

**VEGETATION AND FLORA OF CERTAIN KIPUKAS,
EL MALPAIS NATIONAL MONUMENT, NM**

Submitted by
David L. Bleakly
Bleakly Botanical & Biological
3813 Monore NE
Albuquerque, NM 87110

Submitted to
Resource Management Specialist

December 1996

VEGETATION AND FLORA OF CERTAIN KIPUKAS, EL MALPAIS NATIONAL MONUMENT, NM

SUMMARY

The vegetation and flora of nine kipukas, of different substrates, ages, sizes, and locations, in El Malpais National Monument, Cibola county, New Mexico, are described and compared among themselves, to two nearby sedimentary outcrops off the flows, and to the lava flows surrounding them. Seven of the kipukas are entirely sedimentary, are covered mostly with pinyon-juniper woodlands and some smaller stands of ponderosa pine, and are vegetationally very similar to each other and to nearby sedimentary outcrops. Two kipukas with sand dunes contain some different plants, but otherwise are not much different than the other kipukas. Lava flows are always distinctive visually, geologically, and botanically from the kipukas. A plant species-area correlation among the kipukas is positive ($R^2 = 0.411$). Other tenets of the theory of island biogeography were not investigated in detail, but lava does not appear to be a barrier to plant movement between kipukas or between kipukas and off-lava habitats, and kipukas do not seem to be good models for testing the theory. Twenty plant taxa, all natives, and two families new to the list for the monument were found. Evidence for livestock grazing was present in two of the kipukas and likely in two others. Apparently devastating fires did not occur on the kipukas as a result of the lava flows that made them. Observational evidence suggests that the sand dunes found on two kipukas appear to have been in place before they were surrounded by lava.

INTRODUCTION

LITERATURE REVIEW

Literature concerning kipukas, in arid temperate habitats or elsewhere, is very sparse. Almost all research concerning the effects of volcanic activity on vegetation is focused on primary succession, the colonization of new, sterile cinder or lava landscapes. The scientific appeal of studying the relatively rare phenomenon of primary succession apparently far outweighs the study of the much more common situation of secondary succession in spite of its unusual occurrence on kipukas and its association with volcanic activity.

An almost astounding amount of information is available about the geological aspects of volcanic activity in Hawaii. But the few Hawaiian ecological studies, mostly concerning primary succession in tropical habitats, probably have little applicability to

temperate situations (Mueller-Dombois & Lamoureaux 1967; Smathers & Mueller-Dombois 1974). Some isolated, rare, and scattered volcanic occurrences, such as Mount St. Helens, Alaskan eruptions, Mt. Pelee in the Caribbean, and eruptions in the tropical Pacific, etc., may attract much attention and are reported in the literature, but these, too, have not occurred in temperate habitats and/or the volcanic extrusives have not been flowing lava. Volcanic activity worldwide is not as rare as the literature might suggest because usually only those eruptions that are easy to reach, near population centers, or that otherwise affect human activities receive attention (Chester 1993). Also the recent volcanic activity that has been well-reported often has been composed of ash or cinders falls or lahars, or both, which have different effects on vegetation than flowing lava. The physical isolation of most eruptions and the inherent danger in obtaining firsthand information on the effects of volcanic activity on vegetation account for the dearth of data.

Volcanic activity in North American is limited to the areas west of the eastern edge of the Rocky Mountains with almost all of the active volcanoes in the Cascade Mountains. Only a few continental interior volcanic fields in dry temperate habitats have been studied ecologically. Craters of the Moon National Monument, Idaho, and the lava field of which it is a part are the source of a few studies (Carter-Lovejoy 1982; Eggler 1941; Tisdale et al. 1965). Nothing but strictly geological literature has been found concerning the San Francisco Volcanic Field in Arizona. Several lava fields in New Mexico, including the Zuni-Bandera (of which ELMA is a part), have been dated or studied geologically, but only ELMA (Lindsey 1951; Lightfoot et al. 1994) and the Carrizozo lava fields (Shields and Crispin 1956) have been studied ecologically. It is indeed fortunate that such an isolated place as ELMA that poses little threat to human safety and that is less inviting, perhaps, to a biologist than a mountain range, has received any attention at all by ecologists and geologists.

KIPUKAS AT ELMA

Within the boundaries of the Zuni-Bandera Volcanic Field (ZBVF), the series of lava flows that comprises most of ELMA, are numerous kipukas of various ages, sizes,

and substrates. Their ages vary with the ages of the lava flows that surround the pre-existing surfaces that became kipukas. The sedimentary outcrops that became kipukas predate the emplacement all of the lavas in the ZBVF, and probably the dunes (located only in the northeastern part of the monument) also predated the emplacement of most or all the flows. (See the Discussion for more about the dunes.) Sizes vary from far less than an acre to many square miles. The outcrops are erosional remnants that were created after the rise of the Zuni Uplift from Permian, Jurassic, and Cretaceous limestones and sandstones.

Parts of any flow, except the McCartys, can potentially become kipukas, although apparently there are no Twin Craters flow kipukas (Maxwell 1986). Since it is the youngest, the McCartys cannot compose a kipuka although it often causes the formation of them. Some of the largest kipukas are not located within the boundaries of the monument (e.g., Hole-in-the-wall and Cerritos de Jaspe) although a large Hoya kipuka, mostly within the park, is located in the northeast.

Substrates can be an older flow, an outcrop of sedimentary rocks (Permian, Jurassic, or Cretaceous limestones and sandstones), or, rarely, sand dunes (only in the northeast part of the monument). Conformationally, kipukas are of two types. Sedimentary outcrops taller than the depth of the surrounding flow will naturally form a kipuka. But many lava kipukas are "flat" and the surrounding flow may form a more-or-less level plain or a very irregular surface with low relief. Usually a "wall" is present at the boundary.

ISLAND BIOGEOGRAPHY

Kipukas (islands of older substrate surrounded by a wide expanse of inhospitable or barren lava) are analogous in some ways to actual islands. The theory of island biogeography (MacArthur & Wilson 1967) was developed in an attempt to explain observations of species' (mostly birds') distributions on oceanic islands, but the concepts were applied immediately to almost any other circumstance which could be considered islandlike, including individual host plants serving as islands for certain insects (Janzen 1968). The three major groups of issues addressed were (1) species-

area relationships; (2) colonization and extinction, which interact to produce a theoretical equilibrium in the number of species on a particular island. That is, there is a theoretical ideal equilibrium number of species that is determined by the size of the island and its distance from other islands and/or the mainland and by the balance between the rates of colonization and extinction. And (3) islands closer to the mainland contain more species than remoter islands. The species-area relationship refers primarily to islands being relatively low in number of species compared to continents or large land masses. Therefore, larger areas or islands support more species than smaller areas or islands for a variety of reasons. Truly isolated islands (e.g., Hawaiian islands, Madagascar), physically and/or temporally, house many endemic species probably because colonization is chancy and very infrequent and the successful immigrants supplied the genetic raw material for further evolution. Both colonization and extinction may be particularly important on small and/or remote islands.

While many biologists wholeheartedly embraced the theory of island biogeography, by the late 1970s, there were others who doubted its veracity in many cases (Gilbert 1980). In fact, most examples and experiments failed to support the theory because it oversimplified the complex ecology of islands of any type. Also in the 1970s, conservation biologists began to apply island biogeography theory to the study of remnant habitats for rare animals, reserve design, and especially proposed corridors for the movement of animals between isolated patches of suitable habitat. This field of endeavor has proceeded apace but recently some ecologists have questioned the effectiveness of corridors (Simberloff et al. 1992).

By extension of the above ideas, kipukas may be considered islands. Small kipukas may support fewer plants than larger ones. The sand dune kipukas in the neck area of ELMA may be considered simply another type of sedimentary kipuka. Or, because their ecology is so different than any other substrate in the monument, dunes may be conceived as islands of sand whether they exist in kipukas or as free-standing dunes away from lava flows. In another sense, the entire ZBVF itself may be considered to be two different types of islands simultaneously: (1) a mass of basalt flows in a sea of nonvolcanic rocks, and (2) a reverse island of relatively mesic habitat

surrounded by relatively dry landscape.

METHODS

Although five kipuka study areas were designated for investigation (in bold, Figure 1 and Table 1), two other kipukas, the lava flows surrounding the kipukas, and two nearby sedimentary outcrops composed of the same rocks as some of the kipukas, were surveyed in addition (Table 1). This was done to help reveal differences or similarities in vegetation, geology, and topography, if any, among and between these features.

Los Medanos had been visited once and the other kipukas several times since 1991. All were studied again in July and August 1996. The majority of each kipuka was inspected carefully by investigating all apparent habitats, observing the geography and geology, and noting plants and evidence of wildfire and livestock use. Unknown plant species were collected for later identification. A list of plants noted in all the study areas is presented in Appendix A. Since some kipukas were visited more than others, these will have more complete species lists. No observations were made of animal life.

RESULTS

Of the nine kipukas investigated (Table 1), all but two sand dune kipukas (Los Medanos [LOME] and Los Medanos Southeast [LOMEse]) are sedimentary outcrops. Geological information about the kipukas is mostly from Maxwell (1986) and partly from Condon (1989). Mesita Blanca (MEBL), Mesita Blanca Southeast (MEBLse), Hidden Kipuka (HIDD), and Encerrito (ENCE) are composed of tall outcrops of Permian sandy limestones from three different map units which, to me, are not visually distinguishable in the field. The formations or map units are, from oldest to youngest, Yeso (Py), Glorieta Sandstone (Pg), and San Andres Limestone (Psa). Vegetation is similar on these four kipukas, regardless of the map unit. Some portions are distinctly more calcareous than others and often display pits and channels caused by slightly acidic precipitation.

A black and white topographic map of a mountainous region, likely in the Andes. The map features a grid system and various place names. In the upper left, 'SABL' and 'LOME' are visible. Below them, 'ENCE' and 'LOMEse' are labeled. To the right, 'MCCA' is marked. Further right, 'NTKI', 'MTKI', 'STKI', and 'NPSS' are listed. In the lower left, 'BANDI', 'HIDD', 'HOYA', 'MEBL', and 'MEBLse' are labeled. The map shows contour lines, a river, and a road. A compass rose indicates North.

The Three Kipukas (THKI) consist of Jurassic and/or Cretaceous sandstones. What was called Zuni Sandstone (Jurassic) by Maxwell (Jz, 1986) is now called the eolian facies of the Recapture Member of the Morrison formation (Condon 1989). The Cretaceous map unit (Kdo) on THKI apparently consists of part of the Dakota Sandstone. The Jurassic sandstone forms cliffs and the softer Cretaceous material has formed gentler slopes.

LOMEse is composed entirely of sand dunes. LOME is about half sand dunes and half Hoya lava. No rocks were observed in the dune areas of LOME or in LOMEse. The dunes apparently predate the formation of the kipukas in which they now exist (see Discussion). The two smallest sedimentary kipukas (South Three Kipukas [STKI] and North Three Kipukas [NTKI]) are nearly flat and without outcrops but contain abundant pieces of sandstone. The taller sedimentary kipukas (Middle Three Kipukas [MTKI], ENCE, MEBL, MEBLse, and HIDD) contain large rock outcrops and many rocks. All the study sites are described in detail in Appendix B.

All the sedimentary kipukas have a fringe of colluvium of varying width around most or all of the perimeter. In some cases, the colluvium appears to have covered lava that originally extended to the very base of the outcrop so that what appears now to be the edge of the kipuka, is in fact lava with a veneer of colluvium (e.g., ENCE, parts of HIDD, and perhaps others). The eroded material is deepest near the outcrop, in any case, but appears to be up to about 3 ft (0.9 m) deep in some places at the outer edge. This figure was inferred after noting that, occasionally, approximately three foot deep pockets in the lava could be seen near the edge of the kipuka, with the surface of the adjacent colluvium approximately level with top of the pocket. Colluvial fringes are grassy and much more open than the higher, rockier parts and support different plants, such as rabbitbrush (*Chrysothamnus* sp.), horsebush (*Tetradymia canescens*), fourwing saltbush (*Atriplex canescens*), and winterfat (*Krascheninnikovia lanata*).

The vegetation on the higher parts (the majority) of the sedimentary kipukas is mostly pinyon-juniper woodland with scattered small ponderosa pines. Near the edges of the kipukas and on pahoehoe portions of the surrounding lava flows, ponderosa pines predominate. In parts of some kipukas, such as MEBL, there are open ponderosa

woodlands on rocky shallow slopes. Aa lava anywhere in the monument, including near kipukas, is almost barren. Blue grama (*Bouteloua gracilis*) is most common grass on the kipukas and most other areas in the monument.

Table 1. Kipukas, lava flows, and other areas investigated during this study. Study areas: **BOLD** = target kipukas; *ITALIC* = lava flows studied; **NORMAL** = other areas; kipukas (target or not) followed by name of surrounding flow in parentheses.

STUDY AREA (lava flow in which kipuka is located)	ACRONYM	SUBSTRATE; COMMENTS	KIPUKA SIZE (acres)
South, Three Kipukas (THKI) (McCartys flow)	STKI	Jurassic sandstones	6.1
Middle, Three Kipukas (THKI) (McCartys flow)	MTKI	Jurassic & Cretaceous sandstones	164.6
North, Three Kipukas (THKI) (McCartys flow)	NTKI	Cretaceous sandstone	10.6
Los Medanitos, southeast (McCartys flow)	LOMEse	sand dunes	22.4
Los Medanitos, dunes (McCartys flow)	LOME-D	sand dunes; LOME-D & LOME-L are part of the same kipuka	88.2
Los Medanitos, lava (McCartys flow)	LOME-L	Hoya lava flow, mostly soil-covered (D + L = 162.2 ac)	74.0
North Pasture sandstone	NPSS	sedimentary outcrops (Jurassic & Cretaceous sandstones) near THKI	
Sandstone Bluffs	SABL	sedimentary outcrops (Jurassic & Cretaceous sandstones) near LOME	
<i>McCartys flow</i>	MCCA	McCartys flow near east side kipukas	
Encerrito kipuka (Twin Craters flow)	ENCE	Permian sandy limestones	50.0
<i>Twin Craters flow</i>	TWIN	Twin craters flow around ENCE	
Mesita Blanca, southeast (Hoya flow)	MEBLse	Permian sandy limestones, southeast of the larger, main MEBL	36.0
Mesita Blanca (Hoya flow)	MEBL	Permian sandy limestones	118.4
Hidden Kipuka (Hoya and Bandera flows)	HIDD	Permian sandy limestones	75.2
<i>Hoya flow</i>	HOYA	Hoya lava flow near MEBL & HIDD	
<i>Bandera flow</i>	BAND	Bandera flow near HIDD	

Some plants with flexible habitat requirements are found almost everywhere in monument, including the study sites. Excluding the gymnosperms, species found at six or more of the nine kipukas studied are listed in Table 2. These plants may be abundant at a site or merely present. Several others not listed are nearly as widespread.

Table 2. Widespread plants on study kipukas (6 or more of 9 kipukas).

skunkbush (*Rhus trilobata*)
fringed sage (*Artemisia frigida*)
cutleaf (*Bahia dissecta*)
white aster (*Chaetopappa ericoides*)
hairy goldenaster (*Heterotheca villosa*)
hyaline herb (*Hymenopappus filifolius*)
pingue (*Hymenoxys richardsonii*)
horsebush (*Tetradymia canescens*)
James hiddenflower (*Cryptantha cinerea*)
Colorado bladderpod (*Lesquerella rectipes*)
slimleaf plainsmustard (*Schoenocrambe linearifolia*)
blackspined hedgehog cactus (*Echinocereus coccineus*)
spiny star (*Escobaria vivipara*)
plains pricklypear (*Opuntia polyacantha*)
Fendler spurge (*Chamaesyce fendleri*)
Gambel oak (*Quercus gambelii*)
wavyleaf oak (*Quercus x pauciloba*)
wax currant (*Ribes cereum*)
Colorado four o'clock (*Mirabilis multiflora*)
New Mexico olive (*Forestiera pubescens*)
winged wild buckwheat (*Eriogonum alatum*)
James wild buckwheat (*Eriogonum jamesii*)
New Mexico fameflower (*Talinum confertiflorum*)
wholeleaf Indian paintbrush (*Castilleja integra*)
scarlet penstemon (*Penstemon barbatus*)
mountain mock vervain (*Glandularia wrightii*)
banana yucca (*Yucca baccata*)
birdbill dayflower (*Commelina dianthifolia longispatha*)
Fendler flatsedge (*Cyperus fendleri*)
blue grama (*Bouteloua gracilis*)
bottlebrush squirreltail (*Elymus longifolius*)
wolftail (*Lycurus setosus*)
mountain muhly (*Muhlenbergia montana*)

No state or federal listed threatened or endangered plant species were encountered during this study. *Mammillaria wrightii* Engelm. var. *wrightii*, that is found on STKI, MTKI, and NPSS and occasionally elsewhere in the monument, was considered endangered in New Mexico in 1994, but was downlisted to List 4 in 1995 in light of accumulating evidence that it is much more common in the state than previously thought (Sivinski & Lightfoot 1995). *Astragalus egglestonii*, a regional endemic found only in west-central New Mexico and extreme eastern Arizona, is present on HIDD and MEBL as well as in the higher northwestern part of the monument. However, it is not considered rare and is not listed as threatened or endangered.

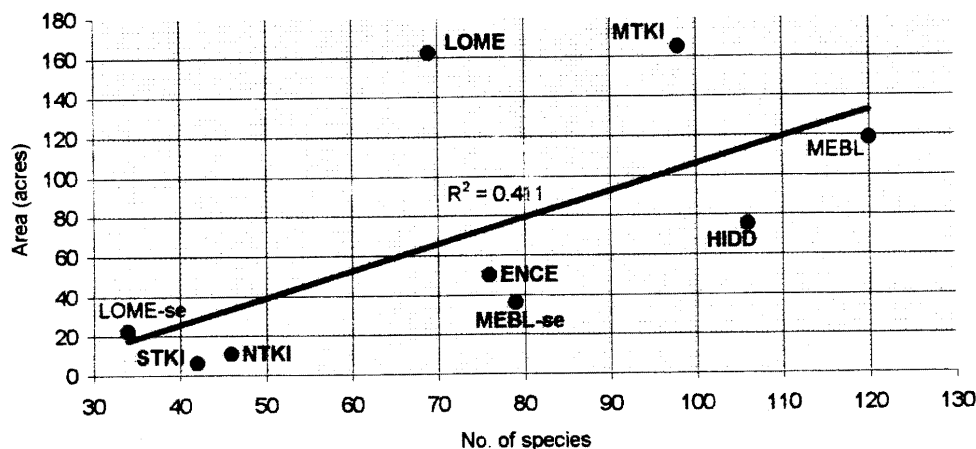
Only about seven alien plants were encountered (Appendix A; marked with @).

Mullein (*Verbascum thapsus*) is the most widespread alien and it seems to have become integrated into some areas without seriously disrupting the ecosystems. Introduced plants tend to be weedy and occasionally aggressive, but except for mullein, no evidence of spread or invasion is apparent.

Since the submittal of the biological inventory (Lightfoot et al. 1994), twenty additional plants, most of which were found during this survey, are now known to occur in ELMA (Appendix C). See a separate document for a complete and nomenclaturally updated list for the monument.

There is good correlation between area and species diversity among the study kipukas ($R^2 = 0.411$; Figure 2). The slope of a regression line and the R^2 value are used to indicate the intensity of the association between two variables. A perfect correlation has an R^2 of 1 and a slope of 45° . No correlation has an R^2 of 0 and no slope (flat, horizontal line). Generally, an R^2 greater than about 0.25 is considered significant. The statistics found in Figure 2 indicate that the species-area hypothesis holds for the nine kipukas studied in ELMA. That is, the larger kipukas tend to support larger numbers of plant species. Mueller-Dombois and Lamoureux (1967) and Carter-Lovejoy (1982) found strong positive correlations between kipuka size and number of plant species. Other aspects of the island biogeography theory were not tested.

Figure 2. Species-area relationship among 9 kipukas.



Although most species show no obvious patterns in distribution among the study sites, some may be grouped in various ways. Several plants tend to be present in either the eastern or western portion of the monument (Table 3). This seemingly arbitrary distinction probably reflects basic differences in the abiotic environments between the two regions. The western part is higher in elevation, wetter, and cooler, contains kipukas with older sedimentary substrates, and consists generally of older lava flows with greater soil development. The eastern part is lower in elevation, dryer, and warmer, contains kipukas with younger sedimentary substrates or sand dunes, and consists predominately of the McCartys flow, the youngest, least soil-covered lava in the monument. Almost certainly the three correlated factors of elevation, precipitation, and temperature account for most of the east-west plant distribution differences among the study areas. Not considered in Table 3 are: the pigweeds (*Amaranthus* sp.), milkweeds (*Asclepias* sp.), rabbitbrushes (*Chrysothamnus* sp.), thistles (*Cirsium* sp.), wirelettuce (*Stephanomeria* sp.), rockcresses (*Arabis* sp.), goosefoots (*Chenopodium* sp.), unidentified milkvetches (*Astragalus* sp.), unidentified four o'clocks (*Mirabilis* sp.), unidentified broomrapes (*Orobanche* sp.), oxalis (*Oxalis* sp.), unidentified purslanes (*Portulaca* sp.), cinquefoils (*Potentilla* sp.), unidentified bromes (*Bromus* sp.), most single records, and plants found apparently exclusively on lava flows. Often there are many other records compiled during the biological inventory (Lightfoot et al. 1994) of the plants listed in Appendix A from sites other than the study areas. These data are considered in determining the east or west distribution patterns outlined in Table 3.

One of the most unusual habitats in the monument, and indeed in the region, is sand dunes. The closest and only other dunes in the area known to me are near Laguna. Since physical and ecological conditions on dunes differ substantially from the surrounding substrates, in some senses, they may be considered islands (Pavlic 1985). As a group, psammophilic (adapted for growth in sand) plants have evolved life form, structural, and architectural modifications to help survival in this habitat. Because the dunes in the study areas cover only a few acres, little specialization is apparent and no unusual species were observed. Several plants commonly found in sandy areas in the Southwest are present in the dunes: sand sage (*Artemisia filifolia*), gilia beardtongue

Table 3. Plants with predominately eastern or western distributions in ELMA.

WESTERN DISTRIBUTION

slender lipfern (*Cheilanthes feei*)
smooth cliffbrake (*Pellaea glabella*) [MEBL & HIDD]
alligator juniper (*Juniperus deppeana*) [HIDD only]
Rocky Mountain juniper (*Juniperus scopulorum*)
smooth sumac (*Rhus glabra*)
mountain springparsley (*Pseudocymopterus montanus*)
pearly everlasting (*Anaphalis margaritacea*)
pussetoes (*Antennaria parvifolia*)
Fendler hawkweed (*Hieraceum fendleri*)
New Mexico groundsel (*Senecio neomexicanus*)
Easter daisy (*Townsendia exscapa*)
creeping mahonia (*Mahonia repens*)
manyflower puccoon (*Lithospermum multiflorum*)
spreading sandwort (*Arenaria lanuginosa saxosa*)
Huachuca Mountain morningglory (*Ipomoea plummerae*)
threadstem spurge (*Euphorbia revoluta*)
catnip noseburn (*Tragia ramosa*)
Eggleston milkvetch (*Astragalus egglestonii*)
mountain goldenpea (*Thermopsis rhombifolia montana*)
Drummond false pennyroyal (*Hedeoma drummondii*)
bristle flax (*Linum aristatum*)
prairie flax (*Linum lewisii*)
New Mexico yellow flax (*Linum neomexicanum*)
scarlet beeblossom (*Gaura coccinea*)
tufted evening-primrose (*Oenothera caespitosa*)
redroot wild buckwheat (*Eriogonum racemosum*)

showy fameflower (*Talinum pulchellum*)
red raspberry (*Rubus idaeus strigosus*)
pygmy bluet (*Houstonia wrightii*)
quaking aspen (*Populus tremuloides*)
purplewhite owllover (*Orthocarpus purpureoalbus*)
woolly mullein (*Verbascum thapsus*)
nodding onion (*Allium cernuum*)
big bluestem (*Andropogon gerardii*)
Indiangrass (*Sorghastrum nutans*)

EASTERN DISTRIBUTION

lesser spikemoss (*Selaginella densa*) [MTKI only]
maidenhair spleenwort (*Asplenium trichomanes*) [McCartys flow only]
Fendler springparsley (*Cymopterus acaulis fendleri*) [SABL only]
brownspine pricklypear (*Opuntia phaeacantha*)
sand sage (*Artemisia filifolia*)
ragwort groundsel (*Senecio multicapitatus*)
spectaclepod (*Dimorphocarpa wislizenii*)
cream pincushion cactus (*Mammillaria heyderi meiacantha*)
Wright nipple cactus (*Mammillaria wrightii*)
painted milkvetch (*Astragalus ceramicus*)
annual wild buckwheat (*Eriogonum annuum*)
alderleaf mountain mahogany (*Cercocarpus montanus*)
gilia beardtongue (*Penstemon ambiguus*)
pale wolfberry (*Lycium pallidum*)
prairie spiderwort (*Tradescantia occidentalis*)
Indian ricegrass (*Oryzopsis hymenoides*)
tumblegrass (*Schedonnardus paniculatus*)
sand dropseed (*Sporobolus cryptandrus*)

(*Penstemon ambiguus*), sandhill muhly (*Muhlenbergia pungens*), dropseeds (*Sporobolus* sp.), tumblegrass (*Schedonnardus paniculatus*), and Indian ricegrass (*Oryzopsis hymenoides*). At least at ELMA, a number of plants seem to be found only or mostly on lava. Such plants found on the study sites include: grass fern (*Asplenium septentrionale*), male fern (*Dryopteris felix-mas*), Plummer woodsia (*Woodsia plummerae*), taperleaf (*Pericome caudata*), Mogollon geranium (*Geranium lentum*), New Mexico giant hyssop (*Agastache pallidiflora*), western virgin's bower (*Clematis ligusticifolia*), rock spirea (*Holodiscus dumosus*), quaking aspen (*Populus tremuloides*), Arizona grape (*Vitis arizonica*), least muhly (*Muhlenbergia minutissima*), and witchgrass

(*Panicum capillare*). These plants relatively mesically adapted, so in effect the lava flows are wetter and thus more suitable than the nearby habitats. This supports the contention that lava flows are in some ways mesic islands in a relatively dry landscape. The same effect was observed in the lava beds near Carrizozo, New Mexico by Shields and Crispin (1956).

COMPARISONS BETWEEN AND AMONG SITES

All the kipukas are visually distinct from the surrounding lava flows in topography, vegetation, and substrate. They are lower or taller than the surrounding lava, are usually vegetated more densely by some different plants (and fringed by a ring of tall ponderosa pines), and are composed of light-colored rocks or sand that contrasts markedly with the dark, lichen-covered basalts surrounding them. Overall, the vegetation among all the sedimentary study kipukas is remarkably similar and is quite different than lava vegetation. Because of deep sand, LOME and LOMEse support several plants not found on the other kipukas but found on SABL (see below). Soil and substrate characteristics probably account for most of the differences in plant species composition between sedimentary sites and lava flows.

Unfortunately there are no data on the plants of Cebollita Mesa or the sedimentary areas of the Zuni Mountains, the nearest "mainlands". There are strong obvious similarities and a few differences between and among MTKI and the nearby outcrops at the edge of the flow (SABL and NPSS). Since STKI and NTKI are so small, it is difficult to compare them with the outcrops or MTKI and so they will be compared mostly between themselves. The part of SABL that has been surveyed for plants is approximately twice the size of MTKI, the largest kipuka in the study, and the surveyed part of NPSS is about the same size as MTKI. All three areas support similar numbers of plants (mean about 95) and consist of the same substrates (Jurassic and Cretaceous sandstones). Some plants are found in all three locations, many are present in two out of three sites, and several are found in only one. SABL is probably the sandiest of the three areas and therefore has several sand-loving plants on it that have not been found

on the other kipukas except LOME (e.g., sand sage, painted milkvetch, gilia beardtongue, sandhill muhly, Indian ricegrass, and spike dropseed). SABL is also the only one of these three that is accessible by vehicle; therefore it contains more weedy plants than the others (e.g., common ragweed, field bindweed, redstem stork's bill, and Lehmann lovegrass).

Because they are near MTKI, SABL, and NPSS and consist of the same substrates, STKI and NTKI are like them botanically, but apparently because they are smaller, they are depauperate in number of plant species. The plants on the two small kipukas are fairly similar to each other in spite of being composed of different substrates. However, NTKI contains some denser, possibly more saline soils than STKI that support species not found on STKI (e.g., dwarf rabbitbrush, horsebush, and fourwing saltbush).

Encerrito kipuka (ENCE) is approximately intermediate in location between the eastern and western sets of kipukas. However, it is composed of slightly older material than the others (Py, Permian Yeso formation). And, of all the sites, it is nearest the Zuni Mountains and the Twin Craters lava flow, the second oldest of the newer lava flows. It shares some plant distribution characteristics with the western kipukas (e.g., slender lipfern, greenthread, threadstem spurge, Drummond falsepennyroyal, prairie flax, and showy fameflower). On the other hand, fourwing saltbush and fragrant ash (*Fraxinus cuspidata*), found mostly in the northeastern part of the monument, are also present on ENCE. Nevertheless, its vegetation does not appear to be significantly different than that on the other sedimentary study kipukas.

The western kipukas, HIDD, MEBL, and MEBLse, are very similar vegetationally to the other sedimentary kipukas. MEBL and MEBLse are accessible by road and to cattle, so the potential for disturbance is relatively high, especially if MEBL is developed for greater visitor useage.

DISCUSSION

SUCCESSION ON KIPUKAS

Succession on kipukas is one of the foci of this project. Any succession occurring on kipukas immediately after their formation would be secondary, the type that begins after fires, floods, or on abandoned pastures or agricultural fields, etc. Although vegetation is damaged, removed, or destroyed, the soil or underlying substrate is not significantly compromised and some roots, seeds, and spores survive. On the other hand, primary succession occurs on sterile, virgin substrates, such as lava flows and deep cinder fields. Therefore, both types of succession are possible in ELMA under different circumstances.

For succession to come about, a disturbance of the ecosystem, large or small, such as those listed above, is a prerequisite. However, the evidence I have found about the effects on vegetation of the emplacement of lava flows indicates that kipukas and nearby areas not covered by lava were not seriously disturbed by fires started by the lava flows.

Although it might seem obvious that extensive wildfires would occur near an active lava flow, apparently in most cases this is not true. I have found no references in the scientific literature concerning wildfires being caused by lava flows. Only two descriptions of the effects of moving lava on forest trees were found in the literature: Eggler (1948) of aa lava flows from the volcano El Paricutin in Mexico and MacCaughey (1917) in Hawaii. Eggler reported that the speed at which the aa moved varied from greater than 15 feet per minute (usually nearer the source) to only a few feet an hour or day (along broader fronts farther from the source). More than 140 trees were overtaken by the lava during three hours of observation. Most of them were simply pushed over and buried by the flow and were not seen to burn (they were undoubtedly consumed eventually). Rarely a tree fell backward onto the flow surface and burned. Not uncommonly, a tree was left standing, completely surrounded by lava, after the flow front had passed; these trees were not incinerated. Eggler's explanation of the

seemingly impossible situation of trees being engulfed by a lava flow but not burning is fairly simple. Aa lava moves slowly enough that the surface and front edge become relatively cool and some lava solidifies. As the flow moves forward, pieces break off the upper front, drop to the flow's foot, and insulate the main mass of the flow as it progresses. Eggler concluded that most of the damage to trees was caused by mechanical forces rather than from fire or radiant heat (which was surprisingly little).

MacCaughey's (1917) descriptions of aa and pahoehoe flows moving through forests in Hawaii are in some ways similar to Eggler's. Slow-moving aa flows can flatten and destroy (but not necessarily burn) a forest and faster-moving pahoehoe flows can stream between trees and leave some or many of them standing without their bursting instantly into flame. MacCaughey also describes the formation of tree molds. Several occurrences of tree casts are well-known in ELMA, particularly on the Bandera flow near Dave Candelaria's old trading post. However, it is not known if the trees originally found in the molds burned shortly after engulfment or if they remained standing and decomposed later.

A proposed sequence of events that lead to the creation of a particularly interesting tree mold in pahoehoe lava at the edge of a small kipuka in the McCartys flow may contribute to a better understanding of the effects of moving lava on trees in ELMA (personal observation). An unusually round, symmetrical hole, about a foot in diameter, opening horizontally, that at first appeared to be a small surface tube, was found to be the mold of the base of a tree, probably a ponderosa or something about the same size. The tree had been engulfed by about two feet of lava and had fallen onto the still fairly soft surface and created a troughlike depression about 6 inches deep, 12 inches wide, and 10 feet long. Before falling, the tree had apparently burned to the point that its branches were reduced to stubs because the casts of two can be seen on the lava surface. The lava then cooled enough to retain the impression of the tree's shape. The tree either finished burning at that time or it decomposed later. The mold of the tree base pinches out at the bottom (or end) of the hole and impressions of charred wood are unmistakable, indicating that the tree may have burned almost through before falling or being pushed over. These observations suggest that this flow

was hotter than that described by Egglar, mostly because the tree was apparently burning while it was still standing, and more similar to some pahoehoe flows described by MacCaughey.

From the limited available evidence, it appears then that most active lava flow fronts are relatively cool and probably ignite only the low-stature vegetation in direct contact with the lava and shortly thereafter bury it. Low plants are simply overwhelmed and smothered before they have a chance support the spread of any fire that may have started. Even faster moving, hotter flows may very well outrun and smother any fires that they start. Special circumstances such high winds, abundant, dry fuel, etc., could, of course, support a wildfire that might actually spread and then behave like a wildfire ignited by other means. Any trees that were still standing after the passage of the flow front, even if they were aflame, would be unable to contribute to a wildfire since they would be surrounded by lava.

The likelihood of wildfire may have been different in the past if community structure was significantly different than that found recently. Community structure and vegetation density during the Holocene has remained fairly uniform on the Colorado Plateau (Betancourt 1990), so at least for the McCartys flow (emplaced about 3000 years ago [Laughlin et al. 1993]) any fires that might have started would probably behave similarly to those occurring today. Thus some fires would burn lightly and others intensely, depending on fuel load, fuel moisture, season of eruption, habitat type (grassland, woodland, etc.), and other factors. Because the vegetation was probably very different in many respects during the Pleistocene, such as higher density of shrubs or grasses or flammable fuels, fires that might have occurred then may have behaved differently than those that occur now.

My unanticipated conclusion is that areas near the ELMA lava flows, including kipukas, were not seriously damaged by fire when the flows were active and that probably only minimal secondary succession occurred in some locations. Any vegetation destroyed or damaged by fire initiated by lava would likely recover quickly. Fire has been a factor in the evolution of the communities in ELMA for hundreds of years (Grissino-Mayer & Swetnam 1995), so any lava-caused fires could be taken in

stride by the vegetation. After recovery, kipukas and other areas not covered by lava would act as sources of propagules for primary succession on the lava flows.

ISLAND BIOGEOGRAPHY

It is tempting to apply island biogeography theories, in particular the colonization/extinction and remoteness aspects, to terrestrial analogs such as kipukas in lava flows. However, there is little if any evidence, particularly relating to plants, that oceanic and terrestrial islands are comparable. Beyond support for the species-area correlation on kipukas, Carter-Lovejoy (1982) obtained no evidence to support the main tenets of classical island biogeography at Craters of the Moon. He determined that, while small kipuka size precluded the establishment of some vertebrates, lava proved to be no barrier to dispersal of plants or animals. At ELMA, no evidence has been found during this or a previous study (Lighfoot 1994) that kipukas are isolated from colonization in the sense of true islands. Kipukas, or lava flows, for that matter, are simply habitat islands that differ physically, chemically, or in other ways from the surrounding substrates in the same way that gypsum outcrops, riparian areas, or mountain tops differ from their surroundings. Conceptually, kipukas in lava flows are indeed islandlike, but I conclude that they do not provide good models for testing the theories of island biogeography mostly because of lack of barriers to dispersal.

KIPUKAS WITH DUNES

Although they constitute only a very small portion of El Malpais, sand dunes in kipukas are unique and fascinating features. According to Bryan and McCann (1943) small dunes are present in several areas near Grants, but they make no mention of the dunes in the lava flows to the south. Several large eolian, presumably dune, kipukas are indicated in Maxwell's (1986) map north of Los Medanos (LOME) mostly off the monument. According to Maxwell (1986), these dune kipukas and other eolian depositions are all of Holocene age (<10,000 years old).

The dunes in LOME and LOMEse are mostly stabilized by vegetation. Almost no sand from LOMEse has blown onto the surrounding McCartys flow. A relative small

amount of sand has moved onto parts of the contiguous Hoya flow on LOME, but essentially none has blown onto the McCartys. Since there is little evidence of sand movement either to or from the dunes in the kipukas, I suspect that the dunes were present before at least some of the ZBVF flows were emplaced and certainly before the McCartys was deposited. The following sequence is suggested as a theory for the origin of the dunes and their location in the lava flows.

Since dunes are windblown features, the sand that comprises them is transported from another location, that is, dunes do not arise in situ from the decomposition of stone. No sandstone outcrops or loose stones were observed on LOME or LOMEse. The sand in the dunes of Great Sand Dunes National Monument, Colorado, was blown by prevailing southwesterly winds from ancient Rio Grande deposits to the west (Johnson 1971). Thus, since the winds in the ELMA area are predominately southwesterly, it seems that the sand in the dunes in the neck area of the monument (between the southeast end of the Zuni Mountains and the northwest corner of Cebollita Mesa), including LOME and LOMEse, probably came from deposits southwest of the dunes' current positions. The source of the sand is unknown but could have been a dry lake bed or other deflationary feature upwind. A lake may have formed behind one of the earlier flows of the ZBVF in a pluvial episode during the last glaciation and then dried at the end of the Pleistocene when the climate warmed. Sand from the lake bed could have blown across an area presumably relatively unimpeded by lava flows. The dunes appear to have formed sometime after the emplacement of the Hoya flow and before the Bandera (and of course the McCartys). They then became kipukas like other tall outcrops which could not be inundated by subsequent lava flows.

RECOMMENDATIONS

MANAGEMENT

No unnatural or adverse ecological trends or circumstances on the kipukas were noted during this study. The kipukas are fairly inaccessible to most visitors, and, except

for grazing and some roads, human disturbance seems minimal and is likely to remain so as long as the kipukas are not developed for recreational use. Kipukas appear to be more susceptible to disturbance than the flows because they are easier to traverse and are obvious locations for camping areas, trails, and fires. For ecological reasons if nothing else, the kipukas should be left undeveloped if possible.

FUTURE WORK

Most rephotographic projects rely on poorly documented images (if any can be found at all of the area of interest) that were taken without the intention of rephotography (Wright and Bunting 1994). Generally no systematic attempts were made by the original photographers to cover all habitats and/or possible sites that could be useful for comparison in the future. It would be worthwhile to design a rephotographic project with the future in mind. The primary objective would be to look for and document vegetation change via photographs and associated written descriptions. Quantitative vegetational data could be collected, if appropriate. These photographs would also be useful historically, culturally, geologically, and likely in other areas. A search should be made of USGS archives and other sources for documented photographs of ELMA. All of Lindeys's 1930s and 1940s sites should be rephotographed as accurately as possible. Detailed location data (using GPS, if possible), site descriptions, and exposure information should be kept for all photographs. These and other old sites should be rephotographed at intervals. In addition, as much as possible of the remainder of the monument should be photographed to form the nucleus of the next round of photos in these areas. Kipukas could be emphasized as well as sites of future development (e.g., campgrounds, buildings), flow edges, and so on. Low altitude vertical and oblique photographs of kipukas and other areas would be useful, also. Most research money is for projects with short lifespans and this project could fall into that category if the initial round of photographs and rephotographs was tied to a vegetation change project. The unique aspect would be that, while such a study could stand alone, it logically leads to other more detailed studies a few years later. The photographic results of such a project

would be a wide variety of images that would cover most of ELMA, physically and temporally, which would be useful immediately but even more so in the future.

The dunes may be worth more study. Additional floristic and vegetational data could be gathered from LOME and the other dune kipukas and compared to dunes off the ZBVF: in the Grants area, the Laguna dunes, and/or dunes elsewhere in the state or southwest.

Sunset Crater National Monument in the San Francisco Volcanic Field (SFVF) of northern Arizona is similar to ELMA in elevation, latitude, and age of flows. No ecological studies are known of the SFVF although a species list is available for Sunset Craters and Wupatki National Monuments (McDougall 1962). A comparison between the two monuments may benefit both areas and help lay the foundation for a better understanding of the ecology of volcanic areas in the Southwest.

LITERATURE CITED

- Allred, K.W. 1993. A field guide to the grasses of New Mexico. Agricultural Experiment Station, New Mexico State University, Las Cruces.
- Betancourt, J.L. 1990. Late Quaternary biogeography of the Colorado Plateau. In: J.L. Betancourt, T.R. Van Devender, and P.S. Martin, eds. *Packrat middens: the last 40,000 years of biotic change*. The University of Arizona Press, Tucson. Pages 259-292.
- Bryan, K. and F.T. McCann. 1943. Sand dunes and alluvium near Grants, New Mexico. *American Antiquity* 3:281-290.
- Carter-Lovejoy, S.H. 1982. The relation between species numbers and island characteristics for habitat islands in a volcanic landscape. *Great Basin Naturalist* 42(1):113-119.
- Chester, D. 1993. *Volcanoes and society*. Edward Arnold, London.
- Condon, S.M. 1989. Modifications to Middle and Upper Jurassic nomenclature in the southeastern San Juan Basin, New Mexico. In: O.J. Anderson et al., eds., *Southeastern Colorado Plateau*. New Mexico Geological Society 40th Field Conference Guidebook. Pages 231-238.
- Eggler, W.A. 1941. Primary succession on volcanic deposits in southern Idaho. *Ecological Monographs* 11(3):277-298.
- Eggler, W.A. 1948. Plant communities in the vicinity of the volcano El Parícutin, Mexico, after two and a half years of eruption. *Ecology* 29(4):415-436.
- Flora of North America Editorial Committee, eds. 1993. *Flora of North America*, Volume 2 (pteridophytes and gymnosperms). Oxford University Press, New York, NY.
- Gilbert, F.S. 1980. The equilibrium theory of biogeography: fact or fiction? *Journal of Biogeography* 7:209-235.
- Grissino-Mayer, H. and T.W. Swetnam. 1995. Effects of habitat diversity on fire regimes in El Malpais National Monument, New Mexico, in: J.K. Brown, R.W. Mutch, C.W. Spoon, and R.H. Wakimoto, tech coords. *Proceedings: symposium on fire in wilderness and park management, 1993 March 30-April 1, Missoula, MT*. General Technical Report INT-GTR-320. Ogden, UT: USDA Forest Service, Intermountain Research Station. Pages 195-200.
- Janzen, D.H. 1968. Host plants as islands in evolutionary and contemporary time. *American Naturalist* 102:592-595.
- Johnson, R.B. 1971. The great sand dunes of southern Colorado. In: H.L. James, ed. *Guidebook of the San Luis Basin*, New Mexico Geological Society, 22nd Field Conference, pages 123-128.
- Kartesz, J.T. 1994. *A synonymized checklist of the vascular flora of the United States, Canada, and Greenland*. Timber Press, Portland, OR.
- Laughlin, A.W., R.W. Charles, K. Reid, and C. Whitel. 1993. Field-trip guide to the geochronology of El Malpais National Monument and the Zuni-Bandera volcanic field, New Mexico. Bulletin 149. New Mexico Bureau of Mines & Mineral Resources, New Mexico Institute of Mining & Technology, Socorro, NM.

- Lightfoot, D.C., D.L. Bleakly, R.R. Parmenter, & J.R. Gosz. 1994. Vegetation and wildlife inventory of El Malpais National Monument. Final Report. University of New Mexico, Department of Biology.
- Lindsey, A.A. 1951. Vegetation and habitats in a southwestern volcanic area. *Ecological Monographs* **21(3)**:227-253.
- MacArthur, R.H. & E.O. Wilson. 1967. The theory of island biogeography. Princeton University Press.
- MacCaughy, V. 1917. Vegetation of Hawaiian lava flows. *Botanical Gazette* **64**:386-420.
- Maxwell, C.H. 1986. Geologic map of El Malpais lava field and surrounding areas, Cibola County, New Mexico. USGS map I-1595.
- McDougall, W.B. 1962. Seed plants of Wupatki and Sunset Craters National Monuments. Museum of Northern Arizona Bulletin 37. Northern Arizona Society of Science and Art, Inc., Flagstaff.
- Mueller-Dombois, D. and C.H. Lamoureux. 1967. Soil-vegetation relationships in Hawaiian kipukas. *Pacific Science* **21**:286-299.
- Pavlik, B.M. 1985. Sand dune flora of the Great Basin and Mojave Deserts of California, Nevada, and Oregon. *Madrono* **32(4)**:197-213.
- Robinson, S. 1994. El Malpais, Mt. Taylor, and the Zuni Mountains, a hiking guide and history. University of New Mexico Press, Albuquerque.
- Rollins, R.C. 1993. The cruciferae of continental North America. Stanford University Press, Stanford, CA.
- Shields, L.M. and J. Crispin. 1956. Vascular vegetation of a recent volcanic area in New Mexico. *Ecology* **37(2)**:341-351.
- Simberloff, D, J.A. Farr, J. Cox, D.W. Mehlman. 1992. Movement corridors: conservation bargains or poor investments? *Conservation Biology* **6(4)**:493-504.
- Sivinski, R. and K. Lightfoot. 1995. Inventory of rare and endangered plants of New Mexico. New Mexico Forestry and Resources Conservation Division; Energy, Minerals and Natural Resources Department. Santa Fe, NM.
- Smathers, G.A. and D. Mueller-Dombois. 1974. Invasion and recovery of vegetation after a volcanic eruption in Hawaii. National Park Service Scientific Monograph Series, Number five.
- Tisdale, E.W., M. Hironaka, and M.A. Fosberg. 1965. An area of pristine vegetation in Craters of the Moon National Monument, Idaho. *Ecology* **46(3)**:349-352.
- Wright, R.G. and S.C. Bunting. 1994. The landscapes of Craters of the Moon National Monument, an evaluation of environmental changes. University of Idaho Press, Moscow, ID.

Appendix A: Plants found on study areas

SCIENTIFIC NAME (synonym)	EAST									MID		WEST					COMMON NAME
	STKI	MTKI	NTKI	LOMEse	LOMED	LOME-L	NPSS	SABL	MCCA	ENCE	TWIN	HOYA	BAND	HIDD	MEBL-se	MEBL	
FERNS & ALLIES																	
SELAGINELLACEAE																	SPIKEMOSS FAMILY
Selaginella densa		1															lesser spikemoss
ASPLENIACEAE																	SPLEENWORT FAMILY
Asplenium septentrionale									1								grass fern
Asplenium trichomanes		1															maidenhair spleenwort
DRYOPTERIDACEAE																	WOOD FERN FAMILY
Dryopteris felix-mas									1								male fern
Woodsia plummerae									1				1		1		Plummer woodsia
PTERIDACEAE																	MAIDENHAIR FERN FAMILY
Cheilanthes feei										1				1	1	1	slender lipfern
Cheilanthes fendleri		1												1			Fendler lipfern
Pellaea glabella simplex +														1		1	smooth cliffbrake
GYMNOSPERMS																	
CUPRESSACEAE																	CYPRESS FAMILY
Juniperus deppeana															1		alligator juniper
Juniperus monosperma	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	oneseed juniper
Juniperus scopulorum									1				1	1	1	1	Rocky Mountain juniper
PINACEAE																	PINE FAMILY
Pinus edulis	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Colorado pinyon
Pinus ponderosa	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	ponderosa pine
DICOTS																	
AMARANTHACEAE							1		1								PIGWEEED FAMILY
Amaranthus sp. @																	1 pigweed
ANACARDIACEAE																	SUMAC FAMILY
Rhus glabra													1				smooth sumac
Rhus trilobata		1	1	1	1		1	1	1	1	1	1	1	1	1	1	skunkbush
APIACEAE																	PARSLEY FAMILY
Cympterus acaulis fendleri								1									Fendler springparsley
Pseudocymopterus montanus														1	1	1	mountain parsley
ASCLEPIADACEAE																	MILKWEED FAMILY
Asclepias sp.															1		1 milkweed
Asclepias asperula asperula		1						1				1					spider or poison milkweed
ASTERACEAE (COMPOSITAE)																	SUNFLOWER FAMILY
Ageratina herbacea (Eupatorium herbaceum)		1							1					1	1	1	white thoroughwort
Ambrosia artemisiifolia									1								common ragweed
Anaphalis margaritacea +															1		1 pearly everlasting
Antennaria parvifolia													1		1	1	1 pussytoes
Artemisia campestris pacifica		1			1	1	1	1	1								1 western sagewort
Artemisia carruthii	1	1							1	1	1	1	1				Carruth wormwood
Artemisia dracunculus										1							silky wormwood, tarragon
Artemisia filifolia					1	1			1								sand sage
Artemisia frigida	1	1	1	1			1	1	1						1	1	1 fringed sage
Artemisia ludoviciana								1	1						1	1	1 Louisiana wormwood
Bahia dissecta	1	1	1				1	1		1	1	1	1	1	1	1	1 cutleaf
Brickellia brachyphylla		1												1	1	1	1 plume brickellbush
Brickellia eupatorioides chlorolepis	1	1		1													southwest kuhnia
Chaetopappa ericoides (Leucelene ericoides)	1	1	1				1	1		1					1	1	1 white aster
Cirsium sp.		1						1		1		1			1	1	1 thistle
Conyza canadensis									1								Canadian horseweed
Dyssodia papposa (Tagetes papposa)																	1 fetid marigold, mayweed
Ericameria depressa (Chrysothamnus depressus)				1													dwarf rabbitbrush
Ericameria filifolia (Chrysothamnus greenei (Gray) Greene) +										1							Greene rabbitbrush
Ericameria nauseosa consimilis arta (Chrysothamnus nauseosus consimilis)																1	rubber rabbitbrush

Appendix A: Plants found on study areas

SCIENTIFIC NAME (synonym)	EAST									MID		WEST					COMMON NAME
	STKI	MTKI	NTKI	LOMEse	LOME-D	LOME-L	NPSS	SABL	MCCA	ENCE	TWIN	HOYA	BAND	HIDD	MEBL-se	MEBL	
Ericameria parryi attenuata (Chrysothamnus parryi attenuatus)													1				Parry rabbitbrush
Ericameria viscidiflora (Chrysothamnus viscidiflorus)		1															viscid rabbitbrush
Ericameria sp. (Chrysothamnus sp.)	1		1	1	1		1		1	1	1				1	1	rabbitbrush
Erigeron canus																1	hoary fleabane
Erigeron colomexicanus		1	1				1	1									running fleabane
Erigeron divergens								1			1						spreading fleabane
Erigeron flagellaris			1				1	1				1		1			trailing fleabane
Erigeron formosissimus formosissimus												1			1	1	beautiful fleabane
Erigeron speciosus												1					aspen fleabane
Gaillardia pinnatifida		1															Hopi blanket-flower
Grindelia aphanactis							1			1							mountain gumweed
Gutierrezia sarothrae	1	1	1				1			1				1	1	1	broom snakeweed
Helianthella quinquinervis														1			false sunflower
Helianthus petiolaris petiolaris								1									prairie or plains sunflower
Heliomeris multiflora nevadensis (Viguiera multiflora)									1								showy goldeneye
Heterotheca villosa		1	1	1	1		1		1	1		1	1	1	1	1	hairy golden-aster
Hieraceum fendleri												1		1			Fendler hawkweed
Hymenopappus filifolius		1		1	1	1	1	1		1				1	1	1	hyaline herb, woollywhite
Hymenopappus flavescens canotomentosus								1									yellow woollywhite
Hymenoxys richardsonii	1	1	1	1			1							1	1	1	pingue, Colorado rubberweed
Machaeranthera canescens glabra (Machaeranthera linearis)					1			1									hoary tansyaster
Machaeranthera gracilis (Haplopappus gracilis)						1	1										goldenweed
Machaeranthera pinnatifida pinnatifida (Haplopappus spinulosus)										1							goldenweed
Machaeranthera tanacetifolia								1									tansyleaf aster
Pericome caudata									1		1						taperleaf
Psilostrophe tagetina								1		1							woolly paperflower
Sanvitalia abertii		1				1		1				1		1	1	1	Albert creeping zinnia
Schkuhria multiflora								1									threadleaf
Senecio flaccidus flaccidus (Senecio douglasii longilobus)						1			1						1		Douglas groundsel
Senecio multicapitatus		1						1									ragwort groundsel
Senecio multilobatus	1	1	1				1	1	1								Uinta groundsel
Senecio neomexicanus mutabilis												1		1			New Mexico groundsel
Senecio sp.											1						groundsel
Solidago velutina (Solidago sparsiflora)														1			three-nerve goldenrod
Solidago wrightii adenophora								1									Wright goldenrod
Stephanomeria sp.							1							1	1	1	wire lettuce
Tagetes micrantha												1					licorice marigold
Tetradymia canescens			1			1	1			1				1	1	1	horsebush
Tetrandeureis argentea (Hymenoxys argentea)		1						1		1				1	1	1	bitterweed
Thelesperma megapotamicum							1			1					1	1	greanthread, Hopi tea
Townsendia exscapa							1										Easter daisy
Townsendia incana								1									hoary townsendia
Tragopogon dubius @			1				1		1			1					western salsify
Tragopogon pratensis @																1	meadow salsify
Verbesina encelioides								1									golden crownbeard
Zinnia grandiflora		1					1			1					1		Rocky Mountain zinnia
BERBERIDACEAE																	BARBERRY FAMILY
Mahonia repens (Berberis repens)												1		1	1	1	creeping mahonia
BORAGINACEAE																	BORAGE FAMILY
Cryptantha cinerea (Cryptantha jamesii)	1	1		1	1	1	1	1	1	1	1	1		1	1	1	James hiddenflower
Cryptantha crassisejala								1									plains cryptantha
Cryptantha fendleri							1										Fendler cryptantha

Appendix A: Plants found on study areas

SCIENTIFIC NAME (synonym)	EAST								MID		WEST					COMMON NAME	
	STKI	MTKI	NTKI	LOMEse	LOME-D	LOME-L	NPSS	SABL	MCCA	ENCE	TWIN	HOYA	BAND	HIDD	MEBL-se	MEBL	
Lappula occidentalis (Lappula redowskii)							1	1			1						stickseed
Lithospermum multiflorum														1			manyflower puccoon
BRASSICACEAE																	MUSTARD FAMILY
Arabis fendleri fendleri								1									Fendler rockcress
Arabis sp.		1	1				1		1			1				1	rockcress
Dimorphocarpa wislizenii	1	1		1	1		1	1									spectaclepod
Erysimum capitatum		1	1				1			1					1	1	plains or western wallflower
Lesquerella rectipes	1	1	1				1	1		1				1	1	1	Colorado bladderpod
Schoenocrambe linearifolia (Thelypodopsis linearifolia)	1	1				1	1	1			1			1	1	1	slimleaf plainsmustard
Thelypodium wrightii									1					1			Wright thelypod
Thlaspi montanum fendleri		1												1			alpine pennycress
CACTACEAE																	CACTUS FAMILY
Echinocereus coccineus (Echinocereus triglochidiatus melanacanthus)	1	1	1			1	1	1	1	1	1	1	1	1	1	1	blackspined hedgehog cactus
Echinocereus fendleri		1				1	1			1	1			1		1	Fendler hedgehog
Echinocereus triglochidiatus triglochidiatus								1									claret cup cactus
Escobaria vivipara (Coryphantha vivipara)	1	1	1			1		1	1	1		1		1		1	spiny star, Arizona beehive cactus
Mammillaria heyderi meiacantha		1					1										cream pincushion cactus
Mammillaria wrightii wrightii	1	1					1										Wright nipple cactus
Opuntia imbricata					1	1		1		1	1						cane cholla
Opuntia macrorhiza		1					1	1								1	low prickly pear
Opuntia phaeacantha	1	1		1	1	1	1		1	1	1						browns pine pricklypear
Opuntia polyacantha	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	plains pricklypear
CAPRIFOLIACEAE																	CAPER FAMILY
Cleome serrulata							1										Rocky Mountain beeplant
CARYOPHYLLACEAE																	PINK FAMILY
Arenaria lanuginosa saxosa		1										1		1	1	1	spreading sandwort
Silene laciniata		1					1	1						1	1	1	Mexican campion or catchfly
Silene scouleri		1					1									1	Scouler catchfly
Drymaria glandulosa +															1		Fendler's drymary
CHENOPODIACEAE																	GOOSEFOOT FAMILY
Atriplex canescens			1					1		1							fourwing saltbush
Chenopodium sp.		1			1		1		1	1	1			1		1	goosefoot
Chenopodium graveolens		1				1						1		1	1	1	ragleaf goosefoot
Krascheninnikovia lanata (Ceratoideis lanata, Eurotia lanata)										1							winterfat
CONVOLVULACEAE																	MORNING GLORY FAMILY
Convolvulus arvensis @								1									field bindweed
Evolvulus nuttallianus +										1							shaggy dwarf morningglory
Ipomoea costellata												1					crestrub morningglory
Ipomoea cristulata								1									transpecos morningglory
Ipomoea plummerae														1	1	1	Huachuca Mountain morningglory
EUPHORBIACEAE																	SPURGE FAMILY
Acalypha neomexicana												1					New Mexico copperleaf
Chamaesyce fendleri	1	1	1				1	1		1				1	1	1	Fendler spurge
Chamaesyce revoluta										1				1			threadstem spurge
Chamaesyce serpyllifolia		1							1					1			thymeleaf spurge
Euphorbia bilobata															1		blackseed euphorbia
Euphorbia exstipulata +										1							squareseed spurge
Euphorbia lurida					1	1		1									shorthorned spurge
Tragia ramosa														1	1	1	catnip noseburn
FABACEAE (LEGUMINOSAE)																	BEAN FAMILY
Astragalus calycosus scaposus										1						1	Torrey milkvetch
Astragalus ceramicus ceramicus									1								painted milkvetch
Astragalus egglestonii														1		1	Eggleston milkvetch

Appendix A: Plants found on study areas

SCIENTIFIC NAME (synonym)	EAST								MID		WEST					COMMON NAME	
	STKI	MTKI	NTKI	LOMEse	LOME-D	LOME-L	NPSS	SABL	MCCA	ENCE	TW/N	HOYA	BAND	HIDD	MEBL-se		MEBL
Astragalus sp.														1		1	milkvetch
Calliandra humilis							1										dwarf stickpea
Dalea compacta								1				1					compact prairieclover
Dalea leporina												1					foxtail prairieclover
Dalea polygonoides +												1					sixweeks prairieclover
Lotus wrightii	1	1					1				1	1		1		1	Wright deervetch
Lupinus kingii kingii	1	1	1				1									1	King lupine
Peteria scoparia +					1												rush peteria
Psoralidium tenuiflorum		1														1	slimflower scurfpea
Thermopsis rhombifolia montana														1		1	mountain goldenpea
Vicia americana minor								1									American vetch
FAGACEAE																	BEECH FAMILY
Quercus gambelii	1	1	1				1			1	1			1		1	Gambel oak
Quercus x paucilobus (Quercus undulatus)	1	1		1	1		1						1	1	1	1	wavyleaf oak
GERANIACEAE																	GERANIUM FAMILY
Erodium cicutarium @								1									redstem stork's bill, filaria
Geranium caespitosum						1		1						1		1	tufted geranium
Geranium lentum									1		1	1					Mogollon geranium
GROSSULARIACEAE																	GOOSEBERRY FAMILY
Ribes cereum		1	1						1	1	1	1	1	1	1	1	wax currant
HYDROPHYLLACEAE																	WATERLEAF FAMILY
Nama dichotomum																1	wishbone fiddleleaf
IRIDACEAE																	IRIS FAMILY
Sisyrinchium demissum																1	dwarf blue-eyed grass
LAMIACEAE (LABIATAE)																	MINT FAMILY
Agastache pallidiflora		1							1			1	1				New Mexico giant hyssop
Hedeoma drummondii										1				1	1	1	Drummond false pennyroyal
Hedeoma nana									1								low false pennyroyal
Monarda punctata lasiodonta							1	1									spotted beebalm
Salvia subincisa		1				1		1				1					sawtooth sage
LINACEAE																	FLAX FAMILY
Linum aristatum								1								1	bristle or awned flax
Linum lewisii										1				1	1	1	prairie flax
Linum neomexicanum												1		1	1	1	New Mexico yellow flax
MALVACEAE																	MALLOW FAMILY
Sphaeralcea digitata		1					1			1	1	1	1	1		1	juniper globemallow
Sphaeralcea fendleri		1	1	1		1		1					1	1			Fendler globemallow
MOLLUGINACEAE																	CARPETWEED FAMILY
Mollugo cerviana												1		1			threadstem carpetweed
NYCTAGINACEAE																	FOUR O'CLOCK FAMILY
Abronia fragrans							1	1								1	snowball sand verbena
Mirabilis diffusa	1	1										1	1	1		1	ribbed spreading four o'clock
Mirabilis glabra				1	1			1									smooth four o'clock
Mirabilis linearis																1	narrowleaf four o'clock
Mirabilis multiflora	1	1	1	1	1	1	1	1		1				1	1		Colorado four o'clock
Mirabilis oxybaphoides +														1		1	smooth spreading four o'clock
Mirabilis sp.										1	1					1	four o'clock
OLEACEAE																	OLIVE FAMILY
Forestiera pubescens (Forestiera neomexicana)	1	1	1			1		1	1	1	1	1	1	1		1	New Mexico olive
Fraxinus cuspidatus								1	1	1							fragrant ash
Menodora scabra		1															rough menodora
ONAGRACEAE																	EVENING-PRIMROSE
Gaura coccinea												1				1	scarlet beeblossom
Oenothera albicaulis								1									whitestem evening-primrose
Oenothera caespitosa									1				1	1	1	1	tufted evening-primrose
Oenothera coronifolia							1										crownleaf evening-primrose
Oenothera laciniata		1			1												cutleaf evening-primrose
OROBANCHACEAE																	BROOMRAPE FAMILY

Appendix A: Plants found on study areas

SCIENTIFIC NAME (synonym)	EAST								MID		WEST					COMMON NAME	
	STKI	MTKI	NTKI	LOMEse	LOME-D	LOME-L	NPSS	SABL	MCCA	ENCE	TW/N	HOYA	BAND	HIDD	MEBL-se		MEBL
Orobanche ludoviciana multiflora								1		1							manyflowered broomrape
Orobanche uniflora								1									oneflowered broomrape
Orobanche sp.		1	1				1				1						broomrape
OXALIDACEAE																	OXALIS FAMILY
Oxalis sp.		1								1		1		1	1	1	oxalis
PLANTAGINACEAE																	PLANTAIN FAMILY
Plantago argyrea								1	1								silvery plantain
Plantago patagonica								1	1	1						1	woolly plantain
POLEMONIACEAE																	PHLOX FAMILY
Ipomopsis aggregata formosissima											1			1	1	1	scarlet skyrocket
Ipomopsis longiflora				1	1			1									whiteflower ipomopsis
Ipomopsis multiflora	1	1		1	1	1	1	1									manyflowered ipomopsis
POLYGALACEAE																	MILKWORT FAMILY
Monnina wrightii												1					blue pygmyflower
Polygala alba										1							white milkwort
POLYGONACEAE																	BUCKWHEAT FAMILY
Eriogonum alatum	1	1		1	1		1			1		1		1	1	1	winged wild buckwheat
Eriogonum annuum				1	1			1									annual wild buckwheat
Eriogonum jamesii	1	1	1			1	1	1	1		1	1	1	1		1	James wild buckwheat
Eriogonum racemosum														1		1	redroot wild buckwheat
PORTULACACEAE																	PURSLANE FAMILY
Portulaca sp.												1		1	1	1	purslane
Portulaca halimoides (Portulaca parvula)		1				1		1									silkcotton purslane
Portulaca oleracea		1	1			1		1									common purslane
Talinum confertiflorum		1	1			1	1	1		1		1		1	1	1	New Mexico fameflower
Talinum pulchellum										1				1	1	1	showy fameflower
RANUNCULACEAE									1		1						BUTTERCUP FAMILY
Clematis ligusticifolia									1		1						western virgin's bower
Delphinium wootonii (Delphinium virescens wootonii)								1									Organ Mountain larkspur
Thalictrum fendleri		1						1									Fendler meadowrue
ROSACEAE																	ROSE FAMILY
Cercocarpus montanus					1			1									alderleaf mountain mahogany
Fallugia paradoxa		1						1	1	1	1	1	1	1	1	1	Apache plume
Holodiscus dumosus									1			1	1				rock spirea, mountain spray
Potentilla sp.									1					1			cinquefoil
Rubus idaeus strigosus												1					red raspberry
RUBIACEAE																	MADDER FAMILY
Houstonia wrightii															1	1	pygmy bluet
SALICACEAE																	WILLOW FAMILY
Populus tremuloides												1	1	1		1	quaking aspen
SANTALACEAE																	SANDALWOOD FAMILY
Comandra umbellata pallida +					1												pale bastard toadflax
SAXIFRAGACEAE																	SAXIFRAGE FAMILY
Heuchera (parvifolia Nutt. ex Torr. & Gray) +		1															littleleaf alumroot
SCROPHULARIACEAE																	FIGWORT FAMILY
Castilleja integra		1	1			1	1	1	1	1	1			1	1	1	wholeleaf Indian paintbrush
Orthocarpus purpureo-albus																1	purplewhite owiclover
Penstemon ambiguus laevisissimus				1	1			1									gilia beardtongue
Penstemon barbatus torreyi		1				1	1			1		1	1	1	1	1	scarlet penstemon
Verbascum thapsus @											1	1			1		woolly mullein
SOLANACEAE																	NIGHTSHADE FAMILY
Chamaesaracha coronopus								1									greenleaf false nightshade
Lycium pallidum								1									pale wolfberry
Physalis hederifolia fendleri		1						1							1		ivyleaf groundcherry
Solanum jamesii		1	1					1		1					1		wild potato
VERBENACEAE																	VERVAIN FAMILY

Appendix A: Plants found on study areas

SCIENTIFIC NAME (synonym)	EAST									MID		WEST					COMMON NAME
	STKI	MTKI	NTKI	LOMEse	LOME-D	LOME-L	NPSS	SABL	MCCA	ENCE	TWIN	HOYA	BAND	HIDD	MEBL-se	MEBL	
Glandularia wrightii (Verbena wrightii)		1				1	1		1	1	1	1	1	1	1	1	mountain mock vervain, Wright or desert vervain
VISCACEAE																	MISTLETOE FAMILY
Phoradendron juniperinum					1												juniper mistletoe
VITACEAE																	GRAPE FAMILY
Parthenocissus quinquefolia (Parthenocissus inserta)									1				1				Virginia or thicket creeper, woodbine
Vitis arizonicus									1			1	1	1	1		Arizona grape
ZYGOPHYLLACEAE																	CALTROP FAMILY
Kallstroemia parviflora +										1							warty caltrop
MONOCOTS																	
AGAVACEAE																	AGAVE FAMILY
Yucca baccata	1	1	1	1	1	1	1		1				1	1	1	1	banana yucca, datil
Yucca baileyi x Y. glauca										1							narrowleaf yucca
COMMELINACEAE																	SPIDERWORT FAMILY
Commelina dianthifolia longispatha	1	1	1	1	1			1	1					1			birdbill dayflower
Commelina erecta angustifolia				1				1						1			narrowleaf dayflower
Tradescantia occidentalis scopulorum					1			1									prairie spiderwort
CYPERACEAE																	SEDGE FAMILY
Bulbostylis capillaris									1								hairsedge
Carex filifolia										1							threadleaf sedge
Carex vallicola Dewey +												1					valley sedge
Cyperus fendlerianus	1	1	1	1	1	1	1	1	1			1	1	1	1	1	Fendler flatsedge
Cyperus squarrosus (Cyperus aristatus)												1					bearded flatsedge
LILIACEAE																	LILY FAMILY
Allium cernuum														1	1	1	nodding onion
Echeadia flavescens (Anthericum torreyi)		1										1		1	1	1	Torrey craglily
POACEAE (GRAMINAE)																	GRASS FAMILY
Andropogon gerardii														1		1	big bluestem
Aristida adscensionis +						1											sixweeks threeawn
Aristida arizonica		1		1			1	1						1			Arizona threeawn
Aristida purpurea fendleriana							1										Fendler threeawn
Aristida purpurea longiseta							1	1									red threeawn
Aristida purpurea purpurea	1						1		1	1							purple threeawn
Aristida sp.	1																threeawn
Blepharoneuron tricholepis			1					1	1		1	1		1	1	1	pine or hairy dropseed
Bouteloua curtipendula						1		1	1	1	1	1		1	1	1	sideoats grama
Bouteloua gracilis	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	blue grama
Bouteloua hirsuta	1	1		1	1	1	1	1									hairy grama
Bromus lanatipes									1								woolly brome
Bromus porteri +															1	1	Porter's brome
Bromus sp.												1	1				brome
Elymus longifolius (Sitanion hystris)	1	1	1				1		1	1	1	1		1	1	1	bottlebrush squirreltail
Elymus smithii (Pascopyrum smithii)								1		1							western wheatgrass
Eragrostis lehmanniana @								1									Lehmann lovegrass
Festuca arizonica		1															Arizona fescue
Koeleria macrantha							1							1	1	1	junegrass
Lycurus setosus		1				1	1	1	1	1	1			1	1	1	wolftail
Muhlenbergia depauperata +																1	sixweeks muhly
Muhlenbergia dubia								1									pine muhly
Muhlenbergia fragilis						1			1								delicate muhly
Muhlenbergia minutissima									1			1				1	least muhly
Muhlenbergia montana	1	1	1				1		1	1	1	1	1	1		1	mountain muhly
Muhlenbergia pauciflora										1							New Mexico muhly
Muhlenbergia pungens					1			1									sandhill muhly
Muhlenbergia torreyi										1							ring muhly
Muhlenbergia wrightii																1	spike muhly
Munroa squarrosa +		1		1		1											false buffalograss

Appendix A: Plants found on study areas

SCIENTIFIC NAME (synonym)	EAST									MID		WEST					COMMON NAME
	STKI	MTKI	NTKI	LOMEse	LOME-D	LOME-L	NPSS	SABL	MCCA	ENCE	TWIN	HOYA	BAND	HIDD	MEBL-se	MEBL	
Oryzopsis hymenoides								1		1							Indian ricegrass
Oryzopsis micrantha			1	1					1			1					littleseed ricegrass
Panicum bulbosum														1			bulb panicgrass
Panicum capillare brevifolium									1			1	1		1		witchgrass
Pleuraphis jamesii (Hilaria jamesii)				1						1							galleta
Poa fendleriana								1									muttongrass
Schedonnardus paniculatus								1									tumblegrass
Schizachyrium scoparium (Andropogon scoparium)	1	1					1		1		1	1	1	1	1	1	little bluestem
Setaria grisbachii +							1										Grisebach's bristlegrass
Sorghastrum nutans +														1		1	Indiangrass
Sporobolus contractus								1									spike dropseed
Sporobolus cryptandrus			1		1	1	1	1		1							sand dropseed
Stipa comata			1					1	1	1						1	needle-and-thread
Stipa neomexicana										1							New Mexico needlegrass
Stipa scribneri								1									Scribner needlegrass
Vulpia octoflora octoflora								1									sixweeks fescue
TOTAL (57 families, appx 285 species)	42	98	46	34	38	47	82	106	60	76	41	71	38	106	79	120	
Nomenclature according to Kartesz 1994, except grasses (Allred 1993), ferns, allies, & gymnosperms (Flora of North America, Vol 2), brassicaceae (Rollins 1993), & other rare exceptions (recent literature)																	
@ = adventive (alien) plant; + = plant new to species list since Lightfoot et al. 1994 (20 new plants in this list)																	
BOLD = target kipukas; ITALIC = lava flows near kipukas; NORMAL = nontarget areas																	
total number of plants on LOME (LOME-D + LOME-L) = 69																	
STKI = southernmost of Three Kipukas (THKI; aka Two Kipukas)						MCCA = McCartys lava flow (around THKI & LOME)											
MTKI = middle of Three Kipukas (THKI; aka Two Kipukas)						ENCE (ZAKI) = Encerrito Kipuka (Zuni-Acoma Kipuka)											
NTKI = northernmost of Three Kipukas (THKI; aka Two Kipukas)						TWIN = Twin Craters flow (around Encerrito)											
LOMEse = small kipuka se of main Los Medanito Kipuka						MEBLse = small kipuka se of main Mesita Blanca											
LOME-D = Los Medanitos kipuka, dunes & sand portion						MEBL = Mesita Blanca (main part)											
LOME-L = Los Medanitos kipuka, Hoya flow portion						HIDD = Hidden Kipuka											
NPSS = North Pasture Sandstone outcrops						HOYA = Hoya flow between MEBL & HIDD											
SABL = Sandstone Bluffs						BAND = Bandera flow near HIDD											

Appendix B. Description of study sites.

The kipukas are described starting from the southeast (South Three Kipukas) and proceeding counterclockwise to the west (Mesita Blanca Southeast). Refer to Figure 1 and Table 1.

Three Kipukas (THKI; South, Middle, and North; also called Two Kipukas) as a group compose one of the five target study areas. They are located southwest of the south end of The Narrows a short distance west of NM-117 and about 21 air miles (34 km) south of Interstate 40. They are aligned outcrops surrounded by the McCartys flow that are geologically and erosionally related to other sedimentary outcrops along the east side of the McCartys flow such as North Pasture Sandstone (NPSS) and Sandstone Bluffs (SABL). The Three Kipukas display the highest concentration of banana yucca (*Yucca baccata*) and down, dead wood known in the monument. The dead wood is presumed to have resulted from the 1950's drought.

South Three Kipukas (STKI) is the smallest kipuka investigated in this study (6.1 acres). It is almost flat with a slight central crown and is composed of Upper Cretaceous sandstones (Kdo of Maxwell 1986). This map unit is composed of several different formations; it is unknown which one comprises the surface of this kipuka. The canopy is dominated by oneseed juniper (*Juniperus monosperma*); the most common grass is blue grama (*Bouteloua gracilis*). The intervening space is sparsely vegetated and is bare in some small places. *Yucca baccata* and down dead wood are common. Although it is near the heavily grazed North Pasture, there is no evidence of livestock usage, probably because of the almost impassable McCartys flow between. There is no evidence of wildfire. Approximately 42 plant species were found (Appendix A).

Middle Three Kipuka (MTKI) is the largest kipuka in the study (164.6) and only slightly larger than Los Medanos kipuka. The strata and kipuka surface dip southeastward so the highest part is along the northwest edge and north tip where there are cliffs. The bulk of the kipuka is shallowly sloped. The cliffs and rim along west and north are composed of noncalcareous sandstone, the Middle Jurassic eolian facies of the Recapture Member of the Morrison formation (Condon 1989). This unit formerly was called the Zuni sandstone (Jz; Maxwell 1986). Above the cliff-forming member and covering the majority of the kipuka is the same unknown formation that composes STKI (Kdo). Understory species composition is somewhat different between higher, rockier portions and the lower, flatter, siltier areas. Nevertheless, pinyon-juniper woodlands dominate the kipuka. Ponderosa pine is scattered throughout but is especially common near the kipuka's edge. One of the most unique habitats in the monument is found on the cliffs at the north end of the kipuka. This small area is quite mesic and supports at least two plants not known elsewhere in the park (lesser spikemoss [*Selaginella densa*] and littleleaf alumroot [*Heuchera parvifolia*]). There is also a dense growth of Fendler lipfern (*Cheilanthes fendleri*) which is also found occasionally on HIDD. Banana yucca and dead wood are common. There is no evidence of wildfire or the presence of livestock. Approximately 97 plants have been found.

North Three Kipuka (NTKI) is the second smallest studied (10.6 acres). It is almost flat with a slight central crown and, according to Maxwell (1986), is composed of

what used to be called the Zuni Sandstone (Jz). It is less tree-covered than the other kipukas in the series. On the west side is a relatively extensive flat area which supports fourwing saltbush and horsebush, neither of which have been found on the other two kipukas. Banana yucca and dead wood are less abundant than MTKI and STKI. There is no evidence of livestock usage. About 46 species have been noted for this site.

Los Medanitos Southeast (LOMEse) and Los Medanitos (LOME) occur in the McCartys flow, are almost adjacent, and are located about 1.5 mi (2.4 km) west of the Little Narrows and about 13 air miles (21 km) south of Interstate 40 (Fig. 1).

LOMEse is a nontarget site and the third smallest (22.4 acres). It however is unique because it is the only kipuka studied that is composed entirely of sand. A large curved dune occupies much of the central portion and windblown or colluvial sand covers the rest. No rocks or outcrops were seen in the kipuka. The vegetation is sparse and mostly composed of scattered oneseed juniper, ponderosa pine, sand sage (*Artemisia filifolia*), and blue grama. No evidence of fire or livestock was observed. Approximately 34 plant species were noted.

Los Medanitos (LOME) is a target site and is the second largest kipuka studied (162.2 acres). Its shape is irregular, different than the other kipukas which are elongate. It is unique among the kipukas since it is composed of both sand dunes (88.2 acres) and Hoya lava (74.0 acres). Vegetation in the sand is sparse and typically dominated by oneseed juniper. Interestingly, though, some dunes support ponderosa pines, trees which are usually found near the kipuka's edges. The balance of LOME is composed of Hoya lava, some of which is mostly level and soil-covered and some which is very irregular with ridges and swales. Flat lava-covered portions of the kipuka, including the ridges and swales, are usually grassy with scattered pinyon/juniper. No evidence of fire was observed. Because the kipuka contains two distinctive substrates, two separate lists of species were assembled (Appendix A). The dunes support about 38 species and the lava about 48; the total number on the kipuka is about 69. A seldom-collected, but technically not rare, plant was found in sand, *Peteria scoparia* (rush peteria or camote del monte; Appendix C).

Livestock at one time were grazed on LOME and probably LOMEse because it is so near. In the Hoya flow part near the northeast edge of the kipuka, a swale with fairly steep, rocky slopes on about 80% of its circumference had been used as a corral. Heavily weathered trees and branches were laid in a fencelike manner at the base of the slope; lesser quantities of wood are found across the opening (the rest presumably decomposed because of contact with the soil). This structure is very similar to makeshift horse or cattle corrals observed in other areas. No livestock droppings were observed on the kipuka. It is suspected that this, and probably other kipukas, were utilized by homesteaders who lived in the area until the 1940s (Robinson 1994).

Encerrito (ENCE; also known as Zuni-Acoma Kipuka [ZAKI] in Lightfoot et al. 1994) is a tall, narrow outcrop of the Lower Permian Yeso Formation (Py) about 50.0 acres in area. It is located near the mouth of Bonita Canyon in the Twin Craters flow about 1 mi (1.6 km) south of the southeastern tip of the Zuni Mountains. A fairly steep-sided ridge runs the length of the kipuka. The colluvial fringe is well-developed and a relatively large lobe extends eastward from near the center. Although it is covered by

colluvium, a layer of lava, distinct from the obviously taller and rougher Twin Craters flow, appears to extend to the very base of the outcrop. It is almost entirely soil-covered and may also underlie the Twin Craters. Pinyon/juniper woodland dominates the majority of the higher parts of the kipuka. No evidence of wildfire was noted.

Approximately 76 plants have been found on the kipuka.

Hidden Kipuka (HIDD) is a target site situated in the western part of the monument. It is about 7 air miles (11.3 km) south of Bandera Crater and about one mile (1.6 km) southeast of the southeast corner of Little Hole. It is about 75.2 acres in extent. HIDD is unique in the study because it is surrounded by flows of two different ages, the younger Bandera on the north and the older Hoya on the south. Permian Glorieta Sandstone (Pg of Maxwell 1986) is the constituent rock. The surface slopes gently upward from the west to the east across the narrow dimension. The tallest point is along the northeastern edge where there is a fairly tall, steep escarpment. Here as in other kipukas, pinyon/juniper woodlands dominate the canopy with blue grama the commonest grass. Several ponderosa pines, particularly along the edges, were scarred by wildfires. At least one tree was seen that had been sampled for dendrochronological study. No evidence of grazing was seen. About 106 plants have been noted on HIDD.

Mesita Blanca (MEBL), the larger sister of the following kipuka, is a nontarget site located about a half mile (0.8 km) southeast of HIDD. It is the third largest of the study areas (118.4 acres) and is surrounded by Hoya lava. MEBL is an elongate feature with a more-or-less central ridge or cuesta that usually slopes gently on the west. A small scarp is intermittently present on the east edge of the ridge. The tallest cliff is at the south end near the two track road. A slight constriction near the kipuka's center corresponds to a preexisting break in the ridge. The majority of the kipuka is composed of Permian San Andres Limestone (map unit Psa). The surface of exposed limestone is usually pitted and etched by acidic precipitation. At the northwest end of the kipuka is a small, almost flat portion that appears different geologically than the majority of the kipuka; Maxwell (1986) tentatively calls this area Glorieta Sandstone (Permian). Pinyon-juniper woodlands and blue grama cover most of the kipuka. Ponderosa pine woodlands are also found in flatter areas below the ridge. No cattle were seen on the kipuka, but evidence of recent livestock grazing (droppings, footprints) is fairly common. Numerous cattle were seen in Little Hole as near as the beginning of the two-track road over the Hoya flow into the kipuka. Fire scars were seen on several ponderosa pines. Approximately 120 plants have been noted on MEBL, the largest number of any kipuka.

Mesita Blanca southeast (MEBLse) is a target site a short distance off the south end of MEBL. This small kipuka (about 36.0 acres) is obviously closely related to its neighbor and is composed of the same material. Its topography is similar and its vegetation is essentially the same as MEBL. Cattle sign were seen but little evidence of wildfire was noted. About 79 plants were found.

Appendix C. Plants new to El Malpais since 1994.

Twenty plant species and two families (Santalaceae and Saxifragaceae) new to the list for El Malpais National Monument, NM, have been found since the Vegetation and wildlife inventory (Lightfoot et al. 1994) was submitted. Nomenclature for these plants is according to Kartesz 1994 except for grasses which is according to Allred (1993). Short annotations are also provided. See separate document for a complete plant list for the monument with nomenclature updated since the inventory report.

PTERIDOPHYTES (FERNS AND ALLIES)

PTERIDACEAE (MAIDENHAIR FERN FAMILY)

- Pellaea glabella** Mett. ex Kuhn ssp. **simplex** (Butters) A. & D. Love SMOOTH CLIFFBRAKE an easily recognized but uncommon, obscure xeric fern with habitat requirements similar to *Cheilanthes*, that is, typically, north-facing cracks in rocks; ranges in part of the Rocky Mountain region; so far, this plant has been found only on sedimentary rocks in Mesita Blanca and Hidden Kipuka

DICOTS

ASTERACEAE (COMPOSITAE; SUNFLOWER FAMILY)

- Anaphalis margaritacea** (L.) Benth. & Hook. f. PEARLY EVERLASTING distinctive-looking perennial, widespread in the west; seen only at Mesita Blanca, but probably occasional elsewhere
- Ericameria filifolia** (Rydb.) L.C. Anders. (*Chrysothamnus Greenei* (Gray) Greene) GREENE RABBITBRUSH small, fall-blooming shrub with linear leaves; a Colorado Plateau and southern Great Basin plant.; collected at ENCE, but probably occasional elsewhere

CARYOPHYLLACEAE (PINK FAMILY)

- Drymaria glandulosa** K. Presl FENDLER'S DRYMARY delicate, inconspicuous annual, with Mexican affinities, but found in AZ and NM and near the north end of its distribution in the monument; probably overlooked and scattered throughout the monument

CONVOLVULACEAE (MORNINGGLORY FAMILY)

- Evolvulus nuttallianus** Roemer & J.A. Schultes SHAGGY DWARF MORNINGGLORY a relatively inconspicuous perennial plant of open sandy areas that is widely distributed in the middle part of the country

EUPHORBIACEAE (SPURGE FAMILY)

- Euphorbia exstipulata** Engelm. SQUARESEED SPURGE small, unremarkable-appearing annual, mostly Mexican in distribution but ranging into AZ, NM, and TX

FABACEAE (LEGUMINOSAE; BEAN FAMILY)

Dalea polygonoides Gray SIXWEEKS PRAIRIECLOVER small, fall-blooming annual, mostly Mexican in distribution but ranging into AZ, NM and TX; probably more common in the monument than now know (Hoya flow between Mesita Blanca & Hidden Kipuka)

Peteria scoparia Gray RUSH PETERIA, CAMOTE DEL MONTE distinctive but not showy and seldomly collected fall-blooming perennial; ranges into western NM from farther south in AZ, TX and Mexico; so far found only in Los Medanos

NYCTAGINACEAE (FOUR O'CLOCK FAMILY)

Mirabilis oxybaphoides (Gray) Gray SMOOTH SPREADING FOUR O'CLOCK easily recognized perennial, somehow overlooked previously; ranges from southwestern US into Mexico; found on Mesita Blanca & Hidden Kipuka and probably elsewhere on sedimentary substrates

Mirabilis pumila (Standl.) Standl. DWARF FOUR O'CLOCK Southwestern US; collected at MEBL

SANTALACEAE (SANDALWOOD FAMILY)

Comandra umbellata (L.) Nutt. ssp. **pallida** (DC.) Piehl PALE BASTARD TOADFLAX fairly distinctive, but inconspicuous herbaceous perennial parasite, widespread in western half of the country; found mostly in sandy soils, in the monument, only on Los Medanos, so far

SAXIFRAGACEAE (SAXIFRAGE FAMILY)

Heuchera parvifolia Nutt. ex Torr. & Gray LITTLELEAF ALUMROOT identification is likely correct but tentative until it can be collected in flower; widespread in mesic habitats in the Rocky Mountains; uncommon on the north-facing cliff/slope of the Middle of the Three Kipukas; its presence reinforces the observation that this location is one of the most unique in the monument (*Selaginella densa*, another mesic species, is apparently found only at this site, also)

ZYGOPHYLLACEAE (CALTROP FAMILY)

Kallstroemia parviflora J.B.S. Norton WARTY CALTROP annual, superficially similar to goathead; widespread annual in southern US and Mexico; found in colluvial area of Encerrito Kipuka, and likely occasional elsewhere

MONOCOTS

CYPERACEAE (SEDGE FAMILY)

Carex vallicola Dewey VALLEY SEDGE widespread in west & into Mexico; dense patch found in a small collapse structure in Hoya flow between MEBL & HIDD

POACEAE (GRAMINAE; GRASS FAMILY)

Aristida adscensionis L. SIXWEEKS THREEAWN relatively inconspicuous, native, weedy annual; very responsive to precipitation; widely distributed in southern US, Mexico and elsewhere; found at Los Medanos, but likely at other locations

Bromus porteri (Coulter) Nash PORTER'S BROME native perennial; closely related & very similar looking to other bromes; scattered in western US; probably more widespread in the monument than is now known

Muhlenbergia depauperata Scribn. SIXWEEKS MUHLY inconspicuous annual very similar to *Muhlenbergia brevis*; ranges from southwestern US into Mexico; found at Mesita Blanca, but probably occasional elsewhere

Munroa squarrosa (Nutt.) Torr. (*Monroa squarrosa*) FALSE BUFFALOGRASS distinctive annual, often associated with anthills, that somehow did not make it into the original list; widespread in western US and Mexico; widespread and probably fairly common in the monument

Setaria grisbachii Fourn. GRISEBACH'S BRISTLEGRASS fairly distinctive annual; ranges from southwestern US into Mexico; apparently uncommon in the monument (collected on Hoya lava in Los Medanos and seen on McCartys lava near NM-117)

Sorghastrum nutans (L.) Nash INDIANGRASS large, distinctive, fall-flowering perennial; widespread in US and Mexico; found so far only on Mesita Blanca and Hidden Kipuka, but probably occasional elsewhere