COMMITTEE MEMBERSHIP

TITLE: Understory Vegetation Composition and Small Mammal Abundance in an Exotic Eucalyptus Forest vs. Adjacent Native Habitat

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TABLE OF CONTENTS

CHAPTER

1. INTRODUCTION .................................................................................................................... 1

2. LITERATURE REVIEW.......................................................................................................... 4
   2.1 Planted Forests as a Risk to Biodiversity ................................................................. 4
       2.1.1 Eucalyptus spp. Around the World .............................................................. 5
   2.2 Eucalyptus in California ................................................................................................. 7
       2.2.1 Environmental Impacts ......................................................................................... 8
       2.2.2 Successful Managements ..................................................................................... 10
   2.3 Eucalyptus in Montana de Oro State Park ............................................................ 11
       2.3.1 Sensitive Species ............................................................................................... 13
       2.3.2 Management Efforts ........................................................................................... 14

3. METHODOLOGY ................................................................................................................ 15
   3.1 Study Area ................................................................................................................... 15
   3.2 Sampling ...................................................................................................................... 16
       3.2.1 Botanical Surveys ............................................................................................... 16
       3.2.2 Small Mammal Surveys ...................................................................................... 16
       3.2.3 Morro Bay Kangaroo Rat .................................................................................... 17
       3.2.4 Data Analysis ...................................................................................................... 17

4. RESULTS ............................................................................................................................. 17
   4.1 Small Mammals ........................................................................................................... 17
   4.2 Eucalyptus globulus .................................................................................................. 19
   4.3 Eucalyptus cladocalyx ............................................................................................... 20
   4.4 Eucalyptus cephalocarpa .......................................................................................... 22
   4.5 Eucalyptus viminalis ................................................................................................. 24
   4.6 Mixed Eucalyptus ..................................................................................................... 26
   4.7 All Eucalyptus vs. Adjacent Native Habitat ......................................................... 34

5. CONCLUSION .................................................................................................................. 35

BIBLIOGRAPHY ...................................................................................................................... 38
Anthropogenic biodiversity loss is a global issue accelerated by continued habitat loss, invasive species, overexploitation of resources, pollution, and climate change (Rafferty 2019). Forests are vitally important as habitats for a major part of the world’s biodiversity, though the ecosystem services provided by natural and planted forests varies (Brockerhoff et al. 2012). Natural forest cover provides habitat for numerous species including birds, reptiles, mammals, and associated understory plant species to each forest. Plantation forests are cultivated ecosystems established by planting and/or seeding in the process of afforestation and reforestation, primarily for wood biomass production, soil and water conservation, or wind protection (Carnus et al. 2006). Although plantation forests provide an effort to mitigate the effects of human-caused deforestation, the planting of nonnative species may put biodiversity at risk in terms of long-term sustainability (Carnus et al. 2006). Introduced species compose 44% of global plantation forests, including 97% of South America’s plantation forests being introduced species, whereas North and Central America have a much lower level of only 4% (FAO 2020). Although it can be argued that planted forests also provide habitat for a variety of species that contribute to biodiversity (Hartley 2002), there may be negative impacts of planted forests depending on the type of plant community it replaces.

A very common tree taxa that is introduced outside of its native range is eucalyptus. More than 80 countries have introduced eucalypts, planting more than 20 million hectares worldwide (Poore 1985, Goded et al. 2019) resulting in 90% of the area being planted outside Australia (Iglesias-Trabado and Wilderstermann, 2008). Due to the various uses of eucalyptus, it cannot be universally answered whether the environmental impacts of introducing eucalyptus species outweigh the economic value; each case must be studied and evaluated individually based on location (Poore 1985). The popularity of this taxa as a plantation species is attributable to their general adaptability, fast growth rate, ability to stump sprout when cut, and wide range of utility. Uses include processed wood products, high value firewood, as well as a variety of ornamental
uses that provide profit for the countries in which they are planted (Poore 1985, Birhanu and Kumsa 2018). However, there are well documented ecological concerns that cause parties to be against their widespread planting including allelopathic effects on soil (Baker 1966, Chu 2014), hydrological drawdown resulting in drying of aquifers (Rodriguez et al. 2010), and providing poor habitat for native wildlife (Brockerhoff 2012). California, which has extensive eucalypt groves that were planted during the 20th century (William and Show 1944), experiences these ecological impacts as well as the risk of catastrophic fire behavior due to the production of oily resins, excessive ground cover from leaf litter fall, and the flammable properties of shedding bark that tend to carry fire into the canopy resulting in dangerous fire conditions, such as crown fires, that put nearby communities at risk (Essler 1993, Wolf 2016). With most of its eucalyptus plantations abandoned due to a lack of profitable uses, California is left with plantations in at least 23 counties that have escaped from their original planting footprint into wild areas and are now considered invasive populations (Wolf 2016).

Eucalyptus is a profitable crop in many locations globally, with extensively documented methods for planting a successful grove and best harvesting practices (Brockerhoff 2012, Birhanu and Kumsa 2018). For areas such as California where eucalyptus is not managed to be harvested, supplemental management practices must be in place if controlling eucalyptus is a management goal. Many reports on the management of eucalyptus, specifically in California, come from agency reports, land managers, and universities that have conducted their own research for their specific management needs. Because it is widely recommended that management be based on the needs of each individual site, it is important that agencies develop management practices based on research relative to their location. Currently, there are few management plans specific to eucalyptus on public lands in California. Examples include Angel Island State Park and Santa Cruz Island of the Channel Islands National Park, both are cases where eucalyptus was successfully removed and restoration efforts are in place to restore native coastal scrub and oak woodland habitat and prevent other invasive species from establishing large populations (Boyd 1997, Casey and Power 2016). The University of California at Berkeley has also conducted studies that address the need for management of the eucalyptus
forest in their area following the Oakland Hills fire (1991) that killed 25 people (Wolf 2016).

In San Luis Obispo County, Montana de Oro State Park (MDOSP) is home to a 350-acre introduced eucalyptus forest consisting of stands of mixed species as well as discrete stands of *E. globulus, E. cladocalyx, E. camaldulensis, E. cephalocarpus,* and *E. virminalis* (Bicknell 1990, Collins 2020). While the eucalyptus in MDOSP were planted in the early 1900s and have become an iconic feature of the park recognized by visitors, necessary plans for the management of these groves are lacking. California State Parks released a general plan for the park that briefly describes the history of the trees and recognizes that their presence jeopardizes the mission of State Parks to maintain landscapes of pre-settlement vegetation (Hook 1988). The general plan recommends that studies be done to determine which indigenous plant communities were displaced by the eucalyptus plantations and to develop a more extensive management plan for the eucalyptus groves. The groves occur primarily on Baywood fine sands, which are wind-blown sands with high organic content deposited during the Pleistocene epoch (USFWS 1998). Baywood fine sand deposits are home to many rare, endemic species including but not limited to the Morro manzanita (*Arctostaphylos morroensis*) and the Morro shoulderband snail (*Helminthoglypta walkeriana*), which were considered endangered, but recently reclassified as threatened (Fish and Wildlife 2020). Previous studies have been done on both of these species (Holland, 1990, Walgren and Andreano 2012), but in order for the California State Parks, San Luis Obispo Coast District, to develop a comprehensive management plan for the eucalyptus groves, further research is needed regarding the ecosystems species present, and potential impacts to native plants and animals found inside and outside the eucalyptus forest.

To address this knowledge gap, I completed botanical and small mammal surveys of species found inside and outside the eucalyptus. Habitats outside of the eucalyptus include coastal scrub, chapparal, and oak woodlands. I assessed eucalyptus impacts on local flora and fauna (including two threatened, endemic species as well as 13 special status plants and animals) using transects distributed throughout the variety of eucalyptus species present at MDOSP. I identified the species composition and abundance within the eucalyptus and compare it to the composition and abundance in the adjacent native habitat types. This study will help
managers to identify whether eucalyptus poses a risk to native habitat within Montana de Oro State Park by excluding native species. Based on environmental factors associated with a eucalyptus forest, I predicted that the exotic habitat created by *Eucalyptus spp.* will reduce fauna and flora diversity and richness inside the eucalyptus forest compared to the surrounding native habitat.

Chapter 2

LITERATURE REVIEW

2. 1 Planted Forests as a Risk to Biodiversity

As the global demand for wood pulp and energy increases, countries have attempted to establish sustainable wood sources through planted forests that come to represent 3% (294 million hectares) of global forest cover; 45% of planted forests are industrial plantations that are intensively managed, composed of one or two native or exotic tree species, and planted with regular spacing that are mainly established for productive purposes, nonindustrial plantations established for ecosystem restoration including soil and water conservation or wind protection account for the remaining 55% (FAO 2020). Although plantation forests provide an effort to mitigate the effects of human-caused deforestation, the planting of nonnative species may put biodiversity at risk in terms of long-term sustainability (Carnus et al. 2006). 44% of global plantation forests are comprised of introduced species, including 97% of South America’s plantation forests being introduced species, whereas North and Central America have a much lower level of only 4% (FAO 2020). Still, countries with low rates of introduced plantation forests are at risk of native habitat and biodiversity loss.

Planted forests are mainly composed of a few genera of fast-growing trees including pines (*Pinus*), spruces (*Picea*), poplars (*Populus*), eucalypts (*Eucalyptus*), rubber (*Hevea*), and teak (*Tectona*) (Brockerhoff et al. 2008). As a result of these plantations as a use for efficient wood production, they are also found to be less capable of providing ecosystem services that are linked to biodiversity (Kelty 2006; Thompson et al. 2009). Some of the services at risk in a planted forest include carbon storage abilities; pollination ability through insects, bats, and birds; biological control forces via microorganisms, invertebrates, birds, and small mammals; seed
dispersal through birds and rodents; soil formation and nutrient availability from invertebrates and microorganisms; overall productivity; reduction of invasive species; and water retention through varieties of plants and soil microorganisms (Thompson et al. 2011). These ecosystem services are related to species and ecosystem diversity that are compromised in a planted forest monoculture. Although there is evidence that plantation forests can provide habitat for valued organisms, this is greatly dependent upon the degree to which the plantation deviates from the native tree species composition and natural forest structure of the area (Brockerhoff et al. 2008), therefore it is accurate to assume that plantation forests usually have less habitat diversity and complexity compared to native forests.

Compared to other economically productive land uses such as pastoral grasslands, plantation forests can be seen as more favorable towards biodiversity due to management practices and a generally higher conservation value (Brockerhoff et al. 2008). As a result, many countries in the tropical and subtropical regions of the world have reported accelerated forest succession on previously deforested sites due to plantations and the development of understory conditions, vegetation structural complexity, and litter and humus layers (Brockerhoff et al. 2008). In such cases, it is important to note the benefits of plantation forests as a positive response to deforestation and native forest fragmentation as a global issue.

2.1.1 Eucalyptus spp. Around the World

In an attempt to further understand the implications of monocultures in various global ecosystems, we take a considerable look at eucalyptus, a tree taxa that is commonly introduced outside its native range of Australia and adjacent lesser areas of Southeast Asia (Boland et al. 2006). More than 80 countries have introduced eucalypts, planting more than 20 million hectares worldwide (Poore 1985, Goded et al. 2019) resulting in 90% of the area of planted eucalyptus being outside Australia (Iglesias-Trabado and Wildstermann, 2008). Of the planted eucalypt forests, more than half of the total area occurs in Brazil, India, and China (Brockerhoff et al. 2012). The popularity of this taxa as a plantation species is attributable to their general adaptability, fast growth rate, ability to stump sprout when cut, and wide range of utility. Uses include processed wood products, to high value firewood, as well as a variety of ornamental uses.
Eucalyptus plantations are commonly planted as a monoculture due to the economic benefit of biomass production (Zhang and Fu 2009) making the species an easy target for critics who argue against the planting of monocultures of any species due to alleged adverse effects on soil, hydrology, and poor habitat for wildlife (Poore 1985). These criticisms have prompted the research and publications of several studies examining the impacts of eucalyptus on ecosystems around the world (Goded et al. 2019; Graca et al. 2002; Resh et al. 2002; Rodriguez et al. 2010; Chu 2014).

The allelopathic effects of eucalyptus is considered to be one of the leading causes of biodiversity loss in their planted areas (Chu et al. 2014). Allelopathic chemicals are substances that are released into the environment and inhibit the growth of plants through ecological processes including volatilization, leaching, foliage litter decomposition, and exudation (Zhang and Fu 2009). Effects of allelopathy were studied in China, a nation that has planted 300 varieties of eucalyptus and is the second largest producer of eucalyptus (Chu et al. 2014). There is strong evidence that the allelopathic chemicals in the soil inhibit the growth of several native Chinese tree species resulting in the loss of a biodiverse understory (Zhang and Fu 2009, Chu et al. 2014). Eucalyptus, a non-nitrogen (N) fixing species, was found to inhibit the growth of other non-N fixing species while having little effect on N-fixing tree species, but due to general allelopathic properties study areas in China experienced diminished seedling survival and growth in monoculture plantations (Zhang and Fu 2009, Chu et al. 2014). In addition to the lack of understory vegetation, adverse effects on bird communities have been reported in countries with eucalyptus plantations (Calvino-Cancela, 2013; De la Hera et al. 2013; Goded et al. 2019) resulting in lower species richness and general abundance of bird species (Goded et al. 2019). Due to current management practices, many studies are done in active eucalyptus plantations where trees are harvested before reaching maturity, increasing plantation age to mitigate biodiversity loss (Calvino-Cancela 2012, Goded et al. 2019). However, there is a lack of information regarding habitat in established eucalyptus plantations due to the amount of actively managed plantations compared to unmanaged groves.

As a result of increased afforestation due to need for wood products, or carbon
sequestration incentives, eucalyptus plantations commonly occupy previously unforested areas such as pastures or grasslands (Calder et al. 2002, Rodriguez et al. 2010). While providing beneficial effects such as improved water quality and reduced runoff, global studies have shown a reduction in water tables throughout various climates, soils, and vegetation cover (Rodriguez et al. 2010). In areas where sustained drought is experienced, the accelerated uptake of water and decrease in water tables is likely to be more greatly observed than in areas that do not experience intense droughts. The issue of water availability is likely to continue increasing due to climate change predictions of increased temperatures and loss of water through evapotranspiration (Rodriguez et al. (2010).

2.2 Eucalyptus in California

Many nations around the world have been successful in the management and harvest of eucalyptus plantations as an economic stimulus (Brockerhoff 2012, Birhanu and Kumsa 2018). In contrast, California is an example of an area where harvest was not viable and resulted in abandoned plantations that have since expanded past their original planting footprint.

In 1856, 40,000 acres of *Eucalyptus globulus* (blue gum eucalyptus) were planted on grasslands or previously forested areas in an effort of reforestation or building and timber purposes (Wolf 2016). As eucalyptus proved to be not useful as timber due to it’s tendency to split, it continued to be planted across the state for fuel, windbreaks, pulp, or for landscaping purposes (Hook 1988). With plantations being established in 23 counties from Humboldt County south to San Diego County, *E. globulus* has since become naturalized due to lack of harvest and management causing it to be considered an invasive population in some areas (Ritter and Yost 2009, Wolf 2016). The overwhelming presence of this species has prompted research that addresses the role of eucalyptus in California ecosystems (Del Moral and Muller 1969, Osterling 1983, Wiley 2002, Suddjian 2004, Fork et al. 2015, Wolf 2016).

2.2.1 Environmental Impacts

One of the greatest risks put forth by the presence of eucalyptus is the risk of extreme fire behavior associated with the species. Like many California native species, eucalyptus evolved in Australia with the presence of periodic fire that resulted in the species being highly flammable, yet
rarely killed by fire (Essler 1993). The production of oily resins, excessive ground cover from leaf litter fall, and flammable properties of shedding bark tend to carry fire into the canopy resulting in dangerous fire conditions, such as crown fires, that put nearby communities at risk (Essler 1993, Wolf 2016). Fire history of California shows that eucalyptus forests will regenerate after exposure to repeated occurrences of extreme fire behavior resulting in dense, varied-aged stands (Osterling 1983) that still leave communities at risk. Management plans for eucalyptus are often put forth as a result of catastrophic events, such as the 1991 Oakland Hills Fire (Russell and McBride 2002, SFRP 2008, Jones 2009, LSA Associates 2009).

Fire is not the only ecological concern associated with eucalyptus in California. The thick litter layer and allelochemical properties have shown to reduce the germination and abundance of native species in coastal areas of California including yarrow (*Achillea millefolium*) and blue wild rye (*Elymus glaucus*) (Watson 2000). In general, studies have found that native perennials prefer native habitat such as oak woodland, compared to eucalyptus woodland and abundance of native plants decreases as eucalyptus groves increase in size due to lack of management (Watson 2000, Sax 2002, Fork et al. 2015). Some studies have found that although relative abundance may be lesser in eucalyptus, species diversity is similar to that of native woodlands due to the presence of understory species providing habitat for invertebrates, amphibians, and birds (Sax 2002). One could expect varied results in studies done where there is not a substantial understory habitat already established within the eucalyptus forest.

Since being naturalized in coastal counties, many species of birds have found nesting habitat in eucalyptus (Sax 2002, Suddjian 2004). This is partially a result of eucalyptus stands being planted in areas that were previous grassland and therefore, not suitable for nesting habitat. Some counties are seeing an increase of eucalyptus use by birds such as Great Blue Herons, Great Egrets, and Double-crested Cormorants that are found to only nest in eucalyptus groves in Santa Cruz County, and a majority of known nests of Red-shouldered and Red-tailed hawks and Great Horned Owls were found in eucalyptus due to better cover provided by eucalyptus compared to native species (Rottenborn 2000, Suddjian 2004). While being a viable habitat for many nesting species, foraging land birds have less success with the species. Nectar
from eucalyptus produces a thick residue (gum) that becomes matted onto the feathers and may plug the nostrils and bills of birds that prevents breathing and feeding, though further research is needed to determine if this is a substantial cause of mortality (Stallcup 1997, Williams 2001, Suddjian 2004). Regardless, birds in Australia evolved to have longer beaks that allow them to feed from eucalyptus without adverse effects unlike North American species that do not have that adaptation (Suddjian 2004). Similar to plant communities that are present amongst eucalyptus, birds that are present in eucalyptus do not equate to the importance of oak woodland and deciduous riparian habitat that has been replaced by eucalyptus. Many oak woodland bird species are not found to use eucalyptus at all, and species that nest in eucalyptus do so at reduced densities (Suddjian 2004).

In a state that is greatly impacted by severe drought, it is important that California consider the hydrological impacts of eucalyptus plantations. Eucalyptus can withstand long, dry summers, but is not considered a drought-tolerant species (USDA 2015). The species is able to survive by tapping into deep water reservoirs that has shown to alter water availability to depths of 45 feet and 100 feet away from the trunk, outcompeting most terrestrial plants for water (Florence 1996, DiTomaso and Healy 2007). In addition to depleting water reservoirs, studies have found that streambeds in the vicinity of eucalyptus plantations are prone to erosion and dewatering (Williams 2002). Streams and riparian corridors are at further risk as the presence of eucalyptus has shown to be poor habitat for invertebrates and decomposers ultimately reducing the quality of the riparian ecosystem (Graca 2002, Walgren and Andreano 2012).

2.2.2 Successful Management

Given the abundance of plantations throughout California, some areas of the state have been aggressive with the removal of eucalyptus. Angel Island underwent a 10-year eucalyptus removal project mainly focusing on E. globulus that was completed in 1996 (Boyd 1997). The park removed 80 out of 86 acres of eucalyptus that had expanded from the original footprint of 24 acres. Angel Island experienced a loss of habitat including coastal scrub and grassland that prevented native plant and wildlife from succeeding. Along with the 1991 Oakland Hills fire, plans to remove the eucalyptus became a priority for the park due to its vicinity to the San Francisco
Bay area. California State Parks (CSP) produced a Focused Environmental Study that addressed concerns, provided background information, and reasons why the restoration methods were appropriate for this park. The park removed 16 acres of eucalyptus via helicopter with great success, removing complete trees and avoiding ground disturbance. Following removal, the park introduced fire and burned piles of remaining debris and stumps. Despite the efficiency of helicopter removal, the high costs placed the project on hold and almost stopped the project indefinitely until CSP contracted with Planned Sierra Resources and outsourced the eucalyptus to a Japanese market that dramatically reduced the cost of removal. A barge holding 1,500 tons of logs were transported from the island, but damages to the barge due to extreme weights required another change to be made to the logging method that required loading directly onto the sea instead of from the beach. As a result, only logs could be barged from the island and the remaining material was made into piles using heavy equipment. A combination of heavy equipment felling machinery, contract tree fellers, and herbicide application created a mixed methods approach of removing and treating the eucalyptus for the following years. After successful removal of the eucalyptus, invasive weed management is a prominent restoration need in the area that continues to be managed through a mix of burning and herbicide application. Native stands of shrubs and grasses have recovered in some areas either by natural occurrence or planting and are expected to reach a natural restored state after several years of outside management.

Santa Cruz Island of the Channel Islands National Park began an oak woodland restoration project in 2010 that involved the removal of eucalyptus from the restoration area. The Channel Islands were another area impacted by the widespread planting of eucalyptus in the early 1900s. Over time, unmanaged eucalyptus outcompeted and displaced native vegetation that would have been riparian woodland (Casey and Power 2016). Removal of eucalyptus was achieved through use of multiple methods approach including burning, chipping, with larger DBH logs being removed from the island or placed in a stockpile to be used for erosion control and construction projects on the island (Casey and Power 2016). The study includes research that supports successful planting efforts inside and adjacent to burn scars from pile burns of
eucalyptus, encouraging the continued management of slash and burn on the island as an effective treatment.

2.3 Eucalyptus in Montana de Oro State Park

With coastal areas of California being a focused area of study for impacts of eucalyptus, we look into the ecological impacts of the eucalyptus grove in Montana de Oro State Park (MDOSP) in San Luis Obispo County. Eucalyptus was first planted in Hazard Canyon of MDOSP in the early 1900s that resulted in dense rows of varied species continuing to expand today. The grove mainly consists of *E. globulus* but is home to a variety of other eucalyptus species including *E. cladocalyx*, *E. camaldulensis*, *E. cephalocarpa*, and *E. virginalis*, *E. bortyoides*, and *E. viridus*; as well as native species such as Monterey Pine (*Pinus radiata*), Monterey cypress (*Hesperocyparis macrocarpa*), and coast live oak (*Quercus agrifolia*) that exist in small patches (Bicknell 1990, Collins 2020). The area in which the eucalyptus was planted originally consisted of grassland, coastal scrub, oak woodland, and riparian forest communities (Hook 1988, Bicknell 1990), which are all habitats that have shown to provide more benefits than eucalyptus plantations. Habitats currently surrounding the eucalyptus forest include maritime chaparral, coastal scrub, and dune scrub (Walgren and Andreano 2012). Similar to plant communities that were affected on Angel Island and Santa Cruz Island, MDOSP is experiencing similar encroachment patterns. There are similar treatments that are currently being practiced and are hoping to expand in MDOSP so it is important to understand treatments being done by other agencies that are known to be successful.

Historically, the area of Hazard Canyon that is currently eucalyptus forest was originally grassland, diverse riparian habitats, and coast live oak woodland that was shaped through frequent fire (Bicknell 1990). In 1949, the eucalyptus planting site was approximately 48.3 hectares (119.3 acres) and by 1986 the area had expanded to 73.5 hectares (181.6 acres) quantifying the expansion at 52% in less than 40 years, with *E. globulus* spreading at a higher rate than other present eucalyptus species (Bicknell 1990). This disputes the claim that eucalyptus does not generally reproduce through germination and does not encroach onto surrounding habitat without deliberate planting (Wolf 2016). During an ~40 year period, some
small areas in MDOSP did experience a retreat of eucalyptus in western areas exposed to salt deposition from ocean breezes where trees experienced crown death and showed growth patterns of growing away from the winds (Bicknell 1990). Given that MDOSP provides conditions suitable for the growth and spread of eucalyptus, one could predict that a current measurement of the eucalyptus forest would be larger than what was last documented in 1986. A recent mapping through GIS identified that the forest expands to an area of approximately 350 acres, though that area is not strictly eucalyptus forest as it encompasses coastal scrub, grassland, and woodland areas that have eucalyptus present (Collins 2020).

In addition to changing riparian woodland habitat to eucalyptus forest, the eucalyptus within the Hazard Creek watershed of MDOSP may be reducing potential summer stream flows to zero (Bicknell 1990). Hazard Creek is the one major drainage that flows through the eucalyptus forest. The Hazard Creek watershed is already prone to low flow due to the lack of springs within the watershed (Bicknell 1990), compared to other watersheds located within the park including Islay Creek and Coon Creek that contain natural springs which provide the watersheds with water from groundwater aquifers. Given the already reduced rates of flow, the addition of eucalyptus creates another source for which the watershed to be depleted. When compared to other habitat types such as coastal scrub and grassland, statistical analysis showed that eucalyptus within the watershed utilizes the most water (Bicknell 1990). There is existing evidence that the eucalyptus are readily pulling from the creek as many of the larger trees in the forest are located within the drainage where there is a high availability of water (Collins 2020). It is estimated that the growth of eucalyptus has resulted in a 40% reduction of streamflow within the channel (Bicknell 1990).

The general plan of MDOSP also recognizes that eucalyptus has played a role in displacing habitat for native riparian plant species in Hazard Canyon (Hook 1988). The natural properties that vary between the different watersheds within the park make it difficult to conduct studies comparing how eucalyptus may be impacting the watershed. A lack of native vegetation associated with the corridor may provide indices that the riparian corridor is not providing the optimal ecosystem services it is capable of due to the eucalyptus.
2.3.1 Sensitive Species

The eucalyptus groves in MDOSP occur primarily on Baywood fine sands, which are wind-blown sands with high organic content deposited during the Pleistocene epoch (USFWS, 1998). Baywood fine sand deposits are home to many rare, endemic species including but not limited to the Morro manzanita (Arctostaphylos morroensis; MM) and the Morro shoulderband snail (Helminthoglypta walkeriana; MSS), which were considered endangered, but recently reclassified as threatened (Fish and Wildlife 2020). The MSS is a terrestrial mollusk that is restricted to 3,100 hectares surrounding the Morro Bay estuary, part of which encompasses the eucalyptus forest in MDOSP (Walgren and Andreano 2012). These species rely on coastal and dune scrub habitat, which prompted research for the abundance of MSS inside and adjacent to the eucalyptus forest. The study found a notable absence of MSS within the eucalyptus that could be attributed to a lack of food source, predation or competition with other snail species, or alterations of light, moisture, and soil properties within the eucalyptus forest (Walgren and Andreano 2012). Due to the original habitat that existed before the eucalyptus, it can be hypothesized that the MSS would be inhabiting the area if eucalyptus were not present and the species may move into habitat if is restored to coastal scrub.

Studies regarding the Morro Manzanita (MM) have shown that the eucalyptus forest in MDOSP exists on habitat that would otherwise be suitable for MM (Tyler and Odion 1996). Like the MSS, MM exists exclusively on Baywood fine sands that now provide habitat for an expanding 350 acre eucalyptus forest. Within the Baywood fine sands, MM is associated with five vegetation types including maritime chaparral, coastal scrub, pure stands of MM, dead MM, and oak dominated stands (Tyler and Odion 1996). MDOSP is also home to the youngest stands of MM at 37 years old, as well as older stands that are older than 47 years old (Tyler and Odion 1996). Like many chaparral species in California, MM is a fire following species that germinates after the presence of fire. Due to a prolonged history of fire suppression, it is possible that MM is inhibited from germinating due to the risk of extreme fire behavior associated with eucalyptus that increases the need for suppression efforts. With much of the MM habitat being replaced by residential development and located on private land (Tyler and Odion 1996), it is important that
efforts be made to preserve any viable habitat and prevent the degradation of existing habitat that may be impacted by eucalyptus. Currently, there is unpublished data on the distribution of MM in MDOSP inside and outside the eucalyptus forest. Further analysis will provide valuable data that will guide future management practices.

Another endemic species that is threatened by extinction due to habitat loss is the Morro Bay kangaroo rat (*Dipodomys heermanni morroensis*), a subspecies of Heermann’s kangaroo rat found only in the Morro Bay area which includes habitat existing in MDOSP. The Morro Bay kangaroo rat has not been captured since 1986 and the last captive individual died in 1993 (Kofron 2016). The impact of optimal habitat loss from residential development as well as the succession of dense vegetation in coastal dune scrub from absence of fire has been identified as the primary cause in the decline of individuals (Kofron 2016). This species relies on Baywood fine sands to move throughout the scrub so it can be hypothesized that the eucalyptus plantation resulted in loss of viable habitat for the kangaroo rat. Characteristic plants associated with Baywood fine sands and coastal dune scrub include deerweed (*Acmispon glaber*), sandmat (*Cardionema ramosissimum*), buckbrush (*Ceanothus cuneatus*), California croton (*Croton californicus*), seabluff wild buckwheat (*Eriogonum parvifolium*), horkelia (*Horkelia cuneata*), and a variety of native grasses (Gambs and Holland 1988). Some of these species are documented occurring in the understory of the eucalyptus forest in MDOSP (Bicknell 1990), but the addition of accumulated leaf litter would likely inhibit the Morro Bay kangaroo rat from using the area as habitat due to lack of mobility and ability to burrow.

Notably, a listed endangered species has come to inhabit eucalyptus groves across coastal areas of central California. *E. globulus* has become an important overwintering site for monarch butterflies and may show preference to nonnative species over native species in some areas even though historically they utilized native trees (Shepardson 1914; Meade 1999; Pleasants and Oberhauser 2012). Natural Bridges State Park in Santa Cruz County is an example of a State Park where *E. globulus* is planted and preserved in a small, designated area identified as monarch butterfly habitat as an interpretation walk for the public. Results from studies in Monterey County showed that monarch butterflies did not show a preference for *E.*
*globulus* over native trees including Monterey Cypress, Monterey Pine, and Coast Redwood (Hamilton et al. 2001). The study also showed that monarchs roosted almost exclusively in native trees at the study sites when previous records showed large numbers roosting in eucalyptus (Hamilton et al. 2001). Various results from coastal communities provide inconclusive results about monarch butterflies seeking habitat in eucalyptus groves. There are currently no studied populations of monarch butterflies overwintering in the eucalyptus of MDOSP nor does the Atlas of Sensitive Species of the Morro Bay Area (2010) list the species in their document designed to guide conservation efforts (Sims 2010).

### 2.3.2 Management Efforts

Management in MDOSP is currently limited due to the vast expansion of the eucalyptus forest and specific permitting needs. The San Luis Obispo Coast District operates under the parameters of a tree removal permit with the California Coastal Commission that allows trees under eight inches DBH to be removed as well as dead trees of any size that are identified as a hazard. A Coastal Development Permit is an additional permit that allows for extensive management to be allowed within the park that authorizes the use of heavy equipment, as well as an expanded ability for tree removal (larger, live trees). The general plan for the park states there is no historic value of the plantation (Hook 1988), though some historians argue that there is historic value that may prevent eucalyptus within the original plantation footprint from being removed. Examples of historic vegetation that is considered exotic but will not be removed includes the Monterey cypress that is planted within the vicinity of the historic Spooner ranch house. The need for management within the eucalyptus increases as the forest becomes unhealthier due to overstocking and competition for resources. Analyses from a forest inventory report show that there is an average of 104 trees per acre in the eucalyptus forest with 81 of those trees identified as *E. globulus* (Collins 2020), in comparison, forest health surveys describe 40-60 trees per acre as an indicator of a healthy forest (MAST 2013). Overcrowding of the forest is also occurring; the majority of trees having relatively small (<12") DBH sizes as the number of trees per acre increased, preventing the growth of competing native species. Due to the abundance of small DBH trees and clear overstocking, it can reasonably be assumed that many
of the trees in the forest are not those of the original plantation and are the result of unmanaged regeneration from an established eucalyptus grove. Further, approximately 21% of *E. globulus* in a given acre are either dead or diseased (Collins 2020).

At the forest level, 78.4% of trees are *E. globulus*, with only 1.1% of the forest being identified as *Q. agrifolia* (Collins 2020). Thus, native coast live oak woodland is significantly underrepresented in today's MDOSP forest. Historically *Q. agrifolia* was a significant part of the indigenous landscape, especially in riparian areas where infrequent fire would have allowed time for oak saplings to survive (Bicknell 1990). As the mission of California State Parks is to “preserve the state’s extraordinary biological diversity” and the general plan of MDOSP has a policy to “ensure the protection and perpetuation of the native oaks” and “promote an increased representation of the younger age classes of oaks”, this could be achieved through extensive removal of the eucalyptus. The general plan addresses eucalyptus as an exotic species that requires management to perpetuate the growth of native plant communities.

There are several ecosystems at risk of biodiversity loss in MDOSP due to the growing eucalyptus grove including coastal scrub, chapparal, grasslands, and oak woodlands. In order to develop management plans that will aid in the goals of State Parks to maintain and encourage the integrity of native habitat for plant and wildlife communities, further research is needed on the current distribution and diversity of plants and wildlife within and outside of the invasive eucalyptus stands. By quantifying the multiple species of concern that are present in the park will help guide land managers in choosing methods that will benefit existing native species and aid in their recovery.

**Chapter 3**

**METHODOLOGY**

3.1 Study Area

The study area consists of native coastal scrub and maritime chaparral habitat that is adjacent to the planted eucalyptus forest in Montana de Oro State Park. Using ArcGIS Pro, transect lines were generated along the edge of the eucalyptus forest at 200-foot intervals. A random number generator was used to identify 20 transects to be used for data collection in the
field. Due to the various species of eucalyptus found throughout the forest, sampling size was chosen to include at least 2 transects per eucalyptus species to allow for evenly distributed coverage.

3.2 Sampling

3.2.1 Vegetation Surveys

Vegetation surveys were conducted in May and June 2021. Once the transect coordinates were established, the center of the plot was placed at the forest edge with 50m extending into native vegetation and 50m extending into eucalyptus habitat (creating a 100m transect line). One m² quadrats were placed alternating either side of the transect line at 5m intervals for the entire length of the transect for a total of 20 quadrats per transect line and a sample area of 20m² per transect (Elzinga 1998). The spacing of quadrats along the transects as well as the distribution between eucalyptus species ensured independence between transects (Elzinga 1998). Within each quadrat, all native and exotic plant species were identified by genus and species, percent cover, and general vigor of plants in the transect were recorded on a survey created using Survey123. A map of the transects can be found in Appendix 1.

3.2.2 Small Mammal Surveys

Two Sherman brand small mammal traps were placed at 10m intervals along the same transect lines used for vegetation surveys. 2 of the transects were omitted due to being in Morro Bay kangaroo rat habitat resulting in 18 surveyed transect lines. The traps were placed in opposing direction to allow for capture from different populations. This resulted in a total of 360 trap nights providing sufficient data for presence/absence small-mammal surveys (Hoffman et al. 2010). Small mammal surveys were conducted in July and August of 2021.

The traps were set with rolled oats and peanut butter and a cotton ball soaked with water to provide a water source and bedding material. Traps were opened at sunset and checked at sunrise to minimize the animals’ time spent in the traps. Animals found inside traps were
transferred to a gallon sized Ziploc bag to be identified. If handling was necessary, protective gloves were worn and standard handling techniques were used to ensure the animals’ safety. Once identification was made or measurements were taken to identify using a taxonomic key, the animal was released close to the site of capture.

3.2.3 Morro Bay Kangaroo Rat

Although the endangered Morro Bay kangaroo rat has not been captured since 1986 and is thought to be extinct, proper precautions will be taken if the species is encountered since the study area is in their native habitat (Kofron et al. 2016, Sorvioes 1996). It is not expected we will observe Morro Bay kangaroo rats, but the presence of other species may serve as indices their population may be existent in low densities. To remain in compliance with the Scientific Collecting Permit issued by the California Department of Fish and Wildlife, transect 8 was omitted from the trapping portion of this study as it falls into the historic habitat range of the Morro Bay kangaroo rat.

3.2.4 Data Analysis

Data was recorded on ESRI Survey123 application. Recorded information for vegetation and small mammal surveys was transferred to Microsoft Excel and statistically analyzed using IBM SPSS Statistics 27. Individual species of vegetation were divided into ground cover
categories including 1) native grass, 2) exotic grass, 3) native forb, 4) exotic forb, 5) native shrub, 6) exotic shrub, 7) bare ground/duff. Within each transect, the average percent cover of each ground cover category was computed for the eucalyptus and adjacent native habitat areas of the transects. These averages were used in paired sample t-tests (N = 5) to analyze the difference in percent cover of vegetative ground cover types between eucalyptus and adjacent native habitat. A chi-square test was used to test for independence between the overall vegetative ground cover of eucalypt stands and the adjacent native habitat (N = 730).

The Simpson’s Index and the Shannon – Weiner Index were used to measure biodiversity of native plants (identified at the species level) identified in eucalyptus and adjacent native habitat types (Table 1) (Simpson 1949, Shannon 1949). These indices provide values to quantify the biodiversity in different plant communities. For the Simpson Index \( D = \sum (n_i * (n_i - 1))/(N * (N - 1)) \), a value can range between 0 and 1 indicating high to low values of diversity, where \( n_i \) is the number of individuals in the species and \( N \) is the total number of individuals in the community. The Simpson Diversity Index \( (1 - D) = 1 - \sum (n_i * (n_i - 1))/(N * (N - 1)) \) values are reported here and measure the probability that two randomly selected individuals belong to different species; where the higher the value, the higher the diversity of species were found in the plant community. The Shannon Index \( H = -\sum p_i * \ln(p_i) \) provides similar \( H \) values, where \( p_i \) is the proportion of the entire community made up of a species. In this index, a low \( H \) value represents low diversity. Both indices were used in this analysis as the Shannon Index provides a way to measure evenness within the community, denoted as \( E_H = H / \ln(S) \), where \( H \) is the Shannon Diversity Index and \( S \) is the total number of unique species. The value can range from 0 to 1 where 1 indicates complete evenness.

Descriptive statistics and a chi-square test was used to test for independence between the small mammal usage of eucalyptus habitat, transition zone, and adjacent native habitat. The transition zone was placed at the edge of the nearest eucalyptus tree at the base of the tree and extended into the native habitat. This area was typically accompanied by native shrub species yet under the dripline of the canopy’s edge.
4.1 Small Mammals

There were 4 different species of small mammals trapped during the survey period including *Peromyscus californicus* (PECA, California mouse), *Peromyscus maniculatus* (PEMA, deer mouse), *Neotoma fuscipes* (NEFU, dusky-footed wood rat), and *Chaetodipus californicus* (CHCA, California pocket mouse). PECA was trapped a total of 33 times; with 8 of those captures being in eucalyptus habitat, 4 being in the transition zone between eucalyptus and native habitat, and 21 being in native habitat. PEMA was trapped a total of 39 times; with 0 captures in the eucalyptus, 2 in the transition, and 37 captures in the native habitat. NEFU was trapped a total of 22 times, with 2 captures in the transition zone and 20 in native habitat. CHCA was trapped a total of 5 times, all captures being in native habitat. Of the 342 traps set in eucalyptus habitat, 334 of those traps were empty throughout the 2-day survey period and there were 8 successful captures. 70 traps were set in the transition zone, in which 62 traps resulted in zero captures and 8 were successful. Of the 321 traps set in native habitat, 238 experienced zero captures and 83 successful captures.

A chi-square test showed the difference in small mammal frequencies between habitat types was significant, $X^2 (6, N = 733) = 87.016$, $p < .001$. Transition zone habitat and native habitat supported more small mammal captures than the eucalyptus habitat.
<table>
<thead>
<tr>
<th></th>
<th>PECA</th>
<th>PEMA</th>
<th>OTHER (NEFU, CHCA)</th>
<th>No Capture</th>
<th>Total Mammals</th>
<th>Total Traps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eucalyptus Habitat</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>334</td>
<td>8</td>
<td>342</td>
</tr>
<tr>
<td>Transition Zone</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>62</td>
<td>8</td>
<td>70</td>
</tr>
<tr>
<td>Adjacent Native Habitat</td>
<td>21</td>
<td>37</td>
<td>25</td>
<td>238</td>
<td>83</td>
<td>321</td>
</tr>
</tbody>
</table>

Table 1: Individual and total counts of small mammal captures in survey area. Light to dark shading highlights lowest to highest counts of small mammals, respectively. (PECA = Peromyscus californicus, PEMA = Peromyscus maniculatus, NEFU = Neotoma fuscipes, CHCA = Chaetodipus californicus)

4.2 Eucalyptus globulus

50% of the study transects were in areas forested by *Eucalyptus globulus*, reflecting that this habitat as it is the most common species planted in MDOSP. These transects resulted in a sample area of 200m². Two of the transects located in *E. globulus* habitat were affected by prescribed burning within the past year in the eucalyptus understory, the adjacent native habitat was not burned. *Eucalyptus globulus* understory vegetative ground cover composes 62% of the forest and is, on average, composed of 94.3% duff, 24.6% exotic grass species, 3.7% native forbs, and 8% native shrubs, which significantly differs from the adjacent coastal scrub habitat, which is primarily composed of native shrubs (42.3%) (*Baccharis pilularis*, *Artemisia californica*, *Toxicodendron diversilobum*, *Acmispon glaber*, *Ericameria ericoides*, *Diplacus auranticus*, *Ceonothus spp.*), native forbs (7.5%) (*Clinopodium douglasii*, *Croton californicus*, *Galium porrigens*), and exotic grasses (11.9%) (*Ehrharta calycina*, *Bromus diandrus*). Additional ground cover categories include native grasses (*Elymus condensatus*), exotic forbs, and exotic shrubs.

The Simpson Diversity Index (1-D) value for *E. globulus* is 0.9 and the adjacent native habitat has a Simpson Diversity Index value of 0.95, indicating higher biodiversity in native habitat. Similarly, the Shannon Index value for the eucalyptus habitat is 2.56 and the adjacent
native habitat has a value of 3.12, supporting the results of higher biodiversity in native habitat. Table 6 shows additional values accounting for evenness and richness within the plant communities.

<table>
<thead>
<tr>
<th></th>
<th>E. globulus</th>
<th>Adjacent Native Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Grass % Cover</td>
<td>0%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Exotic Grass % Cover</td>
<td>24.6%</td>
<td>11.9%</td>
</tr>
<tr>
<td>Native Shrub % Cover</td>
<td>8%</td>
<td>42.3%</td>
</tr>
<tr>
<td>Exotic Shrub % Cover</td>
<td>0.1%</td>
<td>0.05%</td>
</tr>
<tr>
<td>Native Forb % Cover</td>
<td>3.7%</td>
<td>7.5%</td>
</tr>
<tr>
<td>Exotic Forb % Cover</td>
<td>0.2%</td>
<td>0.25%</td>
</tr>
<tr>
<td>Duff/Bare Ground % Cover</td>
<td>94.3%</td>
<td>39.6%</td>
</tr>
</tbody>
</table>

Table 2: Average percent cover of vegetative ground cover categories in transects corresponding to E. globulus habitat. Light to darker shading highlights low to high average percent covers, respectively.

4.3 Eucalyptus cladocalyx

Two transects were located in Eucalyptus cladocalyx habitat with adjacent habitat consisting of native chaparral. The understory of transects within E. cladocalyx (7% of forest) is, on average, composed of 49% exotic grasses and 87.2% duff. The adjacent native chaparral is composed of 65.9% native shrubs, 15% native forbs, and 3.5% exotic grasses.

The Simpson Diversity Index value for E. cladocalyx habitat is 0.82 and the adjacent native habitat had a value of .87, indicating higher biodiversity in the native habitat. The Shannon Index value for the eucalyptus habitat is 1.47 and the value for the adjacent native habitat is 2.23, supporting higher biodiversity in the native habitat.

<table>
<thead>
<tr>
<th></th>
<th>E. cladocalyx</th>
<th>Adjacent Native Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Grass % Cover</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Exotic Grass % Cover</td>
<td>49%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Native Shrub % Cover</td>
<td>3.6%</td>
<td>65.9%</td>
</tr>
<tr>
<td>Exotic Shrub % Cover</td>
<td>5%</td>
<td>3.8%</td>
</tr>
</tbody>
</table>
### Table 3: Average percent cover of vegetative ground cover in transects corresponding to *E. cladocalyx* habitat. Light to darker shading highlights low to high average percent covers, respectively.

<table>
<thead>
<tr>
<th>% Cover</th>
<th>E. cladocalyx</th>
<th>Adjacent Coastal Scrub</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Forb %</td>
<td>1.5%</td>
<td>15%</td>
</tr>
<tr>
<td>Exotic Forb %</td>
<td>0.2%</td>
<td>0.25%</td>
</tr>
<tr>
<td>Duff/Bare Ground</td>
<td>87.2%</td>
<td>27.2%</td>
</tr>
</tbody>
</table>

4.4 *Eucalyptus cephalocarpa*

Two transects were in *Eucalyptus cephalocarpa* and the adjacent coastal scrub habitat. The understory vegetative ground cover of transects within *E. cephalocarpa* (2%) is composed, on average, of 39.25% exotic grasses, 88.75% duff/bare ground, and 1.25% native shrubs. The adjacent coastal scrub is composed of 52.75% native shrubs, 8.25% native forbs, and 32.25% exotic grasses.

The Simpson Diversity Index value for *E. cephalocarpa* is 0.9 and the value for the adjacent native habitat is 0.91, indicating higher biodiversity in the native habitat. The Shannon Index further supports these results with a 1.55 value for the eucalyptus and 2.39 for the adjacent native habitat.

### Table 4: Average percent cover of vegetative ground cover categories in transects corresponding to *E. cephalocarpa* habitat. Light to darker shading highlights low to high average percent covers, respectively.

<table>
<thead>
<tr>
<th>% Cover</th>
<th>E. cephalocarpa</th>
<th>Adjacent Native Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Grass %</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Exotic Grass %</td>
<td>39.25%</td>
<td>32.25%</td>
</tr>
<tr>
<td>Native Shrub %</td>
<td>1.25%</td>
<td>52.75%</td>
</tr>
<tr>
<td>Exotic Shrub %</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Native Forb %</td>
<td>0.25%</td>
<td>8.25%</td>
</tr>
<tr>
<td>Exotic Forb %</td>
<td>0%</td>
<td>0.25%</td>
</tr>
<tr>
<td>Duff/Bare Ground</td>
<td>88.75%</td>
<td>5%</td>
</tr>
</tbody>
</table>
4. 5 Eucalyptus viminalis

Four transects were in *Eucalyptus viminalis* and the adjacent coastal scrub and chaparral habitat. The understory vegetative ground cover of transects within *E. viminalis* (7%) is composed, on average, of 55.5% exotic grasses, 71.75% duff, and 6.6% native shrubs. The adjacent native coastal scrub and chaparral habitat is composed, on average, of 41.25% native shrubs, 8.25% native forbs, and 22% exotic grasses.

The Simpson Diversity Index value for the *E. viminalis* habitat is 0.89 and the value for the adjacent native habitat is 0.91, indicating higher biodiversity in the native habitat. The Shannon Index value for the eucalyptus habitat is 1.55 and the adjacent native habitat is 2.39, supporting higher biodiversity in native habitat.

<table>
<thead>
<tr>
<th>% Cover</th>
<th><em>E. viminalis</em></th>
<th>Adjacent Native Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Grass</td>
<td>0%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Exotic Grass</td>
<td>55.5%</td>
<td>22%</td>
</tr>
<tr>
<td>Native Shrub</td>
<td>6.6%</td>
<td>41.25%</td>
</tr>
<tr>
<td>Exotic Shrub</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Native Forb</td>
<td>0.25%</td>
<td>8.25%</td>
</tr>
<tr>
<td>Exotic Forb</td>
<td>0.5%</td>
<td>0.25%</td>
</tr>
<tr>
<td>Duff/Bare Ground</td>
<td>71.75%</td>
<td>25.2%</td>
</tr>
</tbody>
</table>

Table 5: Average percent cover of vegetative ground cover categories in transects corresponding to *E. viminalis* habitat. Light to darker shading highlights low to high average percent covers, respectively.

4. 6 Mixed Eucalyptus Habitat

Two transects were in mixed eucalyptus species forest and the adjacent coastal scrub and chaparral habitat. The understory vegetative ground cover of mixed eucalyptus (18%) is composed of 36.5% native shrub, 56.4% duff/bare ground, and 30.75% exotic grasses. The adjacent native coastal scrub and chaparral habitat is, on average, composed of 86.5% native shrub, 4.7% native forbs, and 5% duff/bare ground.

The Simpson Diversity Index value for the mixed eucalyptus habitat is 0.91 and the value for the adjacent native habitat is 0.85, indicating higher biodiversity in the mixed eucalyptus
habitat. The Shannon Index value for the eucalyptus habitat is 2.08 and the value for the adjacent native habitat is 2.03, supporting higher biodiversity in the mixed eucalyptus habitat.

<table>
<thead>
<tr>
<th></th>
<th>Mixed eucalyptus</th>
<th>Adjacent Native Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Grass % Cover</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Exotic Grass % Cover</td>
<td>30.75%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Native Shrub % Cover</td>
<td>36.5%</td>
<td>86.5%</td>
</tr>
<tr>
<td>Exotic Shrub % Cover</td>
<td>1.25%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Native Forb % Cover</td>
<td>2%</td>
<td>4.7%</td>
</tr>
<tr>
<td>Exotic Forb % Cover</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Duff/Bare Ground % Cover</td>
<td>56.4%</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 6: Average percent cover of vegetative ground cover categories in transects corresponding to mixed eucalyptus habitat. Light to darker shading highlights low to high average percent covers, respectively.

4.7 Eucalypts vs. Adjacent Native Habitat

Due to limited samples in individual eucalypt species, a chi-square test of independence was performed to examine the relationship between habitat type (eucalypts vs adjacent native habitat) and vegetative ground cover. The relationship between these variables was significant, \(X^2 (5, N = 845) = 137.9, p < .001\). Adjacent native habitat has more diversity than eucalypt habitat.

Average percent cover of individual ground cover categories (native shrub, exotic shrub, native forb, exotic forb, native grass, exotic grass, and bare ground/duff) was determined in the eucalyptus and adjacent native habitat for each transect. The average means of each category were compared in a paired samples t-test. For native shrub species, there was a significant difference in the average percent cover per transect in native habitat (M = 49.92, SD = 22.32) and eucalyptus habitat (M = 9.5, SD = 12.44); \(t(19) = 10.6, p < .001\). The native habitat supports a significantly higher percent cover of native shrub species compared to eucalyptus habitat.

For exotic grass species (*Erharta calycina, Bromus diandrus*), there was a significant difference in the average percent cover per transect in native habitat (M = 14, SD = 11.34) and...
eucalyptus habitat (M = 35.3, SD = 20.81), (t(19) = 4.7, p < .001). The eucalyptus habitat supports a significantly higher percent cover of exotic grasses compared to native habitats.

For native grass species (*Elymus condensatus*), there was not a significant difference in the average percent cover per transect in native habitat (M = .3, SD = .83) and eucalyptus habitat (M = 0, SD = 0), (t(19) = 1.6, p = .12). Native habitat supported more native grasses compared to eucalyptus habitat, though not statistically significant.

For native forb species (*Clinopodium douglasii, Croton californicus, Galium porrigens*), there was a significant difference in the average percent cover per transect in native habitat (M = 7.32, SD = 6.79) and eucalyptus habitat (M = 2.35, SD = 3.79), (t(19) = 4.01, p = .001). The native habitat supports a significantly higher percent cover of native forbs compared to eucalyptus habitats.

For exotic forb species, there was not a significant difference in the average percent cover per transect in native habitat (M = .23, SD = .41) and eucalyptus habitat (M = .20, SD = .55), (t(19) = .21, p = .83). The native habitat had a higher average percent cover of exotic forbs compared to eucalyptus habitat, though the difference was not statistically significant.

For exotic shrub species, (*Carpobrotus chilensis, Conicosia pugioniformus*), there was not a significant difference in the average percent cover per transect in native habitat (M = .45, SD = 1.68) and eucalyptus habitat (M = 1.13, SD = 2.85), (t(19) = 1.55, p = .14). The eucalyptus habitat had a higher average percent cover of exotic shrubs compared to the native habitat, though the difference was not statistically significant.

For duff and bare ground coverage, there was a significant difference in the average percent cover per transect in native habitat (M = 28.55, SD = 18.95) and eucalyptus habitat (M = 84.75, SD = 17.62), (t(19) = 12.43, p < .001). Eucalyptus habitat had a significantly higher average percent cover of duff or bare ground compared to the adjacent native habitat.
Figure 4: Average percent covers of major ground cover categories (exotic grass, native forbs/shrubs, and duff) per transect. Ground cover categories including native grasses and exotic forbs/shrubs were excluded from this graph due to small reported percentages and can be referenced in tables 1-6.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Simpson Index (D)</th>
<th>Simpson Diversity Index (1 – D)</th>
<th>Simpson’s Reciprocal Index (1/D)</th>
<th>Shannon Index (H)</th>
<th>Shannon Evenness Index (E_H)</th>
<th>Richness</th>
<th>Number of Individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. globulus</em></td>
<td>0.1</td>
<td>0.9</td>
<td>9.96</td>
<td>2.56</td>
<td>0.829</td>
<td>22</td>
<td>105</td>
</tr>
<tr>
<td>Adjacent Native</td>
<td>0.05</td>
<td>0.95</td>
<td>18.25</td>
<td>3.12</td>
<td>0.852</td>
<td>39</td>
<td>247</td>
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<tr>
<td><em>E. cladocalyx</em></td>
<td>0.18</td>
<td>0.82</td>
<td>5.5</td>
<td>1.47</td>
<td>0.912</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Adjacent Native</td>
<td>0.13</td>
<td>0.87</td>
<td>7.63</td>
<td>2.23</td>
<td>0.84</td>
<td>14</td>
<td>35</td>
</tr>
<tr>
<td><em>E. cephalocarpa</em></td>
<td>0.1</td>
<td>0.9</td>
<td>10.5</td>
<td>1.55</td>
<td>0.963</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Adjacent Native</td>
<td>0.09</td>
<td>0.91</td>
<td>10.61</td>
<td>2.39</td>
<td>0.882</td>
<td>15</td>
<td>89</td>
</tr>
<tr>
<td><em>E. viminalis</em></td>
<td>0.11</td>
<td>0.89</td>
<td>9.25</td>
<td>2.18</td>
<td>0.908</td>
<td>11</td>
<td>38</td>
</tr>
<tr>
<td>Adjacent Native</td>
<td>0.09</td>
<td>0.91</td>
<td>11.49</td>
<td>2.45</td>
<td>0.905</td>
<td>15</td>
<td>63</td>
</tr>
<tr>
<td>Mixed eucalyptus</td>
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<td>0.91</td>
<td>10.69</td>
<td>2.08</td>
<td>0.948</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>Adjacent Native</td>
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<td>0.85</td>
<td>6.6</td>
<td>2.03</td>
<td>0.845</td>
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</tbody>
</table>

Table 7: Biodiversity index values for all native vegetation identified in eucalyptus stands and adjacent native habitat. Highlighted columns indicate values discussed further in results.
DISCUSSION

Given the need for extensive land management in forested areas due to risk of wildfire, the eucalyptus forest in MDOSP provides a unique opportunity to study potential impacts of exotic forest ecosystems in the central coast of California. Management of the expanding 350-acre forest will not only reduce the risk of high intensity wildfire, but succession of native vegetation will occur through natural recruitment or planting efforts put forth by state parks. Pre-settlement vegetation indicates the forest being planted primarily on oak woodlands, grasslands, and shrublands with Arctostaphylos (manzanita) and Baccharis (coyote brush) dominated shrublands in the adjacent area (Bicknell 1990). This would result in Arctostaphylos and Baccharis plant communities being the likely species to replace the eucalypts. Habitat restoration of this scale will also promote the availability of preferred habitat for birds, mammals, and federally listed species including the Morro shoulderband snail (Walgren and Andreano 2012). Without management, the forest will continue to expand and reduce available habitat needed for native species.

Findings from this study show that adjacent native habitat such as coastal scrub and chaparral plant communities supported more plant and small mammal diversity than all stands of eucalyptus species, except for the transects located in the stands of mixed eucalyptus, which showed higher biodiversity inside the eucalyptus. These results support the hypothesis that eucalyptus is not generally supportive of flora and fauna native to MDOSP. This is likely due to the canopy cover increasing competition for light, thick layers of allelopathic leaf litter, and reduced water availability due to increased uptake from the eucalyptus (Baker 1966, Chu 2014, Rodriguez et al. 2010, Brockerhoff 2012). The higher value of native biodiversity in the mixed eucalyptus stands could be due to these stands being the result of discreet stands spreading into previously established coastal scrub and chaparral plant communities.

Although values found using the Simpson Index and Shannon – Weiner Index showed that native habitat had higher biodiversity than the eucalyptus habitat in most stands, the values reported for Simpson’s Index are very close for both habitat types. This may lead one to determine that eucalyptus supports a diverse understory, however, Simpson’s Index does not account for species richness; whereas Shannon – Weiner’s Index factors in richness resulting in
a greater difference between the biodiversity values for native habitat and eucalyptus habitat. Both indices were used in this study to determine which method would better represent the difference in habitat types based on the data collected. In this case, the Shannon – Weiner index provides a more accurate representation of biodiversity within the eucalyptus forest and adjacent habitat.

Populations of exotic veldt grass (*Ehrharta calycina*) and rip-gut brome (*Bromus diandrus*) are found frequently in all habitat types and may be a factor in inhibiting native shrubs from establishing in eucalyptus, whereas in coastal scrub and chapparal habitat the invasive grasses were introduced into established, mature plant communities. Because the average percent cover for exotic grasses is higher in the eucalyptus understory, invasive weed management may be necessary as eucalyptus is removed and native species are planted in the restoration areas in order to reduce competition and improve survival rates of native seedlings.

Thick layers of leaf litter in the eucalyptus understory may also contribute to the lack of small mammal captures as small mammals may find navigating through the understory difficult compared to native habitat that has open, sandy space. In addition, the limited native vegetation in the eucalyptus habitat decreases the amount of available food sources of which small mammals rely on such as seeds and berries. It is important to note that the lack of small mammal captures in eucalyptus habitat does not mean there are no small mammal populations present within the forest. The lack of captures could be a result of the difficulty in setting stable traps due to the thick layer of leaf litter and duff. Traps that are unstable are usually avoided by small mammals, so the addition of game cameras could potentially confirm whether the absence of small mammals was representative of the habitat. This would provide evidence as to whether it is human error in setting traps or if small mammals avoid the eucalyptus due to difficult travel or limited food sources.

Although the goal of the study design was to study a sample of all stands of eucalypt species in MDOSP, there are discreet stands of *Eucalyptus camaldulensis* that were not surveyed for vegetation of small-mammals due to limited, difficult access. However, given the results of the five other eucalypt stands, it is unlikely the vegetation or small mammal composition
would differ greatly in this habitat. *E. camaldulensis* contributes to only 4% of the eucalyptus understory and is primarily surrounded by *E. globulus, E. viminalis,* and *E. cladocalyx* which would likely provide comparable results. Due to the time of year vegetation surveys were conducted, some annual flowering plants were not accounted for in the surveys. However, an established seedbank of annual vegetation is not expected to exist within the eucalyptus habitat and would likely result in increased biodiversity values in the adjacent native habitat. Additional surveys could be conducted in earlier months to determine the presence of seasonal plants.

Based on the results of this study and others, eucalypts show patterns of excluding native species as the forests become established and continue expanding (Walgren and Andreano 2012). Although there are additional factors that could limit the presence of native species such as soil properties, water and nutrient availability, slope, aspect, and other natural features that would exist in absence of eucalyptus; the pre-settlement vegetation plan suggests these areas could be successfully restored to native coastal scrub or chaparral habitat based on the historic vegetation patterns of grassland and coastal scrub (Bicknell 1990). Continuous monitoring of native species in and around eucalyptus will provide further information on how native species react to management such as forest thinning and native plant restoration planting efforts as well as providing insight regarding any difference in results for areas that do not get managed.

CONCLUSION

This study confirmed hypotheses that eucalyptus does not provide significant habitat for native species found in MDOSP. Without management, the exotic forest will continue to slowly encroach onto native coastal scrub and oak woodland habitat decreasing the availability of preferred habitat of native species. Large amounts of exotic grasses and duff accumulation composing the understory of the eucalyptus forest will also inhibit growth of native species and limit usage of mammals, reducing the overall biodiversity of the park. Removal of this accumulated biomass will create native habitat that will attract insects, small mammals, birds, and large mammals that will likely utilize the native habitat more readily than the eucalyptus forest.

It is unlikely that large stands of eucalypts such as the grove in MDOSP will be planted
elsewhere in California in the future, but it is still important to study the groves that have been establishing and expanding since their original plantings within the last century to determine potential impacts to native species and habitat. As a land management agency, California State Parks has a responsibility to protect natural resources and restore habitat for native species; making the eucalyptus grove in MDOSP a priority area for the San Luis Obispo Coast District. Studies done on the Morro Shoulderband Snail, Morro manzanita, and now the overall vegetation and small mammal inventory provide evidence to the lack of interaction between native species and eucalypts as well as being at risk of further habitat loss due to forest expansion. With careful and intentional planning, the eucalyptus can be thinned and removed in a way that will increase habitat for native plants and animals by reintroducing prescribed fire to the landscape while reducing the threat of high intensity wildfire to surrounding communities by removing hazardous fuel loading.
REFERENCES/WORKS CITED/BIBLIOGRAPHY


Casey, S., & Power, P. (2016). *Native revegetation following eucalyptus removal and pile burning on Santa Cruz Island, California – Channel Islands National Park on Santa Cruz Island, California.*


APPENDIX 1