade the small caves and crevices in which substantial numbers of moss and lichen occur. Were they to do so they would shade out the current residents.

Long-term stability. The long-term stability of the lichen and moss communities is dependent on minimizing disturbance in the area. The colonization rate of species is extremely low and probably restricted to years in which there is moisture present for an extended period of time. Since lichens are a symbiotic association of alga and fungus, the two species have to arrive at the same place at the same time or the two have to arrive as a vegetative propagules containing both species already in the symbiotic association. The chances of diaspore(s) finding a suitable situation for establishment in an environment where growth conditions are unfavorable are low which is supported by the very low cover of the few species present and the low number of individuals per unit area.

In addition, the growth rates of the lichens and mosses in the severe environment at the summit are extremely low. There are very few periods of favorable moisture levels for sustained growth. Even when growth conditions become favorable the lichens and mosses have to undergo a period of resuscitation expending stored resources to repair the damage caused, particularly to membrane systems, during desiccation. Exposed rocks heat up very rapidly exceeding temperatures suitable for metabolic processes. But conversely, in shaded situations where moisture levels may remain high enough for sustained growth, the ambient temperature levels are low enough to slow down metabolic activity substantially. Therefore, recovery of disturbed areas will be extremely low.

Climate change. It is unlikely that increasing global temperatures will have much significant effect on the lichen and moss communities in the summit area because it is not anticipated that the moisture levels will increase. If the ambient temperature increases, lichens and mosses in shaded situations may increase. However, those in exposed situations may be further stressed but the change will probably not result in any measurable differences in the community structure or cover because the environment is so stressful already.

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Future studies:

1. Continue evaluation of the specimens collected along the corridor from the Hale Pohaku to the summit. However, further collections in XXX Gulch.
2. Measure the temperature of rock surfaces throughout the day and night to better understand the conditions under which the lichens are growing.

3. Measure the water retention of the different rock types to understand how long moisture is retained in the rock and therefore potentially available to the lichens. Measure the pH of these rocks to see if they are different which could also account for the distribution of the different lichen species.
4. A broader evaluation of the lichens of Mauna Kea above treeline. Studies in wetter situations may provide more robust specimens for determination, particularly if specimens can be found after a prolonged period a wetter condition when spores in good condition can be found. There is some indication of this from the cave on the cinder cone on the southern side just below the summit and the lava field around Waiau in both of which areas some surprising well developed specimens were found.

Appendix D2: Updated annotated Checklist

The following annotated list was updated in August, 2013, by its original author, C. W. Smith. The heading information, given immediately below is as it appears, as appended to the original report, referenced as

Berryman, S. and C. W. Smith. 2011. Lichens and Bryophytes of Mauna Kea within the TMT Footprint and Impact Area, Summit of Mauna Kea. Appendix A in Buffer Zone Lichen, Arthropod and Botanical Inventory and Assessment, Thirty Meter Telescope Project, Mauna Kea Science Reserve, Northern Plateau and Hale Pohaku, Hamakua district, Island of Hawaii. Prepared for Parsons Brinckerhoff, Honolulu; Prepared by Pacific analytics, L.L.C., Scio Oregon. (In Preparation)

APPENDIX 1

ANNOTATED LIST OF LICHENS OF MAUNA KEA FROM HALE POHAKU AND ABOVE

December 2011

Acarospora cf. depressa - generally isolated, light brown squamules with minor if any radiating striae. small (generally less than 0.5 mm diam. at the summit) to 1.25 mm diam at Hale Pohaku. At Hale Pohaku are pruinose when exposed which decreases in shaded situations but at higher elevations the pruina is much reduced to absent. K-, C-. Apothecia present but spores not seen. Easily overlooked at the summit because it is very similar to light brown dust in blisters and in some instances may be overlain with light dusting which makes it very difficult to see. In open to shaded situations.

Acarospora sp. 1 – shiny, rosette-shaped thalli. Common on vesiculate rocks particularly in the small pockets. Often fertile with spores. C-, K-. The discolored squamules can be overlooked because they are almost the same color as the substrate. Bleached specimens can be mistaken for *Lecanora polytropa*. Occasionally patches of pruina were observed on some thalli. These were not collected as they were thought to be the same species. There is a white, pruinose species at Hale Pohaku but it is not thought that the pruinose thalli of the summit species bear any relationship. The shiny form is not uncommon at the summit and it can be found in the pitting on suitable rocks with careful searching. There are several other *Acarospora*-like species that cannot be determined because of the absence of apothecia. Some of them may just be poorly developed forms of the two species mentioned.

Aspicilia. desertorum – cf Squamules gray-brown tinged green with cracks radiating from the apothecia. Apothecia 1-3/squamule sunken in the thallus, disc somewhat pruinose. Hale Pohaku.

Buellia cf. fuscochracea – Small, flat to swollen, green areoles, roundish at the periphery but rectangular in the center on an irregular, black hypothallus often smothered in dust. C-, K-. Apothecia black, eccentrically placed, 0.1-0.3 mm diam. flush with areole surface. Hypothecium pale. Spores uniformly thin-walled, uniguttulate, 10-12 x 5-6μ, .

Buellia ?*maunakeansis* – thallus white, pruinose apothecia but not K+ blood red. Intermediate elevations.

Buellia cf. subdisciformis – compact areolate thallus with small black hypothallus, squamules <.5mm diam, pale brown, concave. Apothecia disk black, margin gray, prominent, subsessile. Spores thin-walled 9-11 x 5-6 µm, slightly pinched at equator. K+ yellow→red. Hale Pohaku.

Buellia ?*punctiformis* Greenish gray, thin with domed apothecia. K-. VLBA

Buellia ?punctulata very thin white thallus between black apothecia. K-. Just above Hale Pohaku.

Buellia spp. – another 6+ spp which cannot be determined because of the lack of well-develop thalli and spores.

Caloplaca lithophila – isolated apothecia, K+red, sometimes with very narrow squamulose margin. Abundant on rocks at Hale Pohaku where the thallus is more completely developed and characterized by a white margin to the squamule.

Candelariella vitellina – small, yellow to almost orange squamules, K- or slightly red, very rarely with apothecia. Commonly found in the same situations as *Lecanora polytropa* but it is not as abundant. Found all over the summit area generally on glaciated pahoehoe and pock-marked rubble particularly the red ones. Frequent at Hale Pohaku and up Hale Pohaku Gulch. The corticolous specimens are distinctly yellow, the saxicolous specimens more orange and robust.

Carbonea vitellinaria – small black apothecia on *Candelariella vitellina*. Rare, seen only twice below the TMT footprint area. Identity not confirmed because mature spores were absent from the apothecia.

Diploicia canescens – appressed thallus with marginal lobes and laminal soralia. VLBA and below but not at Hale Pohaku.

Heterodermia albicans – loosely attached laciniae, marginal soralia, K+ red. Hale Pohaku and lower elevations of alpine zone.

Immersaria sp. – compact areolate crust with embedded black apothecia. Tightly adherent to shaded, smooth, vertical andesite rockface in a very difficult position to chip off. Attempts to scrape off some of the thallus resulted in its fragmenting into very small pieces. Only seen on access road to VLBA telescope.

Lecanora muralis – squamules with white margin, prominent apothecia with yellowish discs. Hale Pohaku and lower elevations of alpine zone.

Lecanora polytropa – Very variable, almost white to pale green squamules, often with apothecia. K-. Well developed specimens have a slightly waxy appearance. Bleached specimens are common but must be carefully studied because moribund *Acarospora* and *Lecidea* squamules may appear similar. The most abundant species in the summit area in every habitat other than ash.

Lecanora ? subaurea – Discrete green squamules with marginal soralia which are confined to a small area of the squamule. K-. Becomes more cryptic at higher elevations where it can be confused with poorly developed *L. polytropa* squamules. Generally in heavily shaded situations under rocks. This is the same species that I had previously recorded as *Lecanora* sp.

Lecidea baileyi – I had previously referred to this as *Buellia* 3. It is the extremely common areolate crust in the summit area. The squamules are flat and light brown in the shade but become increasingly convex and a more chestnut brown when exposed to black when moribund. The hypothallus is inconspicuous in the shade but black when exposed. I have not seen any mature spores, not even semi-mature spores in the ascus.

Lecidea ?*maunakeae* – thallus white, almost globose verrucae with numerous, small black apothecia. Similar to *L*. *maunakeae* but the blue-green epithecium is not K+ violet-red. See comments with Unknown 3.

Lepraria 'incana' – small, green with distinct blue tinge, leprose crusts over consolidated dust and old moss tussocks. Rare in deep crevices below TMT footprint.

Lepraria 'vouaxii' – small, green, thick, leprose crusts over consolidated dust. The deep, white lower crust often visible. Uncommon in deep crevices or at the back of small caves generally below TMT footprint. There is an additional but infrequent species in the area with yellowish leprose clumps.

Pseudoparmelia caperata – large, yellow foliose lichen generally on mamane though just above Hale Pohaku on decorticated branch.

Peltula euploca (Ach.) Poelt – on rocks in runoff drainage, frequently with mud and amongst mosses. Found in large gulch west of Hale Pohaku and above, also just above Hale Pohaku. There was also something very similar in a deep crevice just north of Pu'u Pohaku at the summit. Could not reach it for verification.

Physcia adscendens H. Olivier – on mamane at Hale Pohaku. Not found above this elevation.

Physcia dubia (Hoffm.) Lettau – Small light grey, foliose thallus with darker gray marginal soralia with a very few thalline erumpent lesions at base of laciniae with occasional soredia. Rare in protected crevices below the TMT footprint area with a moderately well-developed specimen west of the summit. Common in shaded areas at Hale Pohaku on rock. The depauperate specimens at the summit can be traced back to the form at Hale Pohaku through a series of increasingly typical specimens.

Pseudephebe miniscula – Black, highly branched, fruticose thalli in similar positions as *Umbilicaria decussata* with which it is generally found. Common in suitable sites along with *Umbilicaria*.

Rhizocarpon geographicum – Bright yellow-green squamules, generally with black apothecia. Present in exposed areas generally with *Umbilicaria* species.

Rinodina hawaiiensis – Gray, crustose thallus, with abundant, lecanorine apothecia with dark brown discs. Common on exposed rocks surfaces at Hale Pohaku but not above. There is an additional corticolous species with infrequent apothecia on a white thallus.

Umbilicaria decussata – black, often dusky, squamules, with ridges or crystals, up to 3 cm diam. Smooth underneath. Present on rocks at the summit. On exposed, vertical faces of north to north-east facing andesite rocks and other smooth basalt as well as some deep, somewhat open crevices with north-west to easterly exposure.

Umbilicaria ?*deusta* – Black, smooth upper surface. Lower surface without 'rhizines'. Found only at Sites 1 & 2.

Umbilicaria hirsuta – light grey squamule often tinged brown away from the centre. Obvious 'rhizines' on undersurface. Up to 4 cm diam. Confined to the southernmost plots in the study area other than one station to the west of the north face. Grows in similar position as other species of *Umbilicaria*.

Umbilicaria hyperborea – brown bullate squamules without rhizines on the lower surface. Found above Hale Pohaku is shaded situation. Found only at the summit at Pu'u Wekiu under a lava cave and overhang on the southern face.

Xanthomendoza fallax – This striking orange foliose lichen is common on old mamane trunks and occasionally on shaded rocks throughout Hale Pohaku and adjacent areas.

Unknown 1 – small, thin, light green. Nearly always in deep shade deep in rubble though occasionally deep in crevices. It may be more common than recorded because it is impossible to confirm possible thalli deep in crevices. Apothecia sunken but flush with the surface, with small, grey, asymmetric, uniseptate spores. Seen only once in lowermost site below TMT site.

Unknown 2 – dark grey but light grey in shade, brain coral-like laciniae in the center but margin is laciniate. Alga green. Sterile. Mixed in with *Umbilicaria decussata*. Only specimen seen in the area west of the summit. Found only at Site 18.

Unknown 3 – pale grey to white, thick squamules with a slightly mealy surface, with small black perithecia partially embedded in the squamule but sticking well up from the thallus. Spores simple, rugose, round, 11-14µ. Small thalli predominantly below the TMT footprint area but most abundant and well-developed west of the summit. Or are the perithecia a parasite on *Lecidea maunakeae*? Do not have enough good material to resolve at this time.

Unknown 4 – scattered, white to brownish grey, lumpy squamules over a black hypothallus with postulate soredia. Sterile. Found only at Site 18.

Appendix D3: Preliminary Report of Lichens of UHH Management Lands

Preliminary Report of Lichens of the UHH Management Lands on Mauna Kea

C. W. Smith (unpublished) – Submitted August 9, 2013

LICHENS OF THE MAUNA KEA SCIENCE RESERVE

This report is the latest version on several documents on the lichens of Mauna Kea that I have written over the last ten years. The list of lichen taxa in this area is replete with species identified only to genus, a very unsatisfactory situation. There are a number of species that are indeterminate even to genus. The problem is that the alpine ecosystem of Mauna Kea is a suboptimal environment for lichen growth due to its aridity. The matter is exacerbated by the fact that rain and snow fall has been significantly reduced over the past few years. Lichens can survive for considerable periods without moisture but they do require it for the production of reproductive bodies and spores, on which most determinations at the species level are dependent particularly for crustose species the dominant life form in the alpine area. Most lichens, especially those in the alpine zone have reproductive bodies that continue producing spores over several years. They will resuscitate when adequate moisture is available and resume development but only in cells that are in the early stages of spore development. They will continue development until the spores mature or the moisture is insufficient to continue whichever comes first. Therefore, even at the summit where there are periods of snow cover, the recent reduction in snow and rainfall has resulted in disabling many lichen species being able to complete the full cycle. Yet *Candelariella vitellina* and *Lecanora polytropa* do produce mature spores in the summit area suggesting that there are situations such as the pock-marked surface of the rocks holds enough moisture during the winter snow season to complete spore formation.

In fact, it is in the summit area that the lichens are at their highest abundance and cover but even there it is essentially inconspicuous except in the one exceptional case of the *Umbilicaria* community on the sheer faces of collapse andesite flow fronts. The attached two files give further details on the distribution and ecology of the lichens in the area.

ROAD CORRIDOR

We followed the road corridor up the mountain from Hale Pohaku sampling rock outcrops approximately every 500 m *[sites at intervals of 200 m elevation change. G. Gerrish*] expecting to find higher lichen species abundance and cover at the lower elevations. However, no such relationship existed.

A comparison of the lichen biota above and below the 9,000 ft contour on Mauna Kea is extremely obvious when seen driving up the mountain. Up until just above Hale Pohaku the vegetation is substantial with an obvious lichen component to the trained eye but immediately above it is totally absent. Though present it is sparse and confined to isolate pockets. The corticolous lichens at Hale Pohaku with the conspicuous fruticose *Usnea* ?*glomerata*, and foliose *Pseudoparmelia caperata, Xanthomendoza fallax* and *Physcia adscendens*, dependent on tree branches and bark, are absent from the shrubs above. The dramatically reduced rainfall and cloud cover does not support even corticolous crustose species in sheltered situations. The saxicolous species are similarly affected. The species composition changes dramatically in terms of species and abundance. Three species are found across the whole transect up the mountain: *Candelariella vitellina, Lepraria 'incana',* and *Rhizocarpon geographicum.* A few species are found just above the tree line but no further: *Heterodermia albicans, Lecanora muralis* (abundantly fertile below but small and sparsely fertile above)*, Pseudoparmelia caperata* (a conspicuous yellow foliose lichen on mamane but fragmentary and lignicolous above)*, Peltula euploca* (common adjacent to water seeps in gulleys below the tree line and extremely rarely as very poorly developed squamules just above in very sheltered areas with a possible occurrence at the summit)*, Physcia dubia* (as sparse, poorly developed laciniae above even at the summit) and *Xanthoparmelia wyomingensis* (yellow saxicolous and fertile around Hale Pohaku but rare above and not fertile).

The lower abundance of lichens in the lower reaches of the alpine zone is attributed to:

- The relatively low extent of areas with stable surfaces at least along the transect though there may be a greater abundance of rocky outcrops on other slopes,
- The moderate slope other than on the cinder cones in the summit area probably result in moisture remaining on the surface for longer periods of time,
- The presence of snow and the longevity of its presence providing almost continuous moisture for days or weeks at a time, and
- The almost absence of heavily sheltered areas (small caves, crevices and cavities within sizeable lava stacks).

Though it had been surmised prior to this survey that dust created by traffic travelling up and down the road over the years would have had a negative impact on the lichens along the road corridor casual observations on both sides of the road were insufficient to answer the question because the number of sampling points where lichens were present was totally inadequate. Therefore, the road corridor is in an area where potential environmental impacts on the lichen biota might be a management consideration their presence is negligible.

SUMMIT SCIENCE RESERVE

There are two major lichen communities on the summit of Mauna Kea: the north-facing collapsed andesite lava fronts and the hollow, interior of large lava bubbles.

Lava front. The most visually obvious, substantive lichen community in the summit area is dominated by *Umbilicaria decussata* which is nearly always accompanied by *Pseudephebe minuscula* and generally *Rhizocarpon geographicum* and *Lecidea baileyi*. Where the community occurs it is substantial but its cover was not captured in a formal survey of the area in 2010 for two reasons: none of the places where these communities are found occur within the study plots, and, the intercept for cover classification is a point vertical to the surface of the ground not the individual rock face. The community is confined to the exposed north to north-east facing vertical faces of andesite blocks which suggests that special conditions allow growth there but not elsewhere. Since the community is only found in this position, conditions on flat rock surfaces and other aspects are probably too severe (e.g., inimical daily temperatures, free water runs off rapidly) to allow establishment or growth since the community is not found on other exposed andesite surfaces, either horizontal or vertical surfaces facing in other directions, and there are no isolated thalli elsewhere. The most notable distinction about the aspect of the habitat is that it is shielded from direct insolation for much of the year.

Hollow lava bubbles. The most accessible and prominent example is on the south-west slope of Pu'u Wekiu about 50 m above the road. The bubble is over 3m tall with a south-west facing opening large enough for one to almost squeeze into the hollow interior. Much of the interior surface rock is cover with lichens with *Umbilicaria* species intermixed with *Rhizocarpon geographicum* and *Pseudephebe pubescens* and occasional *Candelariella vitellina* around the opening. Further in there are fragments of *Physcia dubia* and a fairly good cover of a *Buellia* sp. This community is protected from direct sunlight for most of the day; in fact, it feels decidedly cool inside even when it is hot in the direct sunlight. Any moisture from snowdrift or cloud mist is also protected from desiccating winds.

Similar assemblages of lichens including *Lecidea baileyi* but in smaller and more diffuse assemblages are found in well-protected crevices in rocks or among large boulders particularly in the west facing cliff immediately to the north of Pu'u Pohaku. In both of these situations there are some *Lepraria* like as well as what superficially looks like *Peltula euploca* but they are not reachable. One can dislodge some of them but one cannot get the other hand below to catch the fragments as they fall deeper into the crevice or bubble.

Elsewhere the macrolichens are rarely found on the top of rocks but are either under overhangs, in crevices and other protected areas. Lower down the mountain *Umbilicaria* species can be found on open eastern facing rock faces. The summit of the mountain is well known for its dry air, the high number of cloud-free nights, and the stability of the atmosphere all of which suggest that climatic factors do not account for the very notable distinction in the distribution of the *Umbilicaria* community. However, there are topographical differences in the exposure of the andesite rock faces. Since lava flows down the mountain, the flow fronts face in the direction of the aspect of the mountain. It is the fronts and sides of the flows that appear to be the most fragmented such that on the northern side of the mountain most of the fragmented sections face north and on the southern side of the mountain they face southward. The upper area of the flow is protected by the mass of the flow around it and does not collapse. Since there are very few south-facing faces on the northern side of the mountain there is no opportunity for the *Umbilicaria* community to develop there. But even on the southern side of the mountain the south-facing faces are generally free of lichens possibly due to the effects of insolation because crevices and vertical faces with a more northerly aspect are covered with lichen particularly where shaded to some degree. This type of distribution can be seen around the Batch Area and on flows along the road to the VLBA telescope. This hypothesis needs further study.

A wet surface may be important for the initial establishment of a community because it is unlikely that the process could be initiated by a propagule absorbing water from the air. However, it is unlikely that such luxurious colonies (up to 100% cover in patches within the study area) could be maintained by the very infrequent precipitation events as the thalli would rapidly dry out in such a dry environment without further wetting even though shaded from direct sunlight. The absence of all cyanolichens (lichens with a cyanobacterium as the photosynthetic symbiont) which require full saturation of their thalli for growth also suggests that continuous wet conditions are rare. The humidity of the air probably exceeds the dew point every evening as the temperature rapidly drops. The three-dimensional structure of fruticose and foliose lichen thalli would be good sites to intercept such moisture. There is probably enough air movement caused by temperature changes during the evening hours sufficient to facilitate such absorption. This could be verified by visiting the colonies at dawn and checking whether or not the thalli are brittle.

Once a thallus, particularly a foliose or fruticose form, becomes established it will create its own microclimate around the thallus or within the branches. The establishment of its own propagules could be possible as well as enabling other species to establish. However, casual observations suggest that there is no close physical association of one species with another. Rather there are pockets of other species such as *Pseudephebe* in the same community but isolated from the dense *Umbilicaria*. The *Umbilicaria* probably overgrows all other species thus limiting the other species to peripheral situations. The initial colonization events would be few and far between. Most of the communities are large occupying much of the available habitat suggesting considerable antiquity, the result of their very slow colonization and growth. There are smaller, possibly younger, communities but they are quite rare.

The small cave communities are dominated by mosses, principally *Pohlia nutans* with a relatively higher cover than outside the cave of *Lecanora polytropa* and *Candelariella vitellina* frequently on the moss clumps and *Lepraria* in the deeper recesses. The moss clumps are often damp and ash deeper within is visibly damp. During the day the temperature is noticeably cooler inside these small caves. The water may come from percolation from above or snow, hail or rain blown in during storms but protection from the direct sunlight and wind also contributes by limiting evaporation. The porosity and water holding capacity of the lava above the caves is not known.

The occasional lichens and moss elsewhere occur predominantly on rough lava rocks or surfaces or in small cracks and crevices. Iron rich rocks (the redder rock) support the highest number of lichens in these situations. The cinder cones do not support any lichens other than on the occasional larger rocks but even they host few thalli of *Lecanora polytropa* and *Candelariella vitellina*. The substrate is too unstable to allow colonizing lichens to establish.

Though most of the lichens and mosses are on the surface of rocks or in protected situations, four species (*Acarospora* sp 3, *Buellia* sp. 1, *Lecanora* cf. s*ubaurea*, *L. polytropa*) are found on the undersurface of loose rocks (generally under rocks 10-20 cm diam.) or on the surface of rocks underlying other rocks up to depths of approximately 10 cm. These subsurface occurrences were recorded in 22 (76%) of the study sites. Though some lichens are known to prefer crevices and receded habitats, it is unusual that the species recorded here would occur in such a situation. However, in this very severe environment, the increased humidity under the rocks and protection from direct sunlight and wind provides a suitable habitat for survival. There is sufficient light to enable the lichens to grow but none of them have been sufficiently fertile to make any definitive disposition unless they are previously known elsewhere. The one record of *Umbilicaria decussata* was probably where a surface rock had been disturbed since this species requires full exposure for growth.

From a management perspective the most important consideration is to protect the stable rock formations through the whole area.

Respectfully submitted:

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Appendix D4: Excel Data File for Lichen Elevation Gradient Transect

Naming Conventions:

"cf." (confer) indicates a tentative identification at the species level.

Numbered species are assigned to genera but not yet identified to species

Names enclosed in single quotes (') indicate a form that may not have taxonomic authority.

"Undetermined" indicates collection have not yet been assigned to genera.

Elevation (m) of Collection Sites:

1 = 2,800	5 = 3,600
2 = 3,000	6 = 3,800
3 = 3,200	7 = 4,000
4 = 3,400	8 = Entire Astronomy Precinct

"X" indicates presence at collection site.

Lichen Name or Collection Number and Description	Collection Site							
	1	2	3	4	5	6	7	8
Acarospora cf. depressa							x	x
Acarospora sp. #1 (light brown squamules)				x				x
Acarospora sp. #2	x							
Acarospora sp. #3	x							
Acarospora sp. #4 (deep shade)							x	x
Acarospora sp.#5 (mounded thallus, brown squamulose)					x			x
Acarospora sp. #6 (several species, pruinose thallus)	x							
Acarospora sp. #7 (deep shade)	x							

Lichen Name or Collection Number and Description	Collection Site							
	1	2	3	4	5	6	7	8
Acarosproa sp. #8	x							
Aspicilia cf. desertorum	x							
Buellia cf. fuscochracea (small green squamules, black apothecia)	x							
Buellia cf. maunakeansis		x		x				
Buellia cf. punctiformis					x			
Buellia cf. punctulata		x						
Buellia cf. subdisciformis	x							
Buellia sp. #1	x							
Buellia sp. #2 (black, on mamane bark)	x							
Buellia sp. #3 (on shaded mamane wood, gray)	x							
Buellia sp. #4 (black & white-green)							x	x
Buellia sp. #5 (gray, large round apothecia)				x				
Buellia sp. #6 (grey squamulose)					x			
Buellia sp. #7 (pruinose disc)			x					
Buellia sp. #8 (very small. +others)	x							
Buellia sp. #9 (white, large flat apothecia)				x				
Buellia sp. #10 (white, pruinose apothecia)			x					
Buellia sp. #11 (on rock, small, cream colored, embedded black apo)	x							

Lichen Name or Collection Number and Description	Collection Site							
	1	2	3	4	5	6	7	8
Caloplaca lithophila	x							
Candelarilella vitellina	x	x	x	x	x	x	x	x
Carbonea vitellinaria			x		x			x
Diploicia canescens		x		x	x			
Heterodermia "albicans"	x	x	x					
Immersaria sp.					x			
Lecanora muralis	x	x	x					
Lecanora polytropa				x	x	x	x	x
Lecanora cf. subaurea								x
Lecidea baileyi		x	x	x	x	x	x	x
Lecidia cf. maunakeansis	x			x		x	x	x
Lecidia sp. (elevated true margin)			x					
Lepraria 'incana'	x	x	x	x		x	x	x
Lepraria 'vouaxii'							x	x
Lepraria sp.							x	x
Parmotrema sp.		x						
Peltula euploca		x						?
Physcia adscendens	x							
Physcia dubia	x	x	x				x	x
Pseudoparmelia caperata	x							
Pseudophebe pubescens					x		x	x

Lichen Name or Collection Number and Description	Collection Site							
	1	2	3	4	5	6	7	8
Rinodina sp. #2	x							
Umbilicaria decussata					x	x		x
Umbilicaria deusta					x			
Umbilicaria hirsuta		x	x	x	x	x	x	x
Umbilicaria hyperborea				x	x		x	x
Xanthomendoza fallax	x							
Xanthoparmelia wyomingensis	x	x						
Undetermined sp. #1 (bright green squamulose)		x						
Undetermined sp. #2 (chocolate brown apothecia with yellow margin)								x
Undetermined sp. #3 (creamy-yellow leprose mound)							x	x
Undetermined sp. #4 (flat, greenish-gray squamuloase)						x		
Undetermined sp. #5 (gray squamules, crystalline)								x
Undetermined sp. #6 (gray/blackish areolate w. erumpent soralia)					x			
Undetermined sp. #7 (green spp. w/soralia, under rock)					x			
Undetermined sp. #8 (grey squamulose with parasite, on soil in shade)		x						
Undetermined sp. #9 (lime green squamules with erumpent laminal soralia)					x			

Lichen Name or Collection Number and Description	Collection Site							
	1	2	3	4	5	6	7	8
Undetermined sp. #10 (orange, L. polytropa-like on rock, 70% exposed)						x		
Undetermined sp. #11 (orange/tan sp.)							x	x
Undetermined sp. #12 (white/tan-orange crustose on rock)							x	x
Undetermined sp. #13 (white/tan-orange crustose on rock)			x					