Managing the Impacts of Environmental Education in Protected Areas

A Case Study at the Jack and Laura Dangermond Preserve near Lompoc, CA

Photo Source: The Nature Conservancy, Heather Gately 2019

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The Group Project is required of all students in the Master of Environmental Science & Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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ABSTRACT

Protected areas such as national parks, wilderness areas, and other public and private managed lands are important for conserving native biodiversity. However, such areas also offer meaningful life experiences for the people who visit them and can be particularly beneficial for youths that may have limited access to the outdoors. This presents a challenge for managers of protected areas. The same land that needs to be set aside to conserve species can also be important for providing students with opportunities to access the outdoors, learn about the natural world, and become environmental advocates. To address this problem, we focused on the Jack and Laura Dangermond Preserve, a 24,000-acre nature preserve located in western Santa Barbara County, CA that was gifted to The Nature Conservancy in 2017. Through mapping areas with sensitive plant and wildlife habitat, we ranked environmental education trails on the preserve based on ecological impact. We also created a management tool that The Nature Conservancy can use to select trails that provide educational opportunities while reducing impacts to native biodiversity. Notably, we found that all 12 education trails on the preserve pass through areas of low and high ecological impact, and that the best trail depends on each school group's needs and The Nature Conservancy's conservation goals. This project intends to help The Nature Conservancy manage its education programs on the Dangermond Preserve, and offers an approach that other land managers can use to inform decisions about balancing the trade-offs of environmental education in biologically diverse areas.

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AHP	Analytical Hierarchy Process
AW3D30	ALOS Global Digital Surface Model
BCM	California Climate Commons Basin Characterization Model
CA	California
CALFIRE	California Department of Forestry and Fire Protection
CBA	Cost Benefit Analysis
CCH	Consortium of California Herbaria
CDFW	California Department of Fish and Wildlife
CWHR	California Wildlife Habitat Relationships
DEM	Digital Elevation Model
FRAP	Fire and Resource Assessment Program
IUCN	International Union for Conservation of Nature
MCA	Multi-Criteria Analysis
NPS	National Park Service
STATSGO2	State Soil Geographic
STEM	Science, Technology, Engineering, and Mathematics
TNC	The Nature Conservancy
UNEP	United Nations Environmental Program
USFWS	United States Fish and Wildlife Service
WRA	WRA, Inc. Environmental Consultants

EXECUTIVE SUMMARY

The Jack and Laura Dangermond Preserve, located near Lompoc, California, was established in December 2017 by The Nature Conservancy (TNC). Due to the merging climate patterns in this particular area, the Dangermond Preserve is home to a rich abundance of flora and fauna (WRA, Inc. 2017). This 24,000-acre nature preserve supports habitat for several special-status species, including Gaviota tarplant (*Deinandra increscens* ssp. *villosa)*, Lompoc yerba santa (*Eriodictyon capitatum)*, and the California red-legged frog (*Rana draytonii).* As managers of one of the last stretches of undeveloped coastline in Southern California, TNC has a unique opportunity to introduce youths from Santa Barbara County to a biologically diverse area through environmental education. However, there are trade-offs between providing access for students and protecting sensitive plant and wildlife species on the Dangermond Preserve.

While access to nature has been connected to mental, physical, and emotional well-being (Tillmann et al. 2018), attendance in protected areas can alter the aesthetic of the land and impact the health of an ecosystem (Marion et al. 2016). This project serves as an example on how land managers can balance the educational benefits and ecological costs of education programs on nature preserves. By locating areas where habitat for sensitive plants and wildlife intersects with environmental education trails, TNC can better manage the potential impacts that education programs may have on native biodiversity at the Dangermond Preserve.

Our first objective was to identify vegetation and wildlife that are sensitive to human presence and map their suitable habitat on the Dangermond Preserve. Through literature review and consultation with our client, we identified four Conservation Criteria: sensitive vegetation, sensitive raptors, sensitive mammals, and sensitive amphibians. We determined "sensitive" to include species with documented behavioral changes to human presence or listed status at the federal, state, or local level. Protecting these four Conservation Criteria can help maintain overall biodiversity on the preserve due to their influence on the food chain and ecosystem health. To map the suitable habitat of these four Conservation Criteria, we utilized past and present spatial data on species' habitats and locations on the Dangermond Preserve.

For the sensitive vegetation criterion, we identified areas where current habitat for sensitive plants intersect with suitable habitat for three invasive plant species: black mustard (*Brassica nigra),* iceplant (*Carpobrotus edulis)*, and perennial veltdgrass (*Ehrharta calycina)*. We considered these overlapping habitats to be "vegetation hotspots". These hotspots represent areas where sensitive vegetation is most vulnerable to human impact, as these areas are where invasive plant species are most likely to outcompete sensitive plant species. We found that the majority of the vegetation hotspots are located along the southern edge of the preserve, with a few hotspots occurring along the preserve's eastern border. Increased trail use within these hotspots could accelerate the conversion from native and sensitive plant communities to invasive plant communities.

For the sensitive mammals criterion, we identified areas of highest potential for disturbance to six focal species. The focal species represent various trophic levels and include the American badger (*Taxidea taxus*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), mountain lion (*Puma concolor*), and mule deer (*Odocoileus hemionus*). To locate areas on the preserve where human presence would be most impactful to mammals, we overlaid the highly suitable habitat for each of the six focal species. The resulting overlay analysis indicated that human presence across much of the preserve would affect fewer than four of the focal species, with one small habitat area in the eastern end of the preserve affecting five focal species.

For the sensitive raptors criterion, species were chosen due to their top-down control on the ecosystem and include bald eagles (*Haliaeetus leucocephalus*), golden eagles (*Aquila chrysaetos*), Cooper's hawks (*Accipiter cooperii*), peregrine falcons (*Falco peregrinus*), American kestrels (*Falco sparverius*), red-tailed hawks (*Buteo jamaicensis*), and ospreys (*Pandion haliaetus*). The methods for raptors were similar to those for the sensitive mammals. From a literature review, we determined the potential flushing distances for each raptor species to understand how human disturbance would affect each species. We conducted an overlay analysis of the highly suitable habitats for each of the focal species and added buffers based on flushing zones. This allowed us to estimate the number of raptor species that would be subject to flushing across different areas of the preserve. We found that all areas on the preserve are within the potential flushing zone of at least one raptor species. The central and southern parts of the preserve are within the potential flushing zones of up to six raptor species.

Sensitive amphibians were chosen as our fourth Conservation Criterion due to their status as bioindicators for ecosystem health. Specifically, our focal species included the California red-legged frog (*Rana draytonii*), Pacifc chorus frog (*Pseudacris regilla*), western toad (*Anaxyrus boreas*), and arboreal salamander (*Aneides lugubris*). In order to identify areas that have the highest potential impact to sensitive amphibians, we mapped aquatic habitats on the preserve rather than species' specific habitat. The aquatic habitats include all streams, cattle troughs, and stock ponds located on the preserve, and represent suitable habitats for sensitive amphibians. To analyze the potential impact to focal amphibian species, we added 100 and 200 meter buffers around the suitable habitats, similar to the flushing zones in the raptor analysis. We found that there are high impact areas to sensitive amphibians throughout the preserve, with significant impact in the eastern panhandle. This is due to a dense network of streams in that area. It is particularly important to monitor use in these high impact areas during the breeding seasons for sensitive amphibians.

Our second objective was to rank trails for environmental education on the Dangermond Preserve based on their ecological impact to the four Conservation Criteria. In order to rank each trail, we first developed a preserve-wide ecological impact map using the combined results from the ecological impact analyses for each Criterion explained above. By overlaying the map of education trails with the ecological impact map, we were able to determine the average impact per mile on each trail. However, since the sensitivities of the four Conservation Criteria vary by season, we repeated this process with different weighting schemes that indicate higher sensitivity for certain criteria during different times of the year (for example, breeding season for sensitive amphibians, or nesting season for sensitive raptors). Furthermore, we used additional weighting schemes to indicate differing management priorities on the preserve (for example, considering one criterion as much more important to protect than the rest). In alternating the weighting schemes, the resulting trail ranks and impact scores can more accurately reflect seasonality and The Nature Conservancy's conservation goals.

Generally, all trails have a low impact to sensitive mammals, while sensitive vegetation and sensitive amphibians are impacted on a broader scale ranging from low to high. In addition, sensitive raptors are much more impacted along education trails than the other three Conservation Criteria. It is important to note that the preserve does not have a uniform distribution of impacts, and therefore avoiding impacts to one of the Conservation Criteria may affect another. Additionally, the importance of one criterion may vary seasonally or as The Nature Conservancy's management priorities change over time.

Our third and final objective was to create a management tool to select trails on the Dangermond Preserve that offer suitable educational opportunities while minimizing ecological impacts. The unique history of the land and the abundance of biodiversity that the preserve supports offers rich curricular opportunities for students. For this analysis, we considered educational opportunities on the preserve to include scenic landmarks and diverse vegetation communities, as these can contribute significantly to the quality of student experiences during their program (Clay and Daniel 2000). To address these trade-offs between educational benefits and ecological costs, we developed an interactive web app that allows The Nature Conservancy to select trails for education programming that meet a school group's needs while reducing ecological impacts.

To use the web app, The Nature Conservancy will input general information about the school group: school name, program date, student age, number of students, and number of chaperones. Additionally, TNC will select the trail difficulty, trail length, and travel time that suit the group's abilities and curricular needs. These constraints will then filter out available trails that fit the program criteria. The resulting trails will display the constraints as well as the educational opportunities (scenic landmarks and vegetation communities) and seasonally-weighted ecological impact score. By comparing the educational opportunities and ecological impacts associated with each trail, The Nature Conservancy can make more informed decisions about which trails to use for environmental education.

The purpose of this project was to assist The Nature Conservancy in managing the ecological impacts of environmental education programs on the Dangermond Preserve. This analysis provides our client with reproducible models and tools that can be adapted to fit their management priorities should they change in the future. Based on our findings, our main recommendations are the following:

1. *Assign weights to each Conservation Criterion based on the time of year.* We found that the trail with the lowest ecological impact differs depending on the weights assigned to each Conservation Criterion, meaning that weights play an important role in trail use decision-making. In addition, we found through our literature review that plant and wildlife species on the preserve differ in the timing of biological events such as leafing, seeding, breeding, nesting, and migration. This suggests that there are certain times of year when the use of a trail would be particularly impactful to one or more Conservation Criteria. For example, raptors may be more impacted during the spring and summer when they are breeding, attending to nests, and rearing young. With this in mind, we recommend that managers at the Dangermond Preserve utilize the various weighting scenarios for the Conservation Criteria that reflect the timing of biological events. This will help to account for the effect that seasonality has on species sensitivity, and will result in trail rankings that more accurately reflect the impact to native biodiversity on the preserve.

2. *Hire consultants or researchers to conduct field surveys to supplement the currently available data.* While we have provided thorough and up-to-date information on predicted ecological impacts to the preserve, we did so using data on predicted, rather than validated, species habitat suitability. To assist TNC in making more informed management decisions on the preserve, we recommend that field studies be conducted to: (1) identify and verify the specific locations of the three invasive species in this report (black mustard, iceplant, and perennial veldtgrass), (2) ensure minimal impact to mammals, raptors, and amphibians by locating dens, nests, and breeding habitat, respectively, and (3) determine the specific breeding habitat of amphibians in order to locate the most suitable aquatic habitat and species' specific buffer distances.

3. *Continually monitor and evaluate education program effectiveness.* We recommend that as education programs are implemented on the preserve, TNC continually measures both the

short- and long-term success of such programs. This will involve defining success and identifying ways to measure it. For example, short-term success could be defined as improvements in understanding STEM and environmental science concepts. This could be measured by comparing science test scores between students from similar backgrounds that participated in education programs on the Dangermond Preserve and those who did not. To assess long-term impacts, TNC could survey students that participated in education programs and ask about their academic and career goals. Following up with students to learn about their volunteer experiences, internships, degree programs, and jobs can help TNC assess whether its programs are providing a pipeline model that leads students into environmental careers.

4. *If establishing new trails, prioritize trail development in low impact areas.* While our general recommendation is to avoid building new trails to minimize ecological impacts, TNC may wish to expand their environmental education program in the future. In doing so, the carrying capacity of existing trails may be exceeded, and TNC would need to expand their current trail systems or build new trails. Our ecological impact analysis can help guide TNC's decision-making process on siting new education trails. This analysis is flexible so that TNC can update the model with new weights for the Conservation Criteria as their conservation and management priorities evolve. Before siting any new trails, we recommend running the ecological impact model with the most up-to-date management weights. The low impact areas should be prioritized for the development of new trails. Furthermore, TNC should choose areas of low impact that are accessible from current education trails or other roads currently present on the preserve. This will minimize excess ecological damage by containing trail development to previously impacted areas.

CHAPTER 1: PROJECT OVERVIEW

1.1. Purpose and Objectives

This project serves as an example for land managers on how to balance the ecological costs and social benefits of environmental education in a biologically diverse area. While The Nature Conservancy (TNC) has a unique opportunity to provide environmental education on the Dangermond Preserve, this type of access may conflict with conservation goals. Therefore, the environmental education program on the preserve must be carefully managed. By analyzing where education trails would be most impactful to sensitive plant and wildlife species on the preserve, this project will guide TNC's decision-making process about where to allow access for students such that ecological impacts are minimized or mitigated. The three objectives of this project include:

1. Identify vegetation and wildlife that are sensitive to human presence and map their suitable habitat on the Dangermond Preserve.

2. Rank trails for environmental education on the Dangermond Preserve based on their ecological impact to sensitive vegetation and wildlife.

3. Create a management tool to select trails on the Dangermond Preserve that offer suitable educational opportunities while minimizing ecological impacts.

1.2. Significance

The amount of land included within protected areas globally has almost doubled since the 1992 Earth Rio Summit, and today covers nearly 15% of land on earth (IUCN 2018). However, such areas have varying levels of protective status, and approximately 94% of all national parks, wilderness areas, and other managed lands allow some amount of access for humans (IUCN 2014). There is value to allowing people within protected areas, as engagement with nature can improve human health and may inspire youth and adults to become environmental advocates (Cooper et al. 2015; Ewert, Place, and Sibthrop 2005). Yet when access is not well-planned, it can conflict with conservation goals and create challenges for managers of protected areas (Kangas et al. 2010; McDougall and Wright 2004). Even hiking and camping, which have historically been viewed as compatible with conservation, can accelerate the loss of native plants and alter the richness and abundance of native wildlife (Ballantyne and Pickering 2015; Cole 2004; Larson et al. 2019). As attendance in protected areas worldwide increases, there is a need for management approaches that reduce impacts to native biodiversity (Balmford et al. 2009).

The Jack and Laura Dangermond Preserve, located in western Santa Barbara County, California, represents a valuable case study for managing access in biologically diverse areas. Gifted to The Nature Conservancy in 2017, the preserve was historically managed as a cattle ranch and today represents one of the last stretches of coastline spared from urban development in Southern California. The merging of northern and southern climate patterns at the preserve, in addition to diverse topography and geology, supports more than 370 native plant species and 240 native wildlife species. This includes nearly 60 species with special-status at the federal, state, and/or local level (WRA, Inc. 2017). In an area intermixed with ranches, farms, roads, and urban development, the Dangermond Preserve plays a vital role in conserving the region's flora and fauna.

In addition, the preserve represents an outstanding opportunity for environmental education. Jack and Laura Dangermond, as well as TNC, intend for the preserve to serve as an "outdoor classroom" where students can connect with nature. TNC is currently developing an environmental education program that targets students living in Lompoc, CA and surrounding communities within Santa Barbara County. The goal of this program is to use nature-based, experiential learning as tools to engage students with the outdoors and inspire them to pursue conservation-related academic and career paths. The biodiversity and wilderness of the Dangermond Preserve, in addition to its proximity to nearby Lompoc schools, make it an unparalleled setting for environmental education.

This project will inform decision makers about how to best manage TNC's education programs on the Dangermond Preserve, and may serve as an example for other managers on how to balance the trade-offs of access in protected areas. With a conservation-based management approach, TNC can inspire the next generation of environmental leaders while preserving native biodiversity on the preserve.

1.3. Background

Balancing the Trade-offs of Environmental Education in Protected Areas

Protected areas include national parks, wilderness areas, and other lands that are managed to "achieve the long term conservation of nature and associated ecosystem services" (Dudley 2008). In the United States, national parks alone support more than 600 threatened and endangered species, which accounts for about one-third of all taxa listed under the U.S. Endangered Species Act (National Parks Conservation Association 2019). Yet only about 14% of all land within the nation is protected, as agriculture, logging, mining, and urban development accelerate the loss of habitat elsewhere (Losos et al. 1995; UNEP-WCMC 2019). With this in mind, there is a need to carefully manage protected areas, and to ensure that human activities in such areas reduce or avoid impacts to native biodiversity. This includes activities such as hiking and camping, which are often assumed to be low-impact (Taylor and Knight 2003). As researchers become increasingly aware of how attendance in protected areas can harm native plant and wildlife species, managers are being advised to close access in some areas (Ikuta and Blumstein 2003). However, protected areas can offer meaningful life experiences for the people who visit them.

Access to the outdoors has been connected to improving mental, physical, and emotional health, meaning there are benefits to increasing attendance in protected areas (Tillmann et al. 2018). For example, children who spend more time outdoors tend to have increased attentiveness, lower levels of stress, and a more active lifestyle (Babey, Brown, and Hastert 2005; Dadvand et al. 2017; Wells and Evans 2003). Learning in an outdoor environment can help to increase self-confidence in students and allow them to feel more comfortable working in groups (Scott, Boyd, and Colquhoun 2013). Environmental education has been connected to increased academic achievement and improved science and math test scores (Wheeler et al. 2007). Notably, there is some evidence that environmental education can promote pro-environmental attitudes and motivate students to become more concerned about conservation issues (AIR 2005).

While there are benefits to providing youth with access to the outdoors, children from low-income communities and communities of color have fewer opportunities to engage with nature compared to their white, middle- and upper-class peers (Kibel 2007; Rigolon and Flohr 2014). Barriers that prevent access to national recreation areas in California, for example, include geographic distance, transportation costs, limited information about outdoor activities, lack of representation in the workforce, and implicit discrimination (Roberts and Chitewere 2011). Environmental education in protected areas can help connect underserved youth with the outdoors, and there is a movement among teachers, nonprofit organizations, and activists to improve the livelihoods of children through such programs (Louv 2008).

Managers of protected areas therefore face a complex environmental problem. The same land that needs to be set aside to conserve native biodiversity can also provide benefits to youth and may be important for inspiring students to become environmental advocates. This raises an important question for managers: How can they balance the trade-offs of environmental education in protected areas? Before answering this question, managers first need to understand the ways in which increasing access for students can conflict with conservation goals.

In general, activities such as hiking and camping tend to reduce vegetation cover and plant growth, with most of the impact occurring during the initial, low-level use of an area (Cole 1987). Trampling can also accelerate the spread of invasive plant species, as trails and campsites can act as corridors for the dispersal of non-native seeds (Dickens, Gerhardt, and Collinge 2005).

To reduce the impacts of foot traffic on vegetation, managers are advised to concentrate access onto a small number of trails (Cole 1987, 1995). Yet even when access is concentrated, people can disturb wildlife that rely on protected lands to forage for food, find shelter, and care for young (Taylor and Knight 2003). For example, the presence of humans has been shown to reduce the amount of time that birds spend at their nest and deter mammals from feeding in a given area (Smith et al. 2017; Webber, Heath, and Fischer 2013). Notably, the cumulative impacts of human-wildlife interactions can reduce the richness and abundance of native species in protected areas (Larson et al. 2019).

The impacts of hiking, camping, and other nature-based activities to native biodiversity are a challenge for managers of both public and private protected areas. However, the effectiveness with which government agencies can reduce or avoid impacts to the environment on state and federal lands may be slowed by funding constraints (Ansson 1998) , and agencies may lack the resources needed to manage an area (Kroner et al. 2019). This highlights the need for privately-owned protected areas in which access is closely controlled and land is protected in perpetuity (Langholz and Lassoie 2001).

The Jack and Laura Dangermond Preserve: A Case Study in Protected Area Management

In December 2017, The Nature Conservancy was gifted a 24,000-acre nature preserve in Santa Barbara County, California. Located where the wet, cool climate of Northern California meets with the dry, warm climate of Southern California, the Jack and Laura Dangermond Preserve consists primarily of oak woodland, chaparral, coastal scrub, and grassland, and supports numerous special-status species (WRA, Inc. 2017). The preserve was historically managed as a private cattle ranch and today represents one of the few stretches of coastline spared from urban development in Southern California.

In addition, the preserve is located near Lompoc, CA, a community with Title I school districts. Such school districts are the recipients of the largest amount of federal funds dedicated for education programs with a high number of students enrolled in free and reduced lunch programs (Consolidated State Information 2015; Elementary and Secondary Education Act 1965). Currently, students in Lompoc receive environmental education through after-school STEM programs, workshops, and nature-based field trips (School Accountability Report Card - Find a SARC 2017). The Nature Conservancy has partnered with third-party environmental educators, including NatureTrack, NatureBridge, and REACH, to implement outdoor programs for students in Lompoc that will include day and overnight trips to the Dangermond Preserve. The Dangermond Preserve is not open to the general public, and therefore these trips represent an opportunity for local students to engage with an ecologically and historically significant area that would otherwise be inaccessible. The goal for these programs is to provide students with meaningful learning experiences in a biologically diverse setting and to inspire the next generation of conservation leaders.

The Dangermond Preserve supports a high amount of native biodiversity, and the implementation of outdoor programs will considerably increase the number of people allowed onto the preserve annually. TNC wants to ensure that the impacts of hiking and camping are closely managed to protect the integrity of the land and the species it supports. As TNC plans for environmental education on the Dangermond Preserve, questions that need to be answered include: 1) Which plant and wildlife species on the preserve are sensitive, and where is habitat for such species located? 2) How can trails used for environmental education on the preserve be ranked based on impact to sensitive plant and wildlife species? 3) Where on the preserve can environmental educators provide students with meaningful learning experiences while avoiding or reducing ecological impacts?

The Dangermond Preserve has historically had low numbers of people on the land. Due to its history and ecological significance, The Nature Conservancy is uniquely positioned to preemptively address issues related to increasing access as it plans on implementing environmental education programs. Well-planned access on the Dangermond Preserve will help to conserve native biodiversity while offering students from Lompoc, CA with increased access to the outdoors. The location of the Dangermond Preserve makes it a useful case study in protected area management that will serve as an example of how to balance the trade-offs of environmental education in biologically diverse areas. The methods and tools developed in this project can be replicated by other land managers when deciding how to proactively manage access in protected areas.

CHAPTER 2: OVERVIEW OF METHODS

In order to assist The Nature Conservancy in ranking their trails on the Dangermond Preserve based on minimizing ecological impact, we performed a Multi-Criteria Analysis. This method has been used by land managers, both in the U.S. and globally, to help them make informed decisions when evaluating multiple criteria in protected areas (Cuirong et al. 2016; Quinn, Schiel, and Caruso 2015). The scale of this project first focuses on determining the ecological impacts to the entire preserve for four Conservation Criteria, and then narrows down to the trail level in order to rank them. The steps of our Multi-Criteria Analysis are as follows (Figure 1):

1. Identify Conservation Criteria that are important to protect on the Dangermond Preserve.
2. Assign individual weights to the Conservation Criteria using an Analytical Hierarchy Process.
3. Combine the weighted outputs of the Conservation Criteria into a single map of cumulative ecological impacts on the preserve.
4. Calculate the ecological impact for each trail, and rank trails from lowest to highest impact.

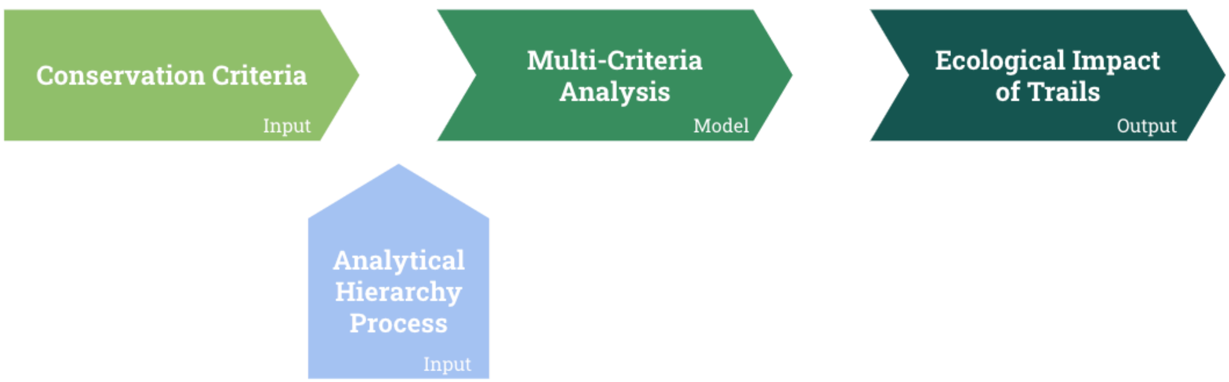

Figure 1: An Overview of the Multi-Criteria Analysis Used to Rank Trails on the Dangermond Preserve. This schematic outlines the general process of how the ecological impact of trails was assessed on the Dangermond Preserve. For the detailed model schematic, see Figure A2.33, Appendix II.

The Conservation Criteria we focused on include sensitive vegetation, sensitive mammals, sensitive raptors, and sensitive amphibians. Due to their influence on the food chain and ecosystem health, conserving these criteria will help to protect overall biodiversity on the Dangermond Preserve. Specifically, native vegetation can provide habitat for native wildlife, and represents a bottom-up control of ecosystems (Schuldt et al. 2019). The mammals we have selected are a representative group of predators, as well as a single ungulate, whose combined ranges cover most of the preserve. Therefore, we expect the protection of these wide-ranging mammals to have cascading effects throughout the preserve, in terms of providing trophic control (Beyer et al. 2007, Ripple and Beschta 2006). We selected raptors for a similar reason;

raptors were chosen over songbirds due to their predatory nature and wide habitat ranges. Their predation also contributes to a top-down control of the ecosystem, while their habitat ranges are greater than that of their non-predatory counterparts (Mäntylä, Klemola, and Laaksonen 2011; Schoener 1968). Lastly, we selected amphibians, rather than all herptiles, due to their population decline globally and status as a bioindicator (Hayes et al. 2002, 2010). This makes their protection paramount to ensuring a healthy ecosystem, as their decline could signal ecosystem degradation (Alroy 2015; Harvey 2018).

Within each Conservation Criterion, we looked at only sensitive species on the preserve. After performing a literature review, we determined "sensitive" as either a documented behavioral change due to human presence, or listed-status at the federal, state, or local level.

Once the Conservation Criteria were established, we then assigned each of them a specific weight. The baseline model assigned a weight of 0.25 to each Conservation Criterion. After establishing this baseline, we then repeated our Multi-Criteria Analysis using different weighting schemes (Table A1.3, Appendix I).

The combination of Conservation Criteria and weights produced a map of ecological impact. From there, we were able to rank the trails by the amount of impact they are predicted to cause. Additionally, since our model produces a preserve-wide ecological impact map, it can be used to look at areas of lesser impact for the siting of potential new trails. The chapter titled "Ecological Impact & Trail Ranking" provides a more detailed methodology.

A detailed map of the trail systems and trails can be found below (Figures 2-6). Trail systems were pre-determined by The Nature Conservancy and are defined as a set of interconnecting trails. Trail systems were broken down into individual trails. These trails were designated based on points of interest within a given trail system. For example, there is a grove of oak trees within the Jalachichi system; the out-and-back trail to this oak grove has been designated as "Jalachichi Oak Grove".

The following chapters delve further into each Conservation Criterion, beginning with sensitive vegetation. In these chapters, we explore the plant communities and species that make up each criterion, along with the impacts humans may cause to them. The "Sensitive Vegetation" chapter presents the individual methods one at a time, due to their compounding nature. The "Sensitive Wildlife" chapter instead presents the methods and results by Conservation Criteria: sensitive mammals, then sensitive raptors, and finally sensitive amphibians.

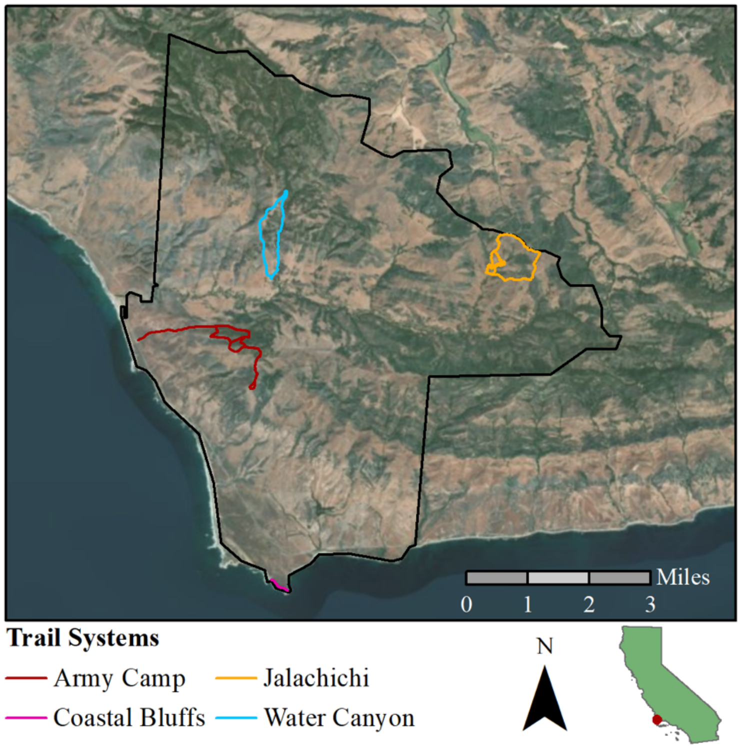

Figure 2: Trail Systems on the Dangermond Preserve. This map shows the four unique trail systems that will be used for environmental education programming.

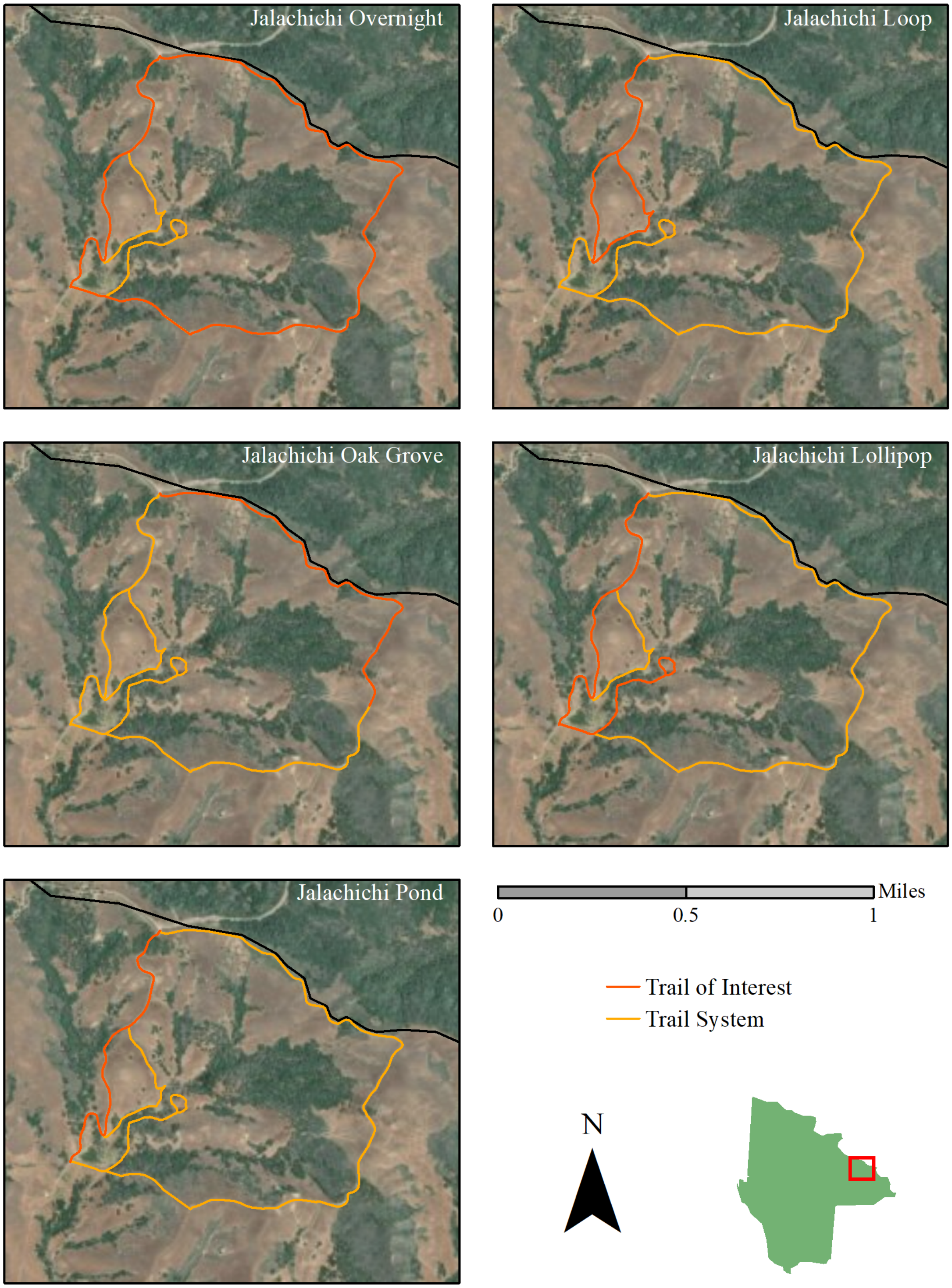

Figure 3: Trails Within the Jalachichi Trail System. The Jalachichi trail system has five trails within it that can be used for environmental education programming.

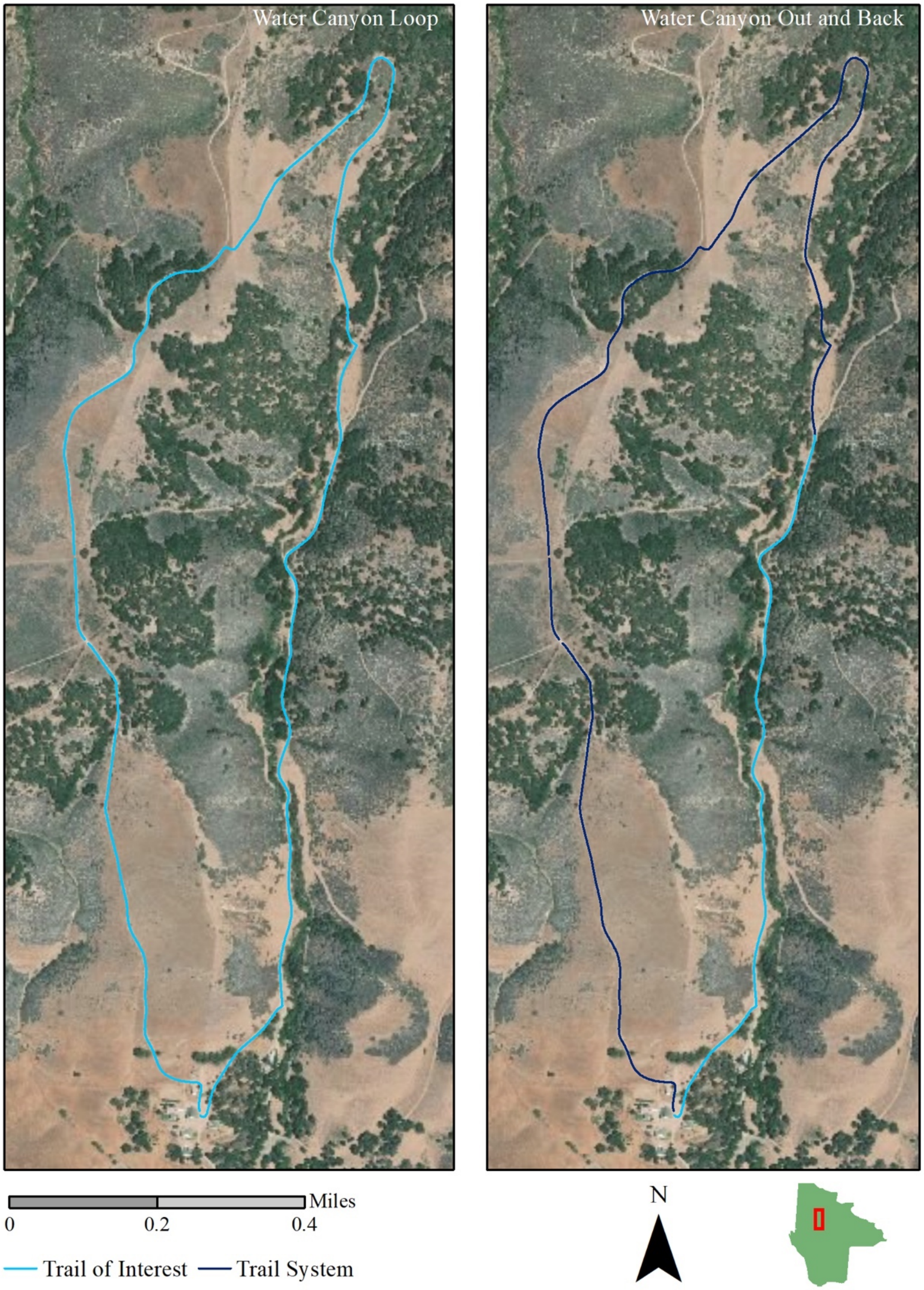

Figure 4: Trails Within the Water Canyon Trail System. The Water Canyon trail system has two trails within it that can be used for environmental education programming.

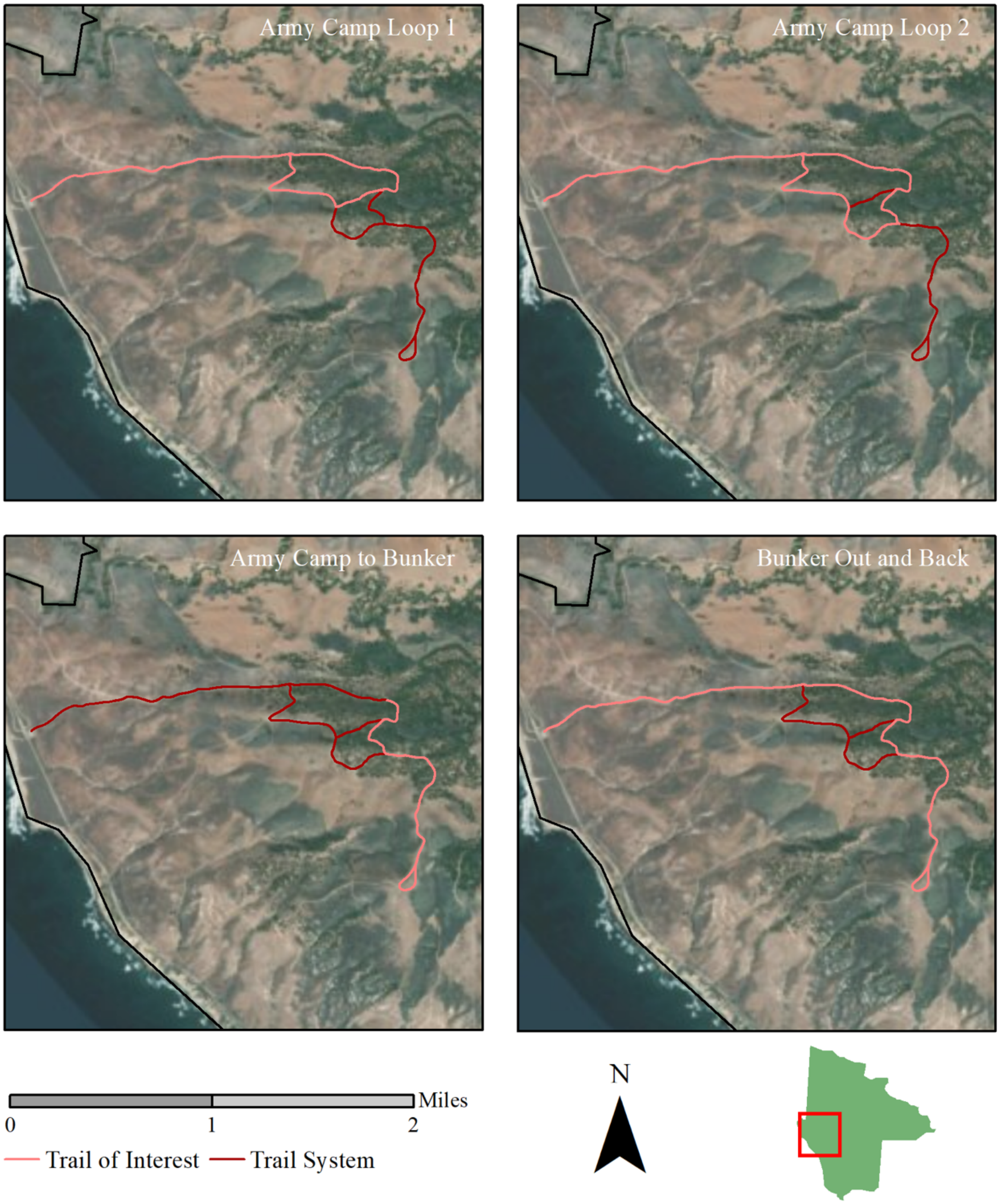

Figure 5: Trails Within the Army Camp Trail System. The Army Campy trail system has four trails within it that can be used for environmental education programming.

Figure 6: Trails Within the Coastal Bluffs Trail System. The Coastal Bluffs trail system has one trail within it that can be used for environmental education programming.

CHAPTER 3: SENSITIVE VEGETATION

3.1 Introduction

In protected areas such as the Dangermond Preserve, managing the impacts of hiking on vegetation represents a difficult but important step in conserving native biodiversity. Much of the impact that hiking causes to vegetation occurs during the initial, low-level use of an area (Cole 1987). This can include the direct loss of plants as well as reductions in plant cover, height, biomass, stem length, number of flowers, and seed production (Liddle 1997). The morphological characteristics of a plant are often an important determinant of its ability to withstand the impact of foot traffic. For instance, grasses, sedges, and low-growing forbs with flexible stems and leaves tend to be more resistant to trampling than woody shrubs and rigid plants (Cole and Monz 2002). Other factors that can affect a plant's ability to withstand trampling impacts include seasonality, topography, soil conditions, and the frequency, intensity, and duration of use by humans (Pickering and Hill 2007).

In addition, invasive plant species are often more resistant to foot traffic than native species. Therefore, activities such as hiking can reduce competition with natives and allow invasive species to use available water, nutrients, light, and space along a trail (Dickens, Gerhardt, and Collinge 2005; Holmes et al. 2010). Trails can also act as corridors for the dispersal of non-native seeds. The seeds of "hitchhiking" species, which include mainly grasses and herbs, can be introduced via shoes, clothing, and equipment (Dickens, Gerhardt, and Collinge 2005; Mount and Pickering 2009). Invasive plant species introduced along trails are not limited to trail edges and may spread into adjacent areas over time (Pickering and Hill 2007). This process can accelerate as use increases and can lead to an overall shift in species richness and abundance in plant communities adjacent to trails (Potito and Beatty 2005). Managers of protected areas therefore face a challenge in balancing access to trails with the control of invasive plant species.

This leads to an important management question at the Dangermond Preserve: Of the trails that may be used for environmental education, which would be the most impactful to vegetation? This project answers this question by identifying where invasive plant species are most likely to thrive in areas with sensitive and special-status plant species. While a number of invasive plant species occur on the preserve, the species we focused on include black mustard (*Brassica nigra*), iceplant (*Carpobrotus edulis*), and perennial veldtgrass (*Ehrharta calycina*). All three species are listed as moderate or high impact on the California Invasive Plant Council list and are management priorities for The Nature Conservancy on the Dangermond Preserve (The Cal-IPC Inventory 2017). These species are also disturbance-associated, meaning they tend to do well in disturbed areas such as along trails (Albert 2017; Brooks 2017; Pickart 2017).

Black mustard is an annual herbaceous plant that grows 0.5-1.5 meters tall and has yellow flowers up to 8 cm in length. While black mustard can be found in numerous plant communities, in Southern California it occurs in grasslands, shrublands, and coastal areas. Its seeds are self-propelled up to several meters and can be dispersed by wind, water, rodents, and human activities. Black mustard matures early in the year, meaning that it can use water and nutrients before native annual plants are able to obtain these resources. It also produces chemicals that inhibit the germination of other species, allowing it to form monotypic stands. Black mustard has invaded approximately half of all coastal scrub habitat in California (Palenscar 2013).

Iceplant, a ground-covering succulent native to South Africa, can form mats up to 40 cm thick and 8-10 meters in diameter. This species has a fibrous root system located in the upper 50 cm of the soil that allows it to readily use moisture from winter rain and summer fog. Iceplant is often found near cliffs and sand dunes, but can also thrive along roads and other disturbed areas. It has been widely planted for aesthetics and to prevent soil loss, and it tends to cover coastal bluff areas in California. Additionally, iceplant can outcompete native plant species, including threatened and endangered species such as Lompoc yerba santa (*Eriodictyon capitatum*) (Parker 2008).

Finally, perennial veldtgrass is a bunch-forming grass that can reach 30-75 cm in height and has flat, green to reddish-purple leaves that are 7-20 cm in length. This species is found primarily in deep, sandy soils and occurs in sand dunes, coastal dune scrub, coastal sage scrub, coastal grassland, maritime chaparral, and oak woodland. It forms dense stands that tolerate only a few species, and has seeds that can be carried by wind, birds, mammals, and humans. In the 1950's and 1960's, perennial veldtgrass was planted north of the Dangermond Preserve on Vandenberg Air Force Base to stabilize sand dunes. Perennial veldtgrass has since outcompeted native species in the region and accelerated the conversion to non-native grassland (Weber 2013).

The Dangermond Preserve was historically a managed cattle ranch, with records of grazing in the area dating back to the Spanish era (WRA, Inc. 2017). Cattle ranching, farming, and other uses of the Cojo and Jalama Ranches undoubtedly contributed to the spread of invasive plants and influenced the richness and abundance of species found on the preserve today. The preserve currently includes approximately 5,000 acres of non-native annual grassland, 1,600 acres of non-native forb stands (upland mustards, upland thistle stands, and fennel), and 200 acres of iceplant mats. An example of invasive plant coverage on the preserve can be seen near Point Conception and Government Point, where iceplant has formed a near monoculture in the area (WRA, Inc. 2017).

Yet while invasive plants are well-established on the preserve, controlling the additional spread of such species can help to protect native plant diversity. Invasive plants are a threat to special-status species, including species such as the Gaviota tarplant (*Deinandra increscens* ssp. *villosa*), Lompoc yerba santa (*Eriodictyon capitatum*), and La Purisima manzanita (*Arctostaphylos purissima*) that are endemic to western Santa Barbara County.

With this in mind, our team set out to model the potential spread of invasive plant species on the Dangermond Preserve. By mapping areas where highly suitable habitat for invasive plant species intersects with habitat for sensitive plants, we would then be able to identify trails on the preserve that would be most impactful to sensitive vegetation, our first Conservation Criteria. In addition, we would be able to use this spatial data as an input into our Multi-Criteria Analysis to rank trails on the Dangermond Preserve.

3.2 Methods

In order to locate areas on the preserve where invasive plant species are most likely to spread and outcompete sensitive plant species, we conducted two initial analyses: a Habitat Suitability Analysis to predict suitable habitat for invasive plant species, and a Hotspot Analysis to identify where highly suitable habitat for invasive species intersects with habitat for sensitive plant species. These "vegetation hotspots" indicate where trails may accelerate the spread of invasive plant species and cause the most damage to sensitive plants on the preserve. With these two analyses, we were then able to score the preserve based on ecological impact to sensitive vegetation. The data and methods we used for the Habitat Suitability Analysis, Hotspot Analysis, and vegetation impact scoring are discussed below. See Appendix II for step-by-step workflows.

3.2.1 Habitat Suitability Analysis

To understand which areas of the preserve are most vulnerable to the spread of invasive plant species, we first needed to locate areas with suitable habitat for the three target species: black mustard, iceplant, and perennial veldtgrass. We modeled the habitat suitability for invasive plant species using MaxEnt, a maximum entropy modeling software. MaxEnt uses species presence points and environmental conditions to predict the distribution of a species across a landscape (Phillips and Dudík 2008). This software has been used for both plant and wildlife species, and allows conservation planners to model species distributions, predict range shifts, and inform management decisions (Elith et al. 2011; Guisan et al. 2013; Wang et al. 2019). Species presence points can often be found in museum and herbarium records, meaning that MaxEnt can be used even when species surveys have not been conducted within a study area.

While plant surveys were conducted on the Cojo and Jalama Ranches between 2012-2017 by WRA, these surveys did not involve recording presence points for invasive plant species.

Therefore, we used species presence points found in herbarium records. In addition to presence points, the inputs we used in MaxEnt included data on climate, soil, and elevation. We gathered data from the following sources.

Data Sources

1. **Species Presence Points:** We obtained the presence points from the Consortium of California Herbaria (CCH), an open-source database managed by the Jepson Herbarium at UC Berkeley. This database includes more than 2.2 million specimen records from 36 institutions in California. Each record lists the name of the collector, scientific name of species, date collected, county, elevation, locality, and longitude and latitude.

2. **Climate Data:** The climate data was sourced from the California Climate Commons Basin Characterization Model (BCM). The BCM provides 30-year climate averages for the state of California and was produced in 2014. Included in the BCM are the following variables: precipitation, air temperature, April 1st snowpack, recharge, runoff, potential evapotranspiration, actual evapotranspiration, and climatic water deficit.

3. **Soil Data:** Soil data came from Data Basin, an online mapping platform that provides spatial data related to land management, natural resources, and the environment. This includes the State Soil Geographic (STATSGO2) database for California, which was developed by the National Cooperative Soil Survey and provides statewide data on soil order, texture, drainage class, and other variables.

4. **Digital Elevation Model (DEM):** The elevation data we used came from OpenTopography, an open-source database with high-resolution topographic data. The ALOS Global Digital Surface Model (AW3D30), a 30-meter resolution DEM, was generated from remote-sensing images collected between 2006 and 2011.

Data Analyses

To prepare the species presence points for MaxEnt, we filtered the data in RStudio to include only the date collected, longitude, and latitude. We used species presence points from 2000-2019 to avoid older records which may have been collected or reported inaccurately. To prepare the environmental data for MaxEnt, we created rasters for the climate, soil, and DEM data in ArcGIS. All rasters were clipped to the extent of California, projected in NAD 1983 2011 California Teale Albers, and had a 30x30 meter cell size.

The species presence points and environmental data served as inputs into MaxEnt. An initial run was attempted using all environmental variables. However, due to coverage issues with the data, the model would not run. Areas with "no data" caused a high number of species presence points to be excluded from the run. Therefore, a second run was conducted using climate water deficit, precipitation, minimum temperature, maximum temperature, elevation, and soil texture. We conducted a jackknife test during this second run of MaxEnt, which analyzes each variable in isolation, as well as collectively. This test is useful in training the model and determining which variables are most important for predicting habitat suitability (Phillips 2017).

The jackknifing results and analysis of variable contributions from this run were used to select environmental variables for the final run in MaxEnt. The environmental variables from these results were chosen because they provided the most percent contribution to the model (Appendix II). Additionally, incorporating certain variables omitted species presence points due to insufficient data coverage. Therefore, the environmental variables included in the final run were climate water deficit, minimum temperature, elevation, and soil texture. Notably, the soil data was coarse in scale and categorical rather than nominal. The combination of these two issues represents a limitation to the invasive plant habitat suitability outputs. See Appendix II for a table of all environmental variables and MaxEnt outputs.

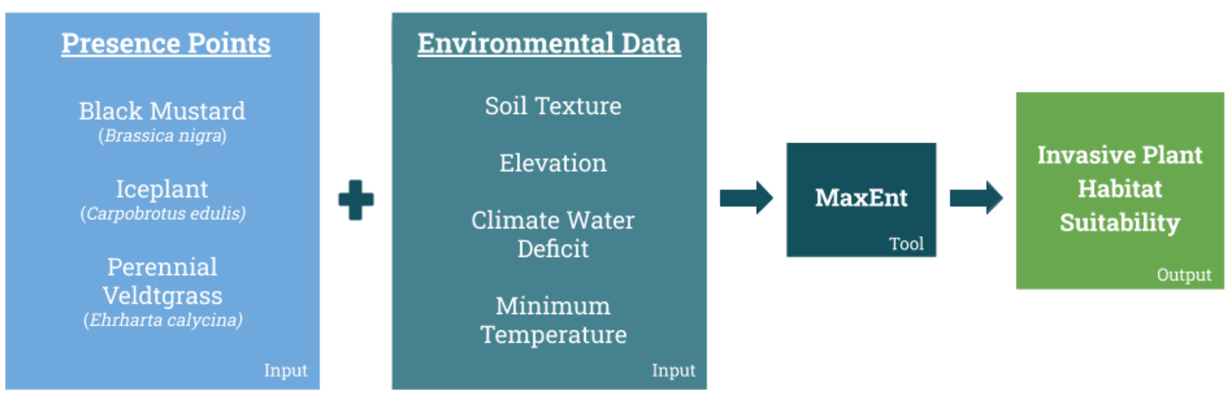

Figure 7: **Invasive Plant Habitat Suitability Schematic.** Schematic of the MaxEnt analysis used to model the habitat suitability for three invasive plant species on the Dangermond Preserve.

3.2.2 Hotspot Analysis

We conducted a hotspot analysis in ArcGIS to identify areas where highly suitable habitat for each invasive plant species overlaps with sensitive vegetation on the Dangermond Preserve. The data for this analysis included invasive plant habitat suitability data from MaxEnt, sensitive plant data from WRA, Inc., and trails data from The Nature Conservancy. See Appendix II for detailed workflows.

Data Sources

1. **Invasive Plants:** The habitat suitability maps for each invasive plant species (black mustard, iceplant, and perennial veldtgrass) were converted into rasters using the ASCII to Raster tool in ModelBuilder in ArcGIS. These rasters were clipped to the Dangermond Preserve extent.

2. **Sensitive Plants:** This data was collected by WRA and provided by The Nature Conservancy via ArcGIS Online. It included a layer of habitat for sensitive plant species and a layer of sensitive vegetation communities on the Dangermond Preserve. We combined this into a single "sensitive vegetation areas" layer using the Union Tool in ArcGIS, and converted this layer from a shapefile into a raster using the Polygon to Raster Tool.

3. **Trails:** The trails data, which included a layer with trails, unpaved roads, and paved roads on the Dangermond Preserve, was provided by The Nature Conservancy via ArcGIS Online. Specifically, we incorporated only the trail systems outlined in the "Overview of Methods" chapter when determining which trails would go through vegetation hotspots.

Data Analyses

We conducted a hotspot analysis using ModelBuilder in ArcGIS (Figure 8) to identify areas where highly suitable habitat for invasive plant species overlaps with habitat for sensitive plants. For each invasive plant species, we used the Reclassify tool to find the top 30% of suitable habitat for black mustard, iceplant, and perennial veldtgrass on the Dangermond Preserve. We then used the Raster Calculator tool to intersect the top 30% of suitable habitat for each invasive plant species with habitat for sensitive plants. The output from this analysis indicated where invasive plant species were most likely to spread into areas with sensitive vegetation on the preserve. We considered such areas to be "vegetation hotspots." Lastly, we added the trails layer to understand where an increase in education programs would be most impactful to our first Conservation Criteria, sensitive vegetation.

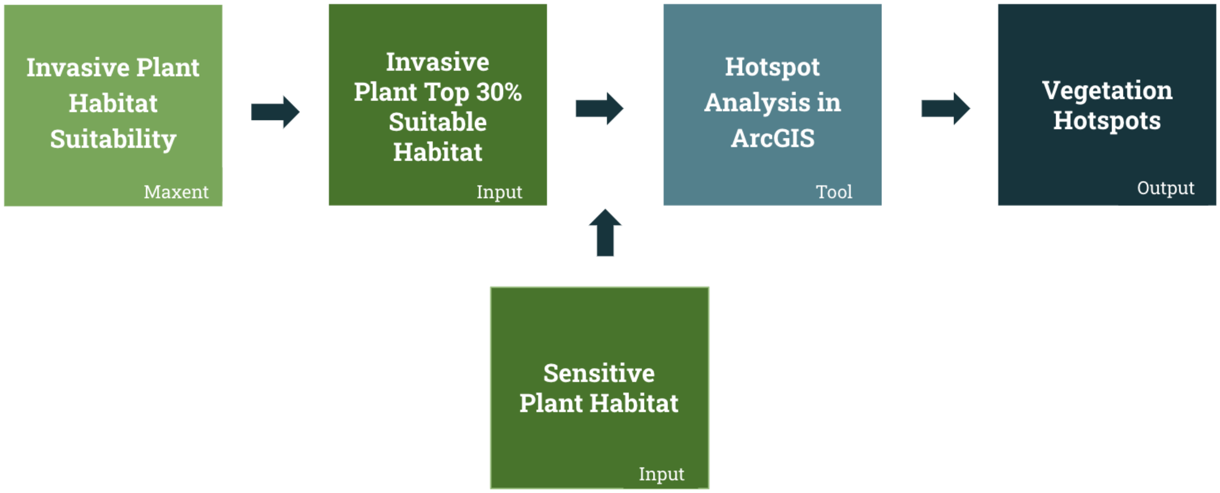

Figure 8: Vegetation Hotspot Analysis Schematic. Schematic of the hotspot analysis conducted in ArcGIS to locate areas where education programs would be most impactful to sensitive vegetation on the Dangermond Preserve.

3.2.3 Vegetation Impact Scoring

Using the outputs from the habitat suitability and hotspot analyses, we were able to score the Dangermond Preserve based on impact to sensitive vegetation. We developed five levels of impact based on the varying association between sensitive vegetation and invasive species across the preserve (Table 1). Using the Reclassify tool in ArcGIS, we binned these levels of impact from 0 to 4, with 0 being the lowest impact and 4 being the highest (See Appendix II for complete workflow). We considered the most concerning areas to be where trails intersect with sensitive vegetation hotspots, as these areas are most vulnerable to the spread of invasive species from foot traffic (Dickens, Gerhardt, and Collinge 2005). Therefore, the sensitive vegetation hotspots were assigned the highest impact score of 4. Areas with sensitive vegetation present but not considered a hotspot were assigned the next highest impact score of 3. Areas with highly suitable habitat for one or more invasive species but no sensitive species present were assigned an impact score of 2. Areas where there is moderately suitable habitat for invasive species and no sensitive species present were assigned an impact score of 1. Lastly, the lowest impact score, assigned a 0, were areas with low habitat suitability for invasives and no presence of sensitive species.

One limitation to this categorization of vegetation is that we used the predicted habitat suitability for our invasive species from MaxEnt. We did not have data on the current distribution of invasive species on the preserve, and therefore some of the impact areas may already contain one or more of the invasive plant species.

Criteria	Attributes	Description	Score
Protecting sensitive and special-status vegetation	Sensitive vegetation hotspot	Sensitive vegetation overlapping with high habitat suitability (70-100%) for one or more invasive plant species	4
	Sensitive vegetation present but not a hotspot	Sensitive vegetation not overlapping with high habitat suitability (70-100%) for one or more invasive plant species	3
	High potential for spread of invasive plant species, but no sensitive vegetation present	High habitat suitability (70-100%) for one or more invasive plant species	2
	Moderate potential for spread of invasive plant species, but no sensitive vegetation present	Moderate habitat suitability (30-70%) for one or more invasive plant species	1
	Low potential for spread of invasive plant species, and no sensitive vegetation present	Low habitat suitability (0-30%) for all three invasive plant species	0

Table 1: Sensitive Vegetation Impact Scores on the Dangermond Preserve. This table describes the impact score and qualitative descriptions associated with each vegetation bin.

3.3 Results

3.3.1 Habitat Suitability

The habitat suitability for each invasive plant species tends to be highest near Point Conception and the coastal areas of the Dangermond Preserve (Figure 9). Habitat suitability is also high for perennial veldtgrass near the eastern end of the preserve and for black mustard near Jalama Road. Overall, the northern end of the preserve has the lowest habitat suitability for each invasive plant species.

While the habitat suitability for black mustard and iceplant tends to transition gradually from high near the coast to low in inland areas, such a trend is not seen for perennial veldtgrass. In contrast, the habitat suitability for perennial veldtgrass transitions rather abruptly moving across the preserve. This may be due to the coarseness of the soil data, which was the only categorical data used in the MaxEnt analyses. The soil changes from loamy to clayey near the middle of the preserve, which matches the abrupt change from high to low habitat suitability for perennial veldtgrass.

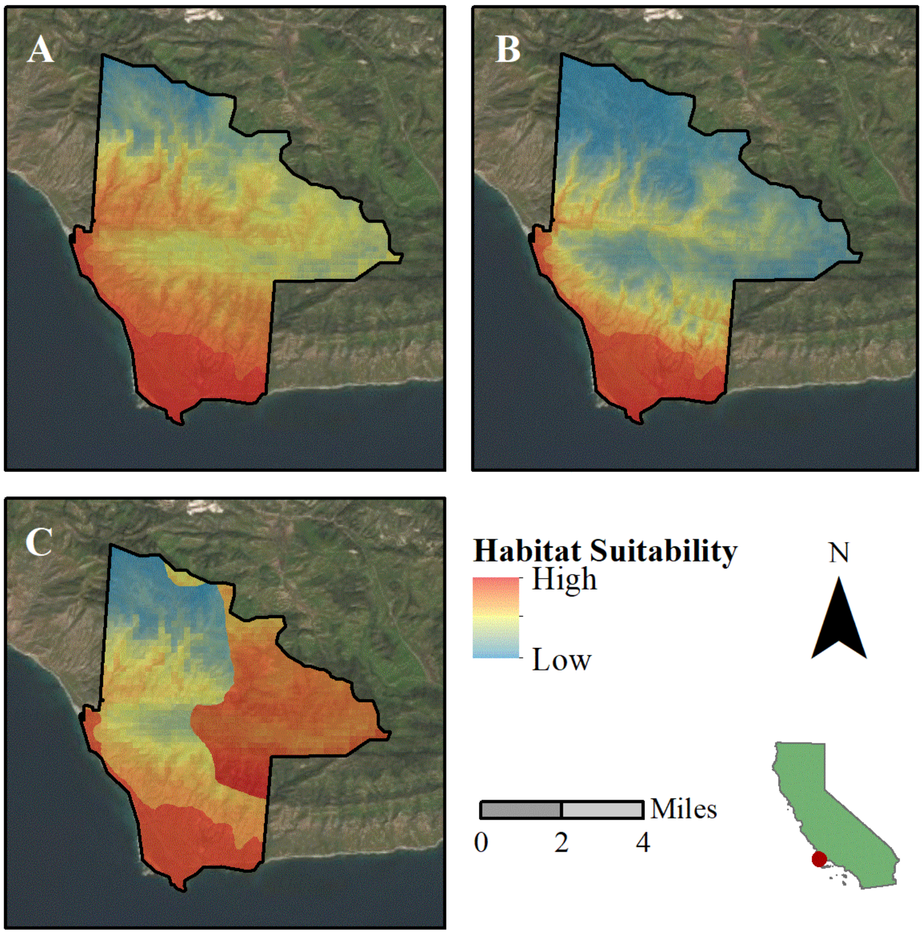

Figure 9: Habitat Suitability for Three Invasive Plant Species on the Dangermond Preserve, A) Black Mustard (*Brassica nigra*), B) Iceplant (*Carpobrotus edulis*), and C) Perennial Veldtgrass (*Ehrharta calycina*). Analyses were conducted in MaxEnt using species presence points, minimum temperature, climate water deficit, soil texture, and elevation. For all three invasive plant species, the most suitable habitat (red) tends to be located in coastal areas while the least suitable habitat (blue) is located in the northern end of the preserve.

3.3.2 Hotspot Analysis

While areas with sensitive vegetation are scattered across the Dangermond Preserve, most are located near the coast and along the eastern end of the preserve (Figure 10). This is due in part to the presence of critical habitat for the Gaviota tarplant, a state and federally listed species that is endemic to western Santa Barbara County. Gaviota tarplant is an annual herbaceous plant that occurs mostly in coastal bluff scrub and can shift in range from year to year, meaning that mapping areas with this species is important.

At least 20 other special-status plants are found on the Dangermond Preserve. Two of which, the La Purisima manzanita and the Lompoc yerba santa, are also endemic to western Santa Barbara County. Areas with sensitive vegetation near the eastern end of Jalama Ranch are mostly stands of La Purisima manzanita (Figure 10). In contrast, Lompoc yerba santa has only been observed in one small area near the northeast end of the preserve, and consultants with WRA. determined that the use of an old ranch road could lead to the complete loss of this species on the preserve (WRA, Inc. 2017).

In addition to special-status species, the preserve also supports 20 vegetation alliances that are listed as sensitive by the California Department of Fish and Wildlife (CDFW) or the County of Santa Barbara. This includes herb, shrub, and tree-dominated communities such as purple needlegrass grassland, lemonade berry scrub, sawtooth goldenbush scrub, and tanoak forests. Tanoak forest, for example, occurs primarily at the eastern end of Cojo Ranch where the Dangermond Preserve shares a boundary with the Hollister Ranch.

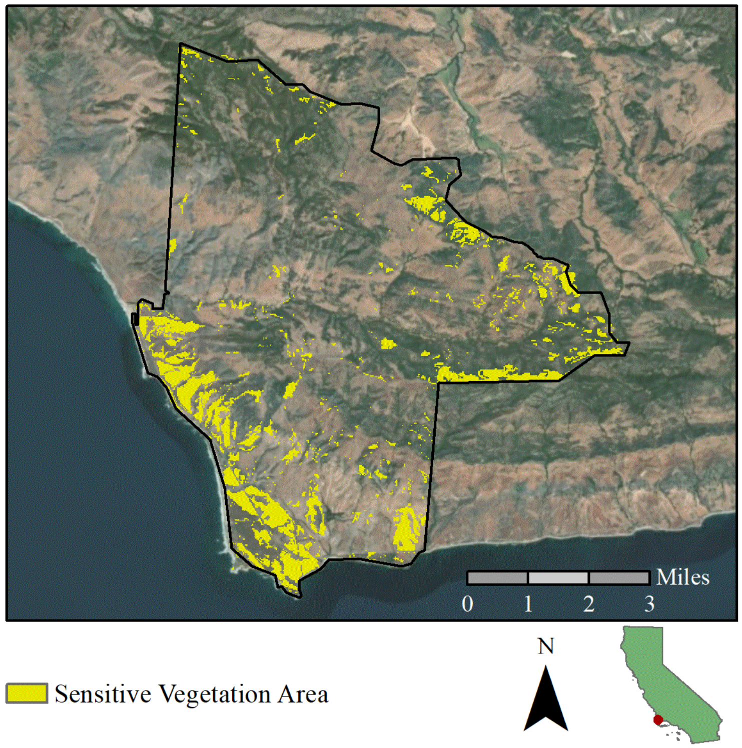

Figure 10: Sensitive Vegetation Areas on the Dangermond Preserve. Layers with special-status plant species and sensitive vegetation communities were combined using ArcGIS. While areas with sensitive vegetation are spread throughout the preserve, they occur in the highest concentration near the coast. This is due primarily to the presence of critical habitat for Gaviota tarplant (*Deinandra increscens ssp. villosa*).

Vegetation hotspots, where the top 30% of suitable habitat for invasive plant species overlaps with habitat for sensitive plants, are found mostly near the coast of the Dangermond Preserve (Figure 11). With black mustard and iceplant as the threat, hotspots tend to be located between the mouth of Jalama Creek and Government Point. With perennial veldtgrass as the threat, there are comparably fewer hotspots near the coast and more along the eastern boundary of the preserve.

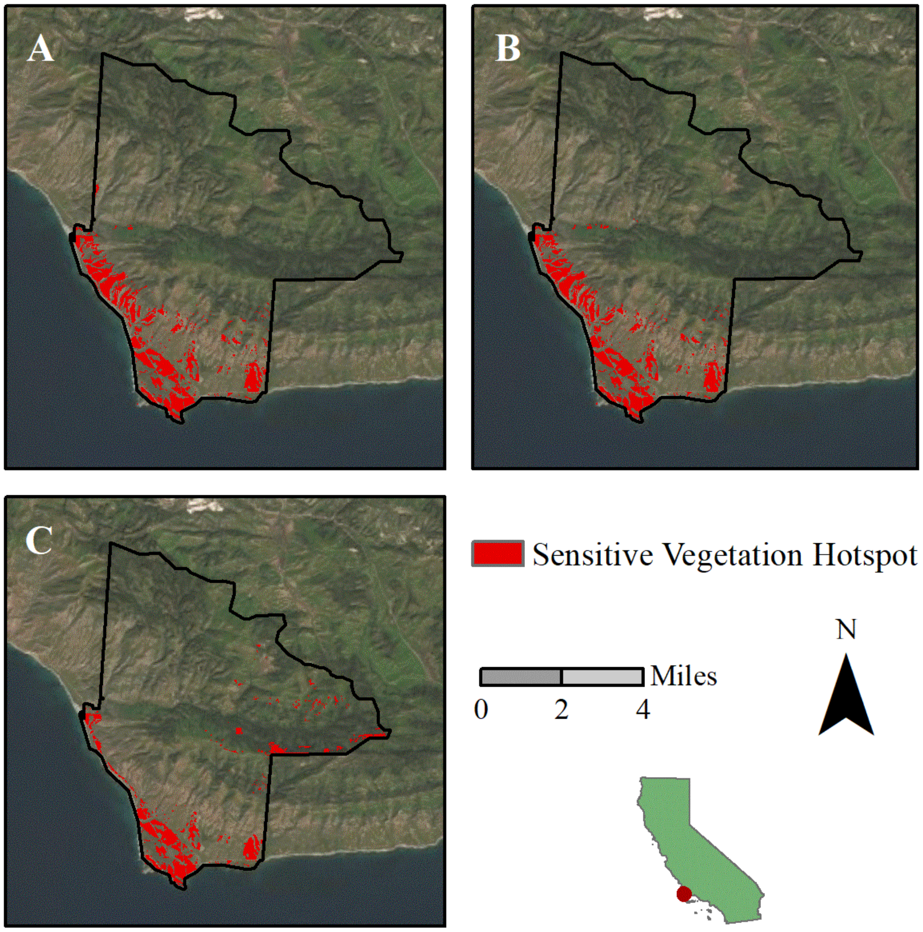

Figure 11: Sensitive Vegetation Hotspots on the Dangermond Preserve. The top 30% of suitable habitat for three invasive plant species, A) black mustard (*Brassica nigra*), B) iceplant (*Carpobrotus edulis*), and C) perennial veldtgrass (*Ehrharta calycina*), was intersected with sensitive vegetation areas using ArcGIS. Hotspots are located primarily in the coastal areas of the preserve.

There are also specific sites where trails that could be used for environmental education overlap with vegetation hotspots. One example is located near the eastern end of the preserve, where the Jalachichi Pond trail passes through a hotspot of purple needlegrass grassland. Purple needlegrass has been observed on the Dangermond Preserve in association with coastal sage scrub and intermixed with non-native annual grasses. Increased use of the Jalachichi Pond trail could lead to the loss of this species in the area and a complete conversion to non-native grassland (Figure 12).

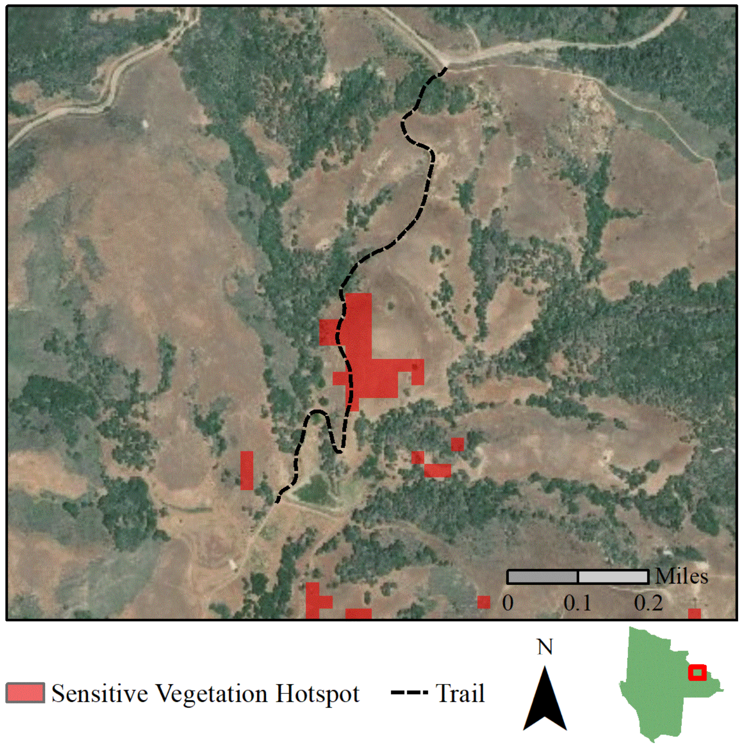

Figure 12: Sensitive Vegetation Hotspot on the Jalachichi Pond Trail. The top 30% of suitable habitat for perennial veldtgrass (*Ehrharta calycina*) was intersected with sensitive vegetation areas using ArcGIS. This hotspot represents an area with purple needlegrass grassland (*Nassella pulchra*), a native bunchgrass. Increased use of the trail could accelerate the conversion to a non-native grassland.

A second example of a trail that overlaps with a vegetation hotspot can be found at the Army Camp trailhead. This is an area with critical habitat for Gaviota tarplant. Increased use of the Army Camp trail system could accelerate the spread of non-natives such as black mustard. Additionally, due to the state and federal status of Gaviota tarplant, surveys for the species must be conducted prior to land disturbance and incidental take permits will be needed from the USFWS and CDFW if impacts cannot be avoided (Figure 13).

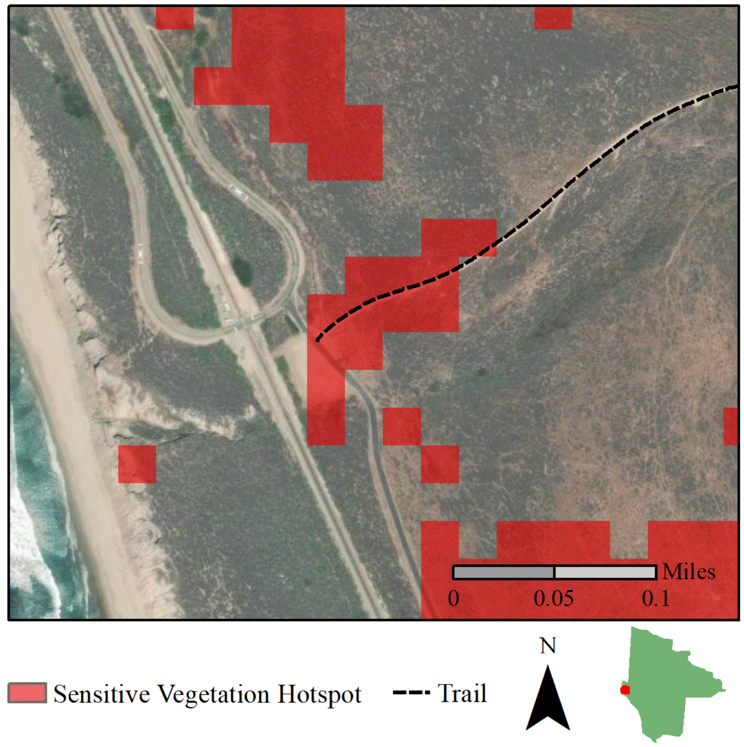

Figure 13: Sensitive Vegetation Hotspot Near the Cojo Gate and Army Camp Trailhead. The top 30% of suitable habitat for black mustard (*Brassica nigra*) was intersected with sensitive vegetation areas using ArcGIS. This hotspot represents an area with critical habitat for Gaviota tarplant (*Deinandra increscens* ssp. *villosa*), an annual plant that is listed as endangered at the state and federal level. Increased human activity near the Army Camp trailhead could accelerate the spread of invasive species such as black mustard.

The Coastal Bluffs trail, located near Government Point on the southern end of the preserve, is a third example of a trail that overlaps with a vegetation hotspot. Iceplant has already formed large, ground-covering mats in the area. However, the area also supports a brownheaded rush seep (*Juncus phaeocephalus*) alliance and has critical habitat for Gaviota tarplant. Brownheaded rush seeps tend to be found in coastal meadows and dune swales, and increased use of the Coastal Bluffs trail could negatively impact this alliance on the preserve (Figure 14). While brownheaded rush seeps are only considered sensitive when associated with wetlands, literature suggests that the protective status of this alliance may need to be increased (Sawyer, Keeler-Wolf, and Evens 2009).

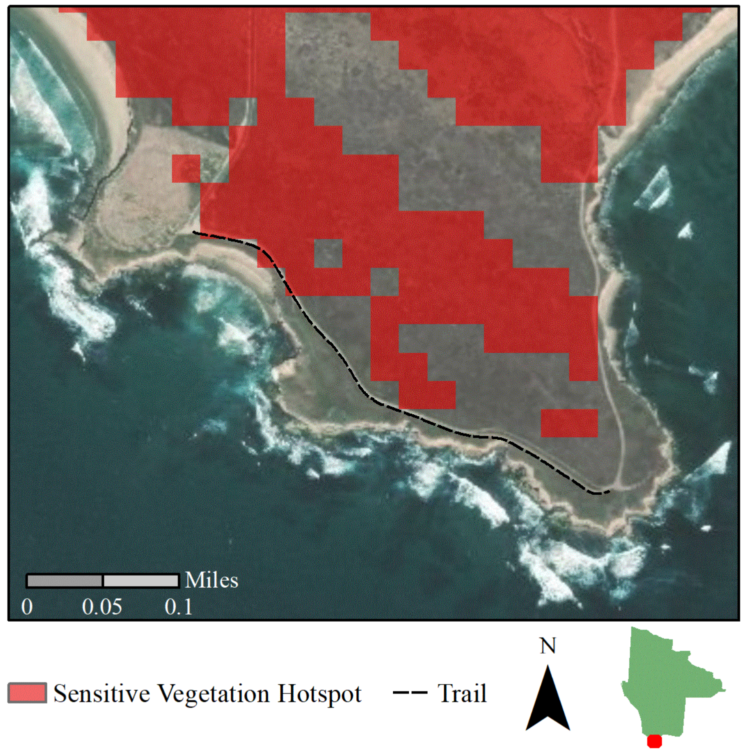

Figure 14: Sensitive Vegetation Hotspot Near the Coastal Bluffs Trail. The top 30% of suitable habitat for iceplant (*Carpobrotus edulis*) was intersected with sensitive vegetation areas using ArcGIS. This hotspot represents an area with a brownhead rush seep (*Juncus phaeocephalus*) alliance and habitat for Gaviota tarplant (*Deinandra increscens* ssp. *villosa*).

3.3.3 Vegetation Impact Scoring

Areas of highest impact to vegetation tend to be located near the coast of the Dangermond Preserve, while areas of lowest impact occur along the northwestern border (Figure 15). The areas in red in Figure 15 are the results of the hotspot analysis and indicate locations where a trail would be most impactful to sensitive vegetation. The dark green areas represent habitats that have low suitability for invasive species as well as no presence of sensitive plant species. These vegetation impact scores were used as an input into the Multi-Criteria Analysis for the sensitive vegetation Conservation Criteria.

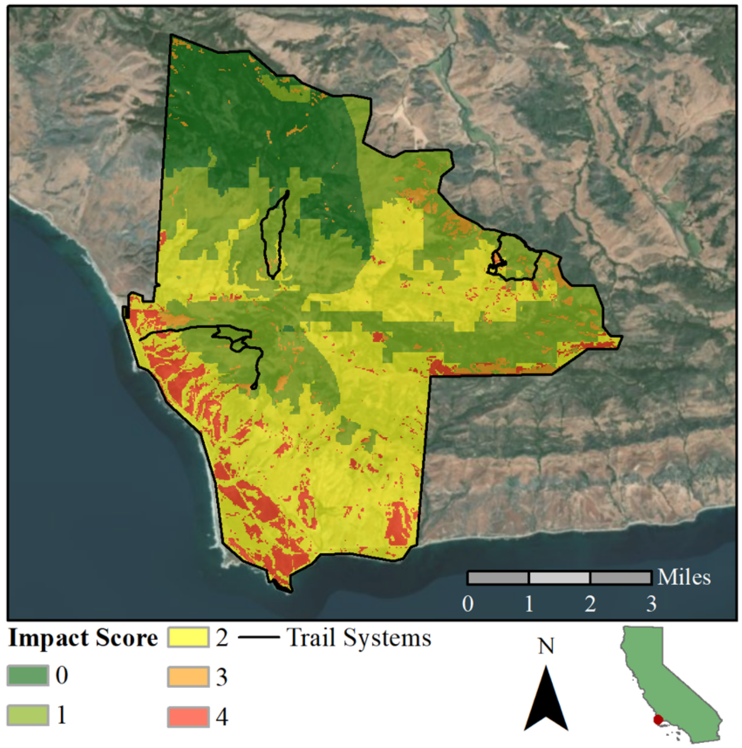

Figure 15: Sensitive Vegetation Impact Scores on the Dangermond Preserve. Preserve-wide impact scores range from low (green) to high (red). A lower score signifies lower impact. A score of 0 refers to areas with low habitat suitability (0-30%) for all three invasive plant species. A score of 1 refers to moderate habitat suitability (30-70%) for one or more invasive plant species. A score of 2 refers to high habitat suitability (70-100%) for one or more invasive plant species. A score of 3 refers to sensitive vegetation overlapping with high habitat suitability (70-100%) for one or more invasive plant species. A score of 4 refers to sensitive vegetation overlapping with high habitat suitability (70-100%) for one or more invasive plant species.

3.4 Discussion

The vegetation impact analysis identified hotspots on the Dangermond Preserve where highly suitable habitat for non-native plant species overlaps with sensitive vegetation. Overall, hotspots tend to be located in the coastal areas of the preserve due to the presence of critical habitat for Gaviota tarplant. This analysis also identified areas where trail and vegetation hotspots intersect, creating a potential risk for the spread of invasive species during education programs. The Jalachichi trail system at the eastern end of the preserve, the Army Camp trailhead near the Cojo Gate, and the Coastal Bluffs trail at Government Point are all areas where increased hiking, camping, and other uses could accelerate the spread of non-native species.

While vegetation is only one of the Conservation Criteria for this project, TNC can take steps to minimize impacts to the individual sensitive plant species on the preserve. This can be accomplished if TNC considers the directionality of trail use during environmental education programs and seasonality of invasive seed dispersal. As aforementioned, there are several trails that pass through both sensitive vegetation and invasive species suitable habitats, including several segments in the Army Camp trail system. Students traveling from an invasive species habitat into a sensitive vegetation habitat or hotspot could increase the risk of spreading invasive plant seeds.

Risk of spreading invasive plant species will be particularly high during invasive plant seeding seasons. Both perennial veldtgrass and black mustard seeds can spread via wind or human activity and are particularly successful at invading disturbed habitats (Palenscar 2013; Weber 2013). For perennial veldtgrass, the seeds germinate during the winter and the plant will grow and flower primarily from December to April (Weber 2013). Avoiding perennial veldtgrass habitats, such as the Jalachichi trail system, during this time will help reduce the risk of invasion into sensitive plant habitats, particularly purple needlegrass grassland. Black mustard is a winter annual plant and flowers from mid-spring to mid-summer. Black mustard seeds can remain persistent even when deeply buried, and can survive up to 50 years or more (DiTomaso et al. 2017). With further disturbance and trail usage, seeds deeper in the seedbank can resurface and continue to grow.

In California, iceplant flowers from January to May and then matures from March to November (Parker 2008). Iceplant seeds do not disperse via wind or human activity, but rather through animal droppings. In fact, the passage of the seeds through the animal gut increases the rate of germination (Parker 2008). Due to this method of dispersal, human foot traffic through iceplant mats will not likely increase the risk of invasion of iceplant, such as along the Coastal Bluffs trail on the southern end of the preserve. Nonetheless, iceplant flourishes in previously disturbed areas, so continual monitoring of the trails and surrounding areas should be a priority in limiting the spread of this species.

While several of the education trails go through areas of moderate and high impact to sensitive vegetation, they are still viable options for education programming. Therefore, TNC should consider seasonality and directionality of trail use before permitting student access on individual trails. Vegetation is only one of the Conservation Criteria in this project, and our assessment of ecological impacts to the Dangermond Preserve included three wildlife Conservation Criteria: sensitive mammals, sensitive raptors, and sensitive amphibians.

CHAPTER 4: SENSITIVE WILDLIFE

4.1 Introduction

A challenge for managers in protected areas involves the mitigation of impacts that occur during human-wildlife interactions. This can include short-term impacts to wildlife, such as increases in stress levels and time spent being alert (Naylor, J. Wisdom, and G. Anthony 2009). This can also include long-term impacts, such as shifts toward nocturnal activity (Gaynor et al. 2018), changes in feeding patterns (Ciuti et al. 2012; Smith et al. 2017), declines in nesting success (Miller, Knight, and Miller 1998), and avoidance of suitable habitat (George and Crooks 2006). While such impacts occur at the individual level, collectively they can interfere with complex trophic relationships and alter the composition of biological communities (Kangas et al. 2010; Rogala et al. 2011). A growing body of scientific literature suggests that declines in wildlife species richness and abundance in protected areas are associated with increases in recreation (Larson et al. 2019).

The outcomes of human-wildlife interactions vary based on taxa and there is a need for additional research on species-specific impacts. For this project, the wildlife Conservation Criteria that we focused on — mammals, raptors, and amphibians — included sensitive species that are known to occur on the Dangermond Preserve. Sensitive species for these analyses include those with specific documented sensitivities to human presence or those with listed-status at the federal, state, or local level. Understanding where these species occur, and the impacts humans may have on them, can help to mitigate impacts when planning visitation from environmental education groups. In this section, we identify the potential for negative human-wildlife interactions for the aforementioned Conservation Criteria.

Mammals

As previously mentioned, the mammals we selected are a representation of various trophic levels. These include an apex predator, many mesopredators, and a primary consumer. Together, these mammals cover a wide-range of habitats on the preserve. As a result, we expect mitigated human impact to have beneficial effects for trophic control. Notably, the harm caused to a single sub-group within the mammal Conservation Criteria could have negative consequences to overall ecosystem health (Fraser 2011).

After referencing the list of species provided by WRA and existing literature, we selected the following species to fill our sensitive mammal Conservation Criteria: American badger (*Taxidae taxus*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), mountain lion (*Puma concolor*), and mule deer (*Odocoileus hemionus*). None of the mammals selected have listed-status at any level, although a few are under consideration by the state of California. Many of the species above have documented avoidance behaviors or high mortality rates due to road infrastructure (Badgers, mountain lions, and mule deer). We have chosen to not include these as human impacts due to the focus of this project on impacts from hiking, camping, and other forms of nature-based recreation. The following table elaborates on the sensitivity of each species (Table 2).

Mammal	Sensitivity to Humans
American badger	Badgers have been documented to occupy areas close to trails less frequently than areas further away (Baker and Leberg 2018).
Bobcat	Bobcat presence is known to decrease with more intense urban areas and along high use trails (George and Crooks 2006; Ordeñana et al. 2010). Additionally, bobcats may exhibit a temporal shift towards increased nocturnality in areas with increased human presence (George and Crooks 2006).
Coyote	While coyotes are known for their habituation to navigating urban environments, those found in protected areas may avoid areas with greater human activity (George and Crooks 2006).
Gray fox	Gray foxes have been documented to occupy areas close to trails less frequently than areas further away (Baker and Leberg 2018).
Mountain lion	Mountain lions exhibit many behavioral changes due to human presence. These include a decrease in feeding time, fleeing due to the sound of humans, and a time differential between fleeing and returning to the same area before and after hearing humans for the first time (Smith et al. 2017).
Mule deer	Mule deer are known to flush if humans are within 100m (Taylor and Knight 2003).

Table 2: Mammal Species' Sensitivities. Focal mammal species sensitivities to human presence. Focal species include American badger, bobcat, coyote, gray fox, mountain lion, and mule deer. A notable trend is that many of these mammals flush or flee due to human presence.

Raptors

Similar to mammals, raptors are important for preservation due to their top-down control on the ecosystem (Mäntylä, Klemola, and Laaksonen 2011). Their control on the environment is often seen through the predation of smaller birds and rodents (Chakarov and Krüger 2010; Muñoz-Pedreros et al. 2010). Additionally, the home-range for raptors is typically greater than that of other avian groupings, such as songbirds or corvids, due to their nutrient dense diet (Schoener 1968). Therefore, by mitigating harm to a wide-ranging group, we expect to also mitigate harm to the species with smaller ranges that fall within those of raptors. For this reason, raptors are the appropriate group to use as a Conservation Criterion, as they provide a conservative lens for which to minimize impact.

Raptors were initially selected from the list of birds known to exist on the preserve. We then filtered that list to only include species with well-documented flushing responses to human presence, gathered from a meta-review paper (Richardson and Miller 1997). Through this filtering process we omitted two owl species from consideration: barn owls and great horned owls. The remaining raptor species include: bald eagles (*Haliaeetus leucocephalus*), golden eagles (*Aquila chrysaetos*), Cooper's hawks (*Accipiter cooperii*), peregrine falcons (*Falco peregrinus*), American kestrels (*Falco sparverius*), red-tailed hawks (*Buteo jamaicensis*), and ospreys (*Pandion haliaetus*). Within this list, bald and golden eagles are federally protected through the Bald and Golden Eagle Protection Act (Bald and Golden Eagle Protection Act 1940).

Amphibians

Amphibians, and not all herptiles, were selected for analysis due to their status as an indicator species for ecosystem health, as well as their documented decline globally (Hayes et al. 2002, 2010). Their presence, absence, and morphology often provide information on environmental health. For example, the presence of pesticides and herbicides have been known to cause limb deformities, as well as hermaphroditism (Hayes et al. 2002; Ouellet et al. 1997). These can lead to lower fitness individuals and a skewed sex ratio, which together have strong potential to alter the composition of local populations. Therefore, local extinction events may signal a highly polluted environment.

While amphibians are known for their sensitivity to environmental health, research also reports sensitivity in relation to distance from a trail. In fact, site occupancy for some species for some species increases further away from trails (R. B. Anderson 2019). For this reason, it is important to create buffer areas around aquatic habitat and cross-check those buffers with potential interacting trails.

Species for this analysis were specifically chosen to include all amphibians with documented presence on the preserve. These species include the California red-legged frog (*Rana draytonii*), Pacifc chorus frog (*Pseudacris regilla*), western toad (*Anaxyrus boreas*), and arboreal salamander (*Aneides lugubris*).

4.2 Methods and Results

In order to achieve the goal of identifying areas of highest potential for disturbance for our three wildlife Conservation Criteria, we conducted an initial analysis for each taxa. For mammals and raptors, this was achieved by performing an overlay analysis of areas of highest potential for disturbance to each focal species. For amphibians, we analyzed aquatic habitat in general, rather than species-specific habitat, to predict the areas of high disturbance potential. The Dangermond Preserve could then be scored based on the impact to each taxa at any given location on the preserve. This allowed us to compare impacts across taxa and combine these impacts in subsequent Multi-Criteria Analyses. The data and methods we used for analyzing mammals, raptors, and amphibians are discussed below.

4.2.1 Mammals

In order to understand the impact to mammals on the Dangermond Preserve, we conducted an overlay analysis to explore where prime habitats exist and overlap for mammals sensitive to humans at the preserve. Data for this analysis included predicted habitat for six mammal species and trails at the Dangermond Preserve. Mammal predicted habitat datasets for bobcats, mountain lions, coyotes, gray foxes, American badgers, and mule deer were sourced from the California Department of Fish and Wildlife (CDFW). Habitat suitability was predicted using California Wildlife Habitat Relationships (CWHR) range maps and CALFIRE-FRAP "best-available" land cover data from 1990 to 2014, along with CWHR habitat suitability ranks. Habitat scores are based on reproduction, cover, and feeding. This dataset provides predicted habitat suitability across the state (from 0.00-1.00), classified into categories of High (0.66-1.00), Medium (0.33-0.66), and Low (0.00-0.33) suitability.

Data Analysis

As outlined above, the California Department of Fish and Wildlife (CDFW) has established thresholds for habitat suitability in their CWHR dataset. We used these thresholds to isolate highly suitable habitats for our overlay analysis. We then used ArcGIS to spatially evaluate the overlap of highly suitable habitat for bobcats, mountain lions, coyotes, gray foxes, American badgers, and mule deer. An overlay analysis was conducted in order to evaluate the overlap of highly suitable habitat, which were selected to only include habitats with a mean suitability rating of 0.66 or above, based on the CWHR classification scheme.

The preserve was given impact scores based on the number of species with highly suitable habitat in a given area (Table 3). Scores ranged from 0, signifying a low number of species impacted (0-2 species), to 4, signifying all mammal species analyzed being impacted. Finally, to analyze potential for human-wildlife interaction on trails, highly suitable habitat and impact scores were overlayed with education trails at the Dangermond Preserve. See Appendix II for a detailed workflow of this analysis.

Criteria	Attributes	Description	Score
Protecting Sensitive Mammal Populations	Potential for all mammal species to be affected	Overlapping highly suitable habitat (66-100%) for 6 mammal species	4
	Potential for high number of mammal species to be affected	Overlapping highly suitable habitat (66-100%) for 5 mammal species	3
	Potential for moderately high number of mammal species to be affected	Overlapping highly suitable habitat (66-100%) for 4 mammal species	2
	Potential for moderate number of mammal species to be affected	Overlapping highly suitable habitat (66-100%) for 3 mammal species	1
	Potential for low number of mammal species to be affected	Overlapping highly suitable habitat (66-100%) for 0-2 mammal species	0

Table 3: Sensitive Mamma Impact Scores on the Dangermond Preserve. Table showing the impact score breakdown for the sensitive mammal criterion. The score ranges from 0-4, with a low score signifying low impact. Each level is associated with an increasing overlap of highly suitable habitat for mammals.

Results

Analysis of mammal disturbance showed few areas on the preserve where all six mammal species could be disturbed due to human presence along a trail (Figure 16). Less than half of the sensitive mammal species on the preserve have the potential for disturbance along most trails. Sensitive mammals have the least potential to be disturbed as a result of human-wildlife interactions along the Jalachichi and Coastal Bluffs trail systems.

All species analyzed have suitable habitat in all Army Camp system trails and the Jalachichi Overnight trail. On the other hand, the Coastal Bluffs trail has only one species, the American badger, with highly suitable habitat along it. Maps of individual species' highly suitable habitat overlayed with trails can be found in Appendix II to address species-specific concerns or management objectives.

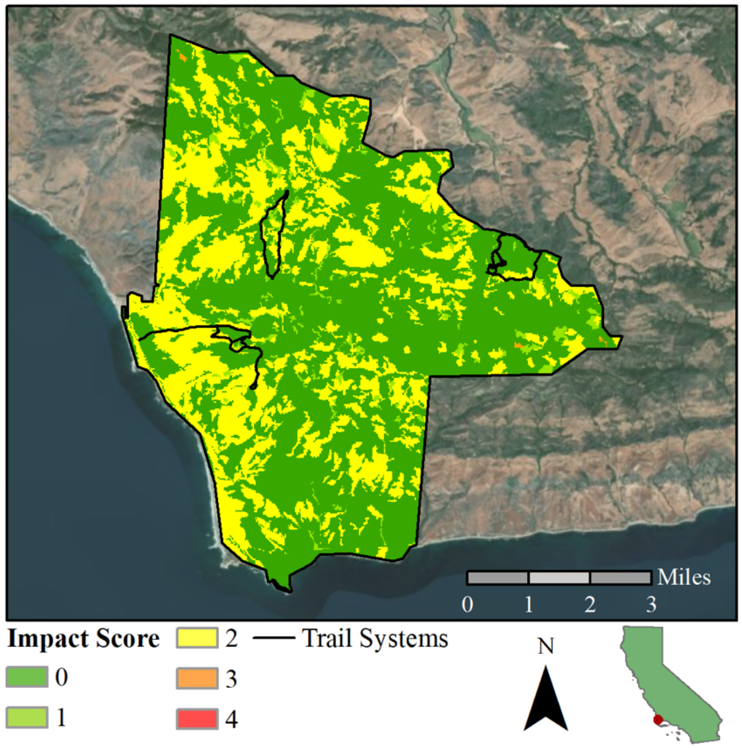

Figure 16: Sensitive Mammal Impact Scores on the Dangermond Preserve. Preserve-wide impact scores range from zero (green) to three (orange). A lower score signifies lower impact. A score of 0 refers to areas with overlapping highly suitable habitat (66-100%) for 0-2 mammal species. A score of 1 refers to overlapping highly suitable habitat (66-100%) for 3 mammal species. A score of 2 refers to overlapping highly suitable habitat (66-100%) for 4 mammal species. A score of 3 refers to overlapping highly suitable habitat (66-100%) for 5 mammal species. A score of 4 refers to overlapping highly suitable habitat (66-100%) for 6 mammal species. Notably, there are no areas on the preserve with an impact score of 4

4.2.2 Raptors

We then conducted another overlay analysis to understand the impacts to raptors on the Dangermond Preserve. For this we determined where potential flushing zones for sensitive raptor species overlap on the preserve and identified where these areas are in relation to the trail systems. Data for this analysis also includes predicted habitat suitability datasets from the California Department of Fish and Wildlife (CDFW). In addition, flushing zones for the sensitive raptor species were determined from a meta-analysis on recommendations for raptor protection (Richardson and Miller 1997).

Data Analysis

Human disturbance to raptors at the Dangermond Preserve was analyzed using buffers around highly suitable habitat. These buffers were determined by identifying specific disturbance distances for the bald eagle, golden eagle, Cooper's hawk, peregrine falcon, American kestrel, red-tailed hawk, and osprey (Table 4). Bald eagles were later removed from this list because they do not have any highly suitable habitat on the preserve (Bald Eagle Predicted Habitat - CWHR B113 [ds2086] 2016). Buffers were first created around highly suitable habitat (mean score of 0.66 or above) for each individual species.

Species	**Buffer Distance (meters)**
Bald Eagle	800
Golden Eagle	1600
Cooper's Hawk	600
Peregrine Falcon	800
American Kestrel	400
Red-tailed Hawk	800
Osprey	1500

Table 4: Buffer Distances for Raptors. Each raptor species was designated an estimated buffer area based on documented flushing distance (Richardson and Miller 1997). Buffers were placed around highly suitable habitat for each raptor species.

Disturbance buffers were overlayed with one another to determine how many species are subject to flushing from highly suitable habitat in any location on the preserve. The preserve was given impact scores based off of the number of species with flushing potential in a given area (Table 5). Scores ranged from 0 to 4, with 0 representing a potential for a low number of raptor species to flush (0-2 species) and 4 representing a potential for all six sensitive raptor species to flush. Impact scores were then overlayed with education trails to determine which trails are the most impactful. See Appendix II for a detailed workflow of the raptor analysis.

Criteria	Attributes	Description	Score
Protecting Sensitive Raptor Populations	Potential for all raptor species to be affected	Overlapping flushing zones for 6 raptor species	4
	Potential for high number of raptor species to be affected	Overlapping flushing zones for 5 raptor species	3
	Potential for moderately high number of raptor species to be affected	Overlapping flushing zones for 4 raptor species	2
	Potential for moderate number of raptor species to be affected	Overlapping flushing zones for 3 raptor species	1
	Potential for low number of raptor species to be affected	Overlapping flushing zones for 0-2 raptor species	0

Table 5: Sensitive Raptor Impact Scores on the Dangermond Preserve. Table showing the impact score breakdown for the sensitive raptor criterion. The score ranges from 0-4, with a low score signifying low impact. Each level is associated with an increasing overlap of flushing distances for raptors.

Results

Analysis of raptor disturbances show a high impact area for all analyzed species in the center and southern parts of the preserve (Figure 17). The Jalachichi trail system has the lowest potential for human-wildlife interaction on the preserve, as it is the only trail system to not impact all six raptor species. However, all areas on the preserve are within the potential flushing zone of at least one species, which means that even areas with low impact scores have potential disturbances resulting from human-wildlife interaction.

The only species that does not have a potential flushing zone on every trail is the osprey, which does not have any potential flushing zones in the Jalachichi trail system. Maps of individual species' highly suitable habitat and flushing zones overlayed with trails can be found in Appendix II to address species-specific concerns or management objectives.

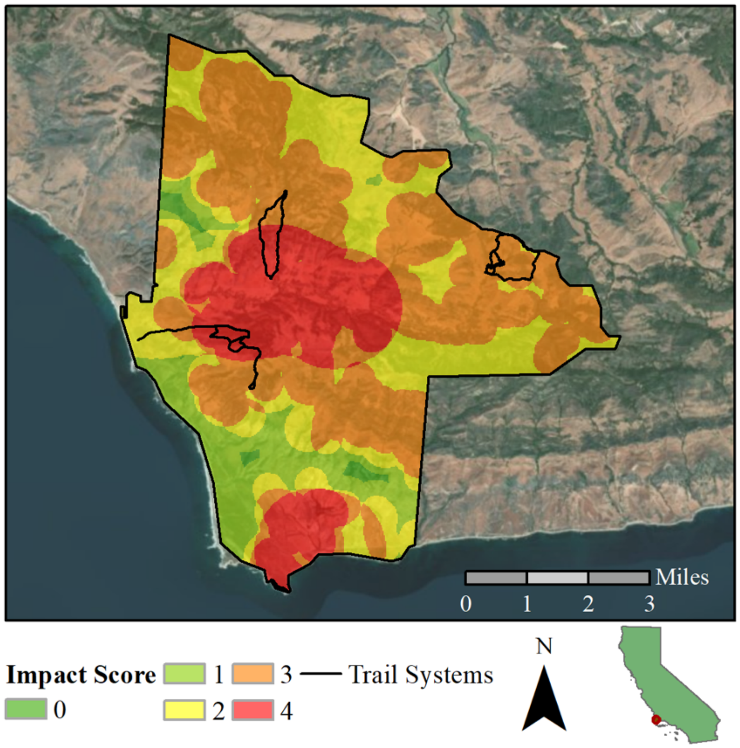

Figure 17: Sensitive Raptor Impact Scores on the Dangermond Preserve. Preserve-wide impact scores range from zero (green) to four (red). A lower score signifies lower impact. A score of 0 refers to areas with overlapping flushing zones for 0-2 raptor species. A score of 1 refers to overlapping flushing zones for 3 raptor species. A score of 2 refers to overlapping flushing zones for 4 raptor species. A score of 3 refers to overlapping flushing zones for 5 raptor species. A score of 4 refers to overlapping flushing zones for 6 raptor species. Areas of highest impact to raptors occur in the central and coastal areas of the preserve.

4.2.3 Amphibians

Finally, to understand the disturbance to amphibians on the preserve we conducted a third analysis based on highly suitable habitat. Due to the lack of available predicted habitat suitability maps from CDFW, all streams, stock ponds, and cattle troughs were used as surrogates for highly suitable habitat (Figure 18). Data for aquatic habitat on the preserve was provided by WRA, Inc.

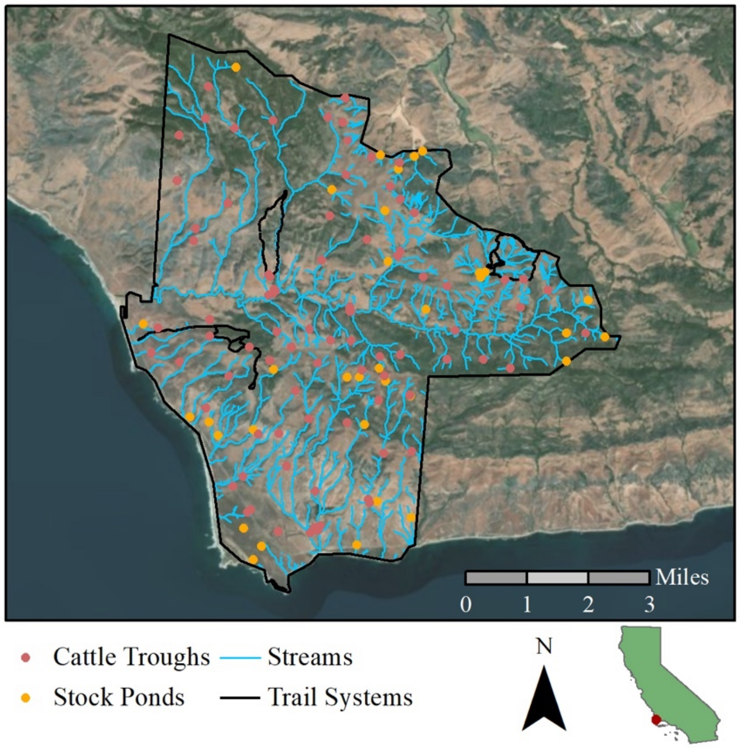

Figure 18: Aquatic Habitats on the Dangermond Preserve. Aquatic habitats include cattle troughs (red dots), stock ponds (yellow dots), and streams (blue lines). The education trails (black lines) are shown to identify proximity to aquatic habitats.

Data Analysis

In addition to streams and creeks, amphibians are known to use stock ponds and cattle troughs as breeding grounds when they are unable to find more suitable aquatic habitat (Buono, Bissattini, and Vignoli 2019; California Red-Legged Frog - Amphibians and Reptiles, Endangered Species Accounts | Sacramento Fish & Wildlife Office n.d.). Impacts to amphibians were analyzed by placing 100 and 200 meter buffers around aquatic habitat on the Dangermond Preserve. These thresholds were selected based on recommendations from literature specifying appropriate distance from aquatic habitat for both the California red-legged frog, and the western toad to be within 50-200 meters (Bartelt, Peterson, and Klaver 2004; Bulger, Scott, and Seymour 2003; Rothermel 2004). Specifically, this literature suggests using a 100 meter (Rothermel 2004) and 150-200 meter buffer around aquatic habitat, as well as a 50-100 meter buffer from the nearest trail (R. B. Anderson 2019). Importantly, these buffers extend far into upland habitat to allow for migratory behaviors after rain events (Fellers and Kleeman 2007). The breadth of these buffers allows for individuals more adept at long migrations to have adequate protection when moving between potential breeding sites. These individuals are key for maintaining genetic diversity and ensuring resilient populations (Fellers and Kleeman 2007).

The preserve was then given impact scores based on the impact zones created in the buffer analysis (Table 6). Scores ranged from 0 to 4, with 0 representing a low impact to amphibians outside of a 200 meter buffer zone, 2 representing between a 100 and 200 meter buffer zone, and 4 representing the highest potential impact within a 100 meter buffer zone from aquatic habitat. Once the buffers were created, education trails were overlayed to again determine the trails with greatest impact. See Appendix II for a detailed workflow.

Criteria	Attributes	Description	Score
Protecting Sensitive Amphibian Populations	High impact to amphibians	Within 0-100m buffer zone around aquatic habitat	4
	Moderate impact to amphibians	Within the 100-200m buffer zone around aquatic habitat	2
	Low to no impact to amphibians	Outside of the 200m buffer zone around aquatic habitat	0

Table 6: Sensitive Amphibian Impact Scores on the Dangermond Preserve. Table showing the impact score breakdown for the sensitive amphibian criterion. The score ranges from 0-4, to be consistent with other wildlife criteria. There are only three levels of impact to incorporate the varying dispersal distances of the species within this criterion (California red-legged frog, western toad, and the arboreal salamander), and their overlapping buffer distances found in literature.

Results

Analysis of amphibian disturbance shows areas of high impact throughout the preserve, with a lower impact in the northwest of the preserve due to a less dense network of streams (Figure 19). The Coastal Bluffs trail system notably has the lowest impact to amphibians on the preserve and does not fall within any impact buffer zone. The Army Camp trails system goes in and out of high and low impact areas, while the Jalachichi and Water Canyon trail systems are located almost entirely within high impact areas.

In addition to aquatic habitat, there are documented presence points of California red-legged frogs and Pacific chorus frogs within 200 meters of the Jalachichi trail system, and of arboreal salamanders within 200 meters of the Army Camp trail system. Maps of documented presence points and individual species' highly suitable habitat (where data was available) overlayed with trails can be found in Appendix II to address species-specific concerns or management objectives.

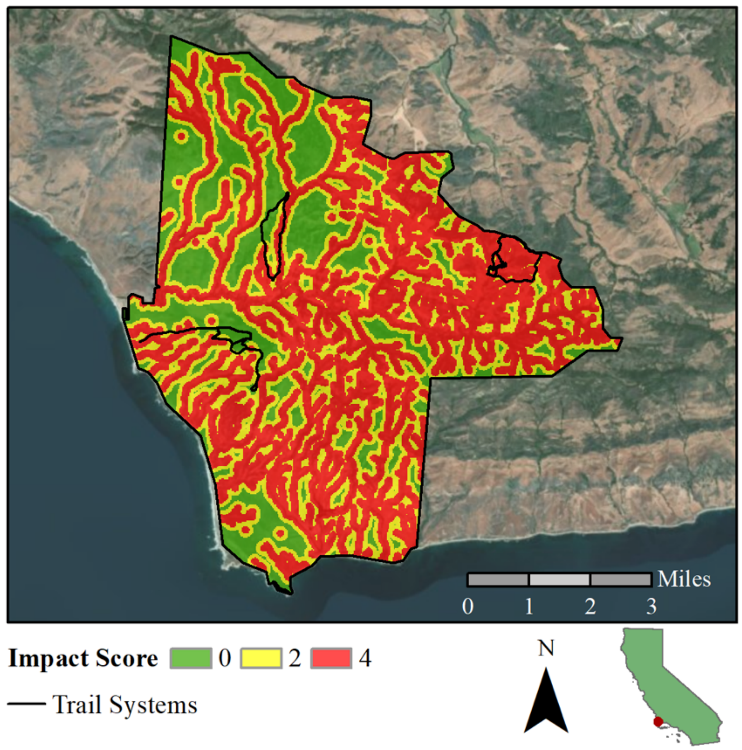

Figure 19: Sensitive Amphibian Impact Scores on the Dangermond Preserve. Preserve-wide impact scores range from zero (green) to four (red). A lower score signifies lower impact. A score of 0 refers to areas that are outside the 200 meter buffer zone around aquatic habitats. A score of 2 refers to areas that are within the 100 - 200 meter buffer zone around aquatic habitats. A score of 4 refers to areas within the 100 meter buffer zone around aquatic habitat. Areas of high impact are throughout the landscape due to the dense network of streams, but are notably less dense in the northern end of the northern end of the preserve.

4.3 Discussion

These analyses identified impacts to mammals, raptors, and amphibians on the Dangermond Preserve. Areas of high impact vary for the three wildlife Conservation Criteria analyzed in this section. Additionally, we analyzed which trails were most impactful to the Conservation Criteria. No trail on the preserve goes through an entirely low impact habitat for any one single criterion. Therefore, when siting environmental education trails, there needs to be a way to rank trails based on the varying levels of impact to Conservation Criteria along the trail. Moreover, there is no location on the preserve that falls within the lowest impact score for all three wildlife categories. This means that avoiding impacts to one Conservation Criterion can have negative impacts to another. Therefore, there needs to be a method to weigh the Conservation Criteria according to management objectives.

CHAPTER 5: ECOLOGICAL IMPACT & TRAIL RANKING

5.1 Introduction

Using the predicted ecological impact maps for the Conservation Criteria, we ranked the trails based on their ecological impact. The preserve does not have a uniform distribution of impacts, and the importance of one criterion may be greater than another during different times of the year or as TNC's preferences change over time.

We used an Analytical Hierarchy Process (AHP), in conjunction with a Multi-Criteria Analysis (MCA), to rank trails according to their combined ecological impact. An AHP allows competing priorities to be differentially weighted, according to the importance of a given stakeholder (Saaty 1977). In our case, using an AHP allowed us to gather the preferences TNC has regarding each of our Conservation Criteria and weigh them accordingly. Using an MCA, we then summed the impacts of each criterion in a given location on the preserve. This methodology has been well documented as an appropriate decision-making process for other nature reserves (Cuirong et al. 2016; Quinn, Schiel, and Caruso 2015). Once the entire preserve had been given a single ecological impact layer, the impact along each trail was calculated. Furthermore, with the use of an AHP, we assessed how trail rankings might change based on seasonality and different single criterion preference schemes, compared to a baseline ranking. The baseline ranking of trails assigned a weight of 0.25 to all Conservation Criteria. All subsequent weighting schemes can be thought of as a sensitivity analysis for trail rankings due to their effects on preserve-wide ecological impact.

5.2 Methods

In order to rank the Conservation Criteria, we used an Analytical Hierarchy Process to categorize the impacts to each Conservation Criterion and assign an "impact score". We followed a similar process outlined in the Cuirong et al. 2016 study. For all Conservation Criteria, we developed a scale of potential ecological impact. This was done on a 0-4 scale, with a low score signifying a low impact. This step was completed in the "Sensitive Vegetation" and "Sensitive Wildlife" chapters. See Table A2.5, Appendix II for the full table of qualitative descriptions of each ecological impact score.

Once we had determined the scale of ecological impact for each Conservation Criterion, we created a survey to gauge TNC's conservation preferences. The survey required TNC to compare the value of each Conservation Criterion against one another using a 5-point Likert Scale, as opposed to a traditional 9-point scale. This was done to reduce complexity and minimize bias by allowing questions to be phrased similar to "Is it more important to protect X or Y", rather than

"How important is it that you protect X over Y" (Figure 20). After these surveys had been received, we used an online tool to calculate the weights of each Conservation Criterion (Goepel 2018).

1. Is it more important to protect sensitive and special-status vegetation or sensitive raptors?

Much more important to protect vegetation than raptors (9)	More important to protect vegetation than raptors (5)	Equally important (1)	More important to protect raptors than vegetation (5)	Much more important to protect raptors than vegetation (9)

Figure 20: Schematic of Survey Questionnaire for Analytical Hierarchy Process. This is a sample question of the full survey associated with The Nature Conservancy's management preferences.

These calculated weights were then implemented into our Multi-Criteria Analysis (Figure 21) to determine the combined ecological impact on the Dangermond Preserve. We used the Raster Calculator tool in ArcGIS to (1) assign weights to the Conservation Criteria, and then (2) combine them to create a single map of preserve-wide ecological impact (Figure 21).

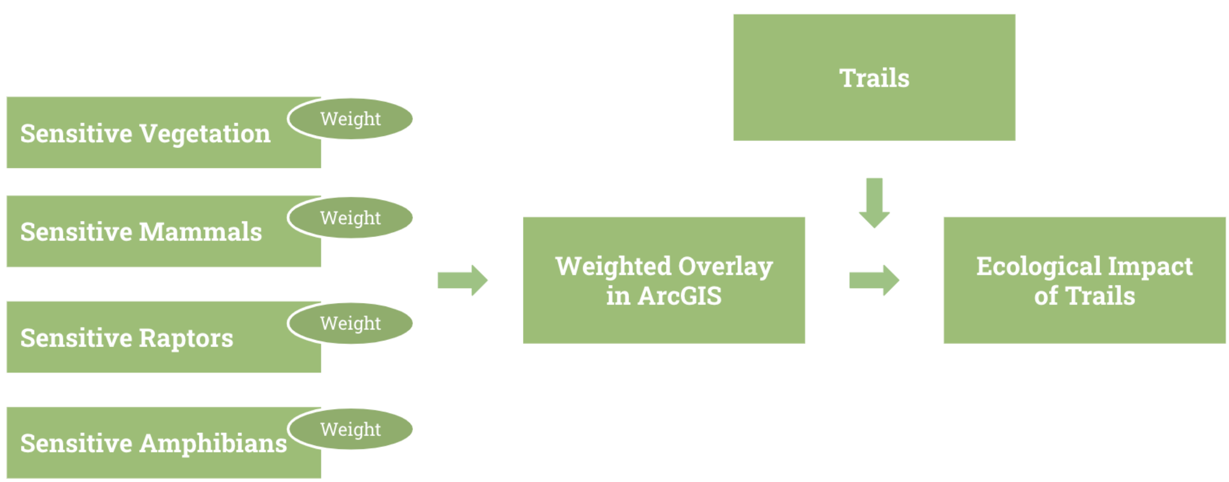

Figure 21: Multi-Criteria Analysis Schematic. This figure illustrates the methods for the Multi-Criteria Analysis. The Multi-Criteria assigns uses the weights from the Analytical Hierarchy Process, and assigns them to each Conservation Criterion. It then combines these layers in ArcGIS using the "Weighted Overlay" tool. Finally, it takes a layer of trails and takes the average of the weighted overlay output along a trail and creates an ecological impact for each trail.

Using the final MCA output of preserve-wide impacts, we ranked individual trails by their ecological impact. We did this by intersecting the raster of ecological impacts with trails and determining the average impact per mile to each trail. Average impact to trails was determined on a 0-4 scale, and categorized into Low (0-1), Moderate (1-2), Moderately High (2-3), and High (3-4) impact. We operated under the assumption that ecological impact on a trail would occur during the initial hike through a given area, and therefore the return trip would not cause additional damage (Cole 1987, 2004). Given this assumption, the distance was only calculated once for trails that have overlapping use during a hike. For example, an out and back trail's ecological impact is only calculated in the "out" direction. A detailed workflow can be found in (Figure A2.34, Appendix II).

For completeness, we used this process with different weighting schemes to determine how sensitive the trail ranks are to Conservation Criteria priorities and seasonal variations (Table 7). We first developed a baseline ecological impact score by weighting all Conservation Criteria equally, with a value of 0.25. The additional weighting schemes were compared to this baseline in order to understand the sensitivity of trails under different scenarios. The additional weighting schemes include:

1. One Criterion only. Under this weighting scheme, a single Conservation Criterion was given a weight of 1, while the other three were given a weight of 0. This was repeated for each Conservation Criterion. This allowed us to determine the drivers of overall ecological impact by analyzing the Conservation Criteria individually and determine how they influence trail ranks. From a management perspective, the difference in trail ranks according to each criterion reveals which criterion is driving the greatest amount of impact along a trail. For example, when looking at raptors only, the trail ranks can tell which trails are predicted to have either the least or most impact to sensitive raptors. Additionally, these ranks can provide further insight into underlying drivers of ecological impact after a different weighting scheme has been used.

2. Vegetation or wildlife only. This weighting scheme simulated potential management regimes that focused only on sensitive vegetation or sensitive wildlife (mammals, raptors, and amphibians). A vegetation only management regime would focus on preventing impacts to sensitive vegetation under the assumption that healthy vegetation supports more diverse trophic levels above it (Scherber et al. 2010). This is the same weighting scheme as the "One Criterion only" weighting scheme for vegetation (i.e., sensitive vegetation gets a weight of 1). A wildlife only management regime would alternatively focus on sensitive wildlife under the assumption that this would inherently not affect vegetation. This weighting scheme would give a weight of 0.333 to mammals, 0.333 to raptors, 0.333 to amphibians, and 0 to sensitive vegetation.

3. One Conservation Criterion "Much More Important" than the rest. This weighting scheme simulates management scenarios highly concerned with one criterion. Here, "Much More Important" corresponds to a greater value in the Analytical Hierarchy Process (Table A2.5, Appendix II). For example, if amphibians are weighted "Much More Important", the remaining Conservation Criteria (raptors, mammals, and vegetation) would be equal to each other, and dramatically lower than amphibians. This example yields a weight of 0.083 for raptors, mammals, and vegetation, and 0.750 for amphibians, and can be seen in the "Amphibians Much More Important" row in Table 7. Finally, this weighting scheme takes into account single criterion priorities while still acknowledging impacts to non-priority Conservation Criteria.

4. Seasonal considerations (Fall, Winter, Spring, Summer). This weighting scheme takes into account seasonal sensitivities of the Conservation Criteria. A Conservation Criterion is considered to have seasonal sensitivities when a species within it is breeding or seeding. If any of the Conservation Criteria had seasonal sensitivities, they were weighted in the AHP as "Much More Important" when compared to the other Conservation Criteria. In the event that more than one Conservation Criteria had seasonal sensitivities, they were weighted equal to one another, but "Much More Important" than the remaining Conservation Criteria.

Seasons were defined in the following way: fall corresponds to September through November; winter corresponds to December through February; spring corresponds to March through May; and summer corresponds to June through August. Amphibians were the only Conservation Criterion to be weighted higher during the fall, due to the start of the breeding season for California red-legged frogs occurring in November (California Red-Legged Frog - Amphibians and Reptiles, Endangered Species Accounts | Sacramento Fish & Wildlife Office n.d.). In winter, amphibians *and* raptors were weighted higher than the other Conservation Criteria. This is because amphibians are sensitive in winter due to the rainy season in Central California, while raptors are sensitive due to the early breeding season of the peregrine falcon (American Peregrine Falcons in California n.d.). For both spring and summer, raptors and vegetation receive higher weights than the other Conservation Criteria. Raptors continue to have a high sensitivity as more species enter and exit their respective nesting seasons (Emmons 2018). Vegetation also receives a higher weight during these seasons since this is when invasive plant species are producing seeds (Pickart 2017).

5. TNC's Criteria-level runs. This run weighs the Conservation Criteria according to the AHP survey results from the Preserve Manager who oversees the Dangermond Preserve. This weighting scheme therefore represents TNC's current conservation priorities for the Conservation Criteria. They determined that sensitive vegetation was "More Important" than sensitive mammals, raptors, and amphibians. This led to a weight of 0.625 being assigned to sensitive vegetation, and a weight of 0.125 being assigned to all other criteria. TNC can use these weights to determine environmental education trail use in line with their current conservation priorities.

6. TNC's Species-level runs. There are two species-level weighting schemes we obtained via the survey results from TNC. The first corresponds to raptors. We asked managers at the Dangermond Preserve to rank the relative importance of each raptor species relative to one another. Their survey responses produced the following weights: golden eagles at 0.357; peregrine falcons at 0.357; Cooper's hawks at 0.071; kestrels at 0.071; ospreys at 0.071; and the red-tailed hawks at 0.071. These weights were placed on a 0-4 scale, where the additive ecological impacts were broken down into five categories (Table A2.7, Appendix II). This new ecological impact scale replaces the original scale used for raptors.

In addition to comparing the raptor species to one another, managers at the Dangermond Preserve were also asked to compare the mammal species to each other. The relative weights of the mammals are as follows: American badgers at 0.518; bobcats at 0.138; gray foxes at 0.138; mountain lions at 0.138; coyotes at 0.034; and mule deer at 0.034. This means that TNC prioritizes the conservation of American badgers more than the other mammal species when given the opportunity. Similar to the new raptor scale, the new mammal weights were also placed on a 0-4 scale. Again, the additive ecological impacts were broken down into five categories (Table A2.6, Appendix II). The management utility for this weighting scheme takes into account the species-specific concerns of TNC. Otherwise, it is analogous to that of the "One Criterion only" weighting scheme.

7. Criteria-level & Species-level runs. This weighting scheme merges the previous two weighting schemes into one. It uses species-level runs as inputs for raptors and mammals into the criteria-level AHP (Table A2.8, Appendix II). The vegetation and amphibian impact scales are consistent with previous runs. This can be used by TNC to get a more holistic view of the preserve-wide ecological impact, while considering all Conservation Criteria, as well as addressing their species-level concerns.

	Relative Weights			
Scenario	**Amphibians**	**Raptors**	**Mammals**	**Vegetation**
Baseline	0.250	0.250	0.250	0.250
Amphibians only	1.000	0.000	0.000	0.000
Raptors only	0.000	1.000	0.000	0.000
Mammals only	0.000	0.000	1.000	0.000
Vegetation only	0.000	0.000	0.000	1.000
Wildlife only	0.333	0.333	0.333	0.000
Amphibians Much	0.750	0.083	0.083	0.083

More Important				
Raptors Much More Important	0.083	0.750	0.083	0.083
Mammals Much More Important	0.083	0.083	0.750	0.083
Vegetation Much More Important	0.083	0.083	0.083	0.750
Fall	0.750	0.083	0.083	0.083
Winter	0.450	0.450	0.050	0.050
Spring	0.050	0.450	0.050	0.450
Summer	0.050	0.450	0.050	0.450
TNC preference Criteria-level	0.125	0.125	0.125	0.625
TNC preference Species-level (Raptors)	0.000	1.000	0.000	0.000
TNC preference Species-level (Mammals)	0.000	0.000	1.000	0.000
TNC preference Species-level & Criteria-level	0.125	0.125	0.125	0.625

Table 7: Weighting Schemes for the Multi-Criteria Analysis. Weighting schemes created through the Analytical Hierarchy Process include a baseline of equal weights, weight assigned to one criterion, much more weight assigned to one criterion than all others, all weight assigned to vegetation or wildlife criteria**,** weight assigned based on seasonality, and weight assigned based on Dangermond Preserve manager preferences.

Trail ranks and average impact scores were then compared to determine sensitivities and drivers of ecological impact on each trail.

5.3 Results

The baseline Multi-Criteria Analysis with equal weights across Conservation Criteria revealed that areas of high and low impact are spread throughout the preserve with a concentration of low impact areas in the north (Figure 22).

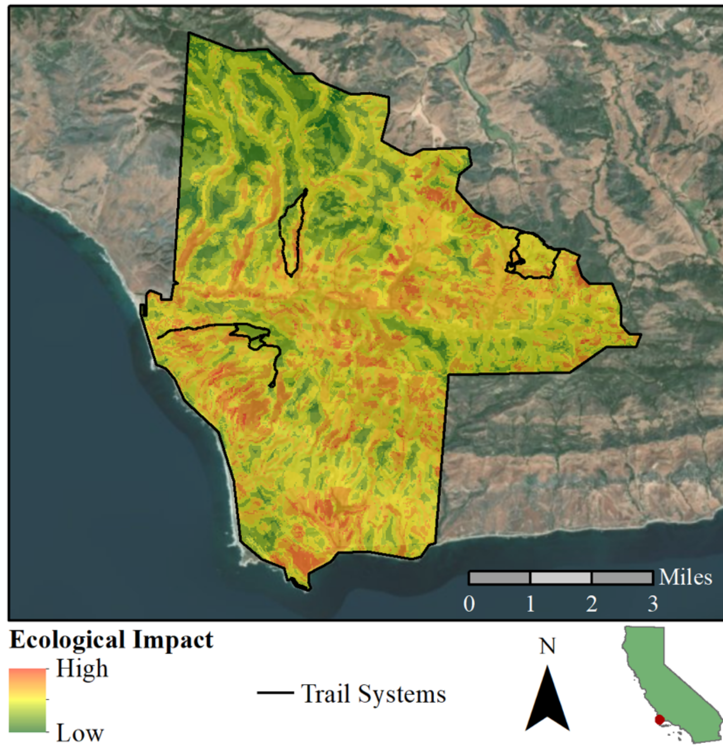

Figure 22: Preserve-wide Baseline Ecological Impact Map. This figure identifies the preserve-wide ecological impacts using equal weights for the Conservation Criteria. Ecological impacts range from low (green) to high (red). Much of the northern end of the preserve is low impact. Areas of high impact are scattered throughout the central and coastal areas.

Additionally, most trails go through areas of both high and low impact. An example can be seen in the Jalachichi Pond trail (Figure 23). The trailhead begins in a low impact area, shown in green, and moves into areas of higher impact, shown in orange and red, for three of the four Conservation Criteria: amphibians, vegetation, and raptors. The areas surrounding this trail are influenced by the streams feeding into the pond, which provides habitat to sensitive amphibians. This area of the preserve is also a sensitive vegetation hotspot where sensitive purple needle grass habitat overlaps with highly suitable habitat for invasive perennial veldtgrass. Additionally, the trail passes through potential flushing zones for four raptor species: red-tailed hawks, golden eagles, American kestrels, and Cooper's hawks.

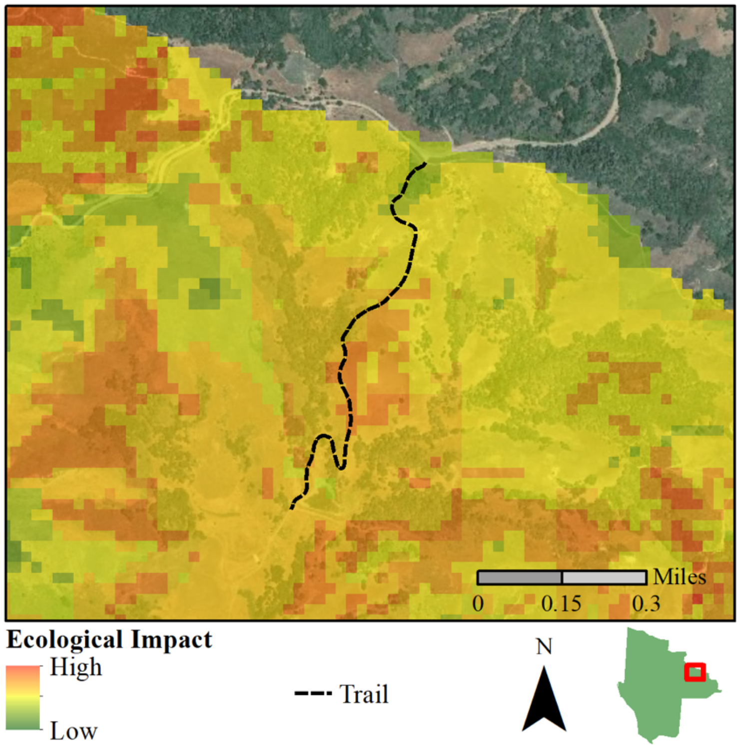

Figure 23: Ecological Impacts Along the Jalachichi Pond Trail. This is an example of an educational trail that goes through areas of both low (green) and high (red) ecological impact. The Jalachichi Pond trail begins in a low impact area, but begins to intersect with moderate to high impact areas. These varying impacts are due to suitable habitat for both sensitive vegetation and sensitive amphibians along the trail.

An example of a trail with Moderate impact is the Coastal Bluffs trail (Figure 24). This trail goes mostly through areas of low impact and is the shortest trail currently considered for environmental education on the preserve. The trail is primarily covered with iceplant and does not overlap high impact areas for amphibians or mammals. However, the trail does intersect potential flushing zones for all six raptor species. Furthermore, to the north of the trail is a critical area for the state and federally endangered Gaviota tarplant.

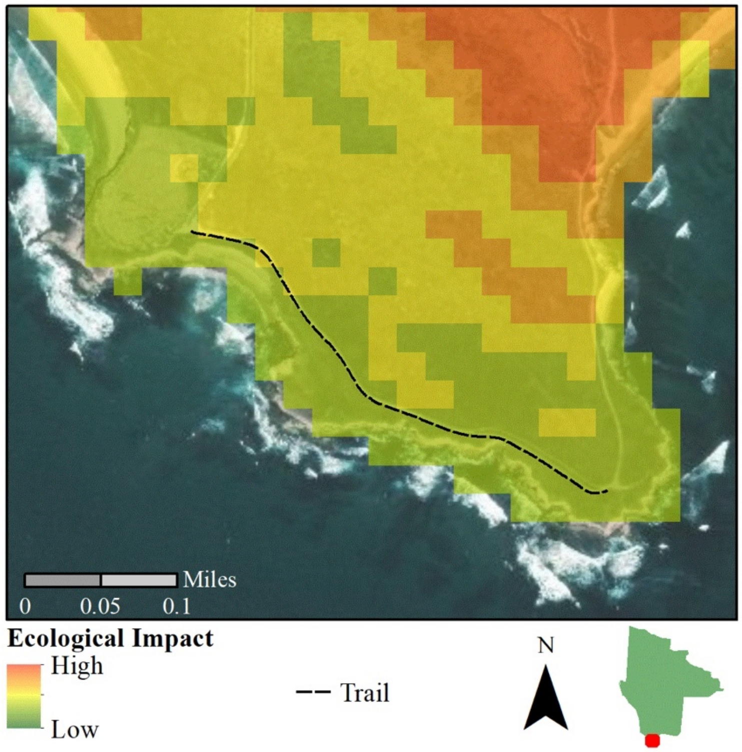

Figure 24: Ecological Impacts Along the Coastal Bluffs Trail. This is an example of an education trail that goes through mainly areas of low impact. The Coastal Bluffs trail does not intersect with suitable habitat for sensitive amphibians or mammals, though there are potential flushing zones for raptors just north of the trail.

In addition to observing the preserve-wide baseline ecological impact, we examined the average ecological impact of each trail (Table 8). The baseline trail ranks reveal that the Coastal Bluffs trail has the lowest impact on the preserve. Other trails with lower overall impact include Army Camp to Bunker, and Bunker Out and Back.

Rank	Trail	Average Ecological Impact Score
1	Coastal Bluffs	1.50
2	Army Camp to Bunker	1.59
3	Bunker Out and Back	1.74
4	Jalachichi Oak Grove	1.83
5	Army Camp Loop 1	1.88
6	Army Camp Loop 2	1.89
7	Water Canyon Loop	1.97
8	Jalachichi Overnight	2.08
9	Jalachichi Pond	2.21
10	Jalachichi Loop	2.22
11	Jalachichi Lollipop	2.23
12	Water Canyon Out and Back	2.46

Table 8: Rank and Average Ecological Impact Scores for Education Trails. The ecological impact score for each trail was determined by calculating the average impact along the trail.

Additionally, we explored another ranking scheme using summed impact along trails instead of an average (Table 9). However, summing impacts results in ranks very closely aligned with distance of trail and does not give much additional insight into ecologically sensitive areas. For example, when summing the impacts, the best two trails are under 1 mile and the worst two trails are over 3 miles.

Summed Rank	Trail	One-way distance of trail (miles)
1	Coastal Bluffs	0.34
2	Jalachichi Pond	0.88
3	Jalachichi Oak Grove	1.09
4	Jalachichi Loop	1.10
5	Water Canyon Out and Back	1.00
6	Army Camp to Bunker	1.56
7	Jalachichi Lollipop	1.41
8	Army Camp Loop 1	2.92
9	Bunker Out and Back	3.41
10	Jalachichi Overnight	2.95
11	Army Camp Loop 2	3.33
12	Water Canyon Loop	3.25

Table 9: Summed Rank of Education Trails on the Dangermond Preserve. This table shows the summed rank of trails on the Dangermond Preserve. We operated under the assumption that ecological impact on a trail would occur during the initial hike through a given area, and therefore the return trip would not cause additional damage (Cole 1987, 2004). Given this assumption, the distance was only calculated once for trails that have overlapping use during a hike. All trails have overlapping use except for the Water Canyon Loop trail and the Jalachichi Overnight trail.

Next, we looked at other weighting schemes, including the weights provided by TNC through the Analytical Hierarchy Process, and additional ranks for a sensitivity analysis. We observed that under the baseline model, areas that appeared as low impact on the preserve were not necessarily low impact for all Conservation Criteria. For example, if three of the four Conservation Criteria were of low impact for an area, the trail would get a Low score despite one criterion having a higher impact. Varying the weights of the different Conservation Criteria allowed us to emphasize important Conservation Criteria under different scenarios.

The AHP was performed at two levels: the criteria-level (vegetation, mammals, raptors, and amphibians) and the species-level. The criteria-level specifically weighted all four Conservation Criteria, whereas the species-level assigned weights to species only within the mammal and raptor criteria. Vegetation were excluded from the species-level analysis due to the focus on hotspots for sensitive vegetation communities, and not individual species. Additionally, amphibians were excluded due to the method of looking at aquatic habitat, and not specific species. At the criteria-level, TNC weighted vegetation “More Important” than mammals, raptors, and amphibians, with the latter three weighted equally. At the species-level for raptors, TNC weighted golden eagles and peregrine falcons “More Important” than the rest of the raptors. For mammals, TNC weighted badgers “More Important” than mountain lions, bobcats, and gray foxes, and “Much More Important” than coyotes and mule deer. Trail ranks and scores were similar when taking into account “criteria-level & species-level” weights or only the “criteria-level” weights (Table 10). Army Camp to Bunker is the least impactful trail, followed by other trails in the Army Camp trail system, whereas the Jalachichi trail system has the most impacts.

The “criteria-level & species-level” ranks and “criteria-level” ranks are different than the equally weighted analysis. For example, while the criteria-level and species-level trail ranks resulted in a Moderate ecological impact for Water Canyon Out and Back, equal weights result in a Moderately High ecological impact. Additionally, while Army Camp to Bunker is ranked with the least impact for both criteria-level and species-level trail ranks, equal weights result in the Coastal Bluffs trail having the lowest ecological impact.

Trail Name	**Criteria-level & Species-level**	**Criteria-level**	**Baseline equal-weights**
Army Camp to Bunker	**1(1.46)**	**1(1.35)**	**2(1.59)**
Army Camp Loop 2	**2(1.62)**	5(1.56)	6(1.89)
Army Camp Loop 1	**3(1.63)**	6(1.57)	5(1.88)
Bunker Out and Back	**4(1.63)**	**2(1.51)**	**3(1.74)**
Water Canyon Loop	5(1.71)	**3(1.56)**	7(1.97)
Coastal Bluffs	6(1.75)	7(1.75)	**1(1.5)**
Jalachichi Oak Grove	7(1.96)	**4(1.56)**	**4(1.84)**
Water Canyon Out and Back	8(1.99)	*9(1.91)*	*12(2.46)*
Jalachichi Overnight	*9(2.15)*	8(1.82)	8(2.09)
Jalachichi Lollipop	*10(2.42)*	*10(2.12)*	*11(2.23)*
Jalachichi Loop	*11(2.45)*	*12(2.16)*	*10(2.22)*
Jalachichi Pond	*12(2.47)*	*11(2.15)*	*9(2.21)*

Table 10: Ranks and Impact Scores for TNC Preference and Baseline Multi-Criteria Analysis Runs. Ranks of education trails at the Dangermond Preserve were calculated based on TNC's Criteria-level & Species-level preferences, their Criteria-level preferences, and a baseline of equal weights for the Conservation Criteria. Ranks are provided with each impact score in parentheses. **Bold** represents the best 4 trails for each weighting scheme, and *italics* represents the worst 4 trails for each weighting scheme. Impact scores were used to categorize trails to have Low (0-1), Moderate (1-2), Moderately High (1-3), and High (3-4) impact. These 3 weighting schemes only have trails with Moderate impact (shown in yellow) and Moderately High impact (shown in orange).

From the sensitivity analysis of varying weights for Conservation Criteria we determined the underlying impacts of trails, criteria-specific priority ranks, and differences in seasonal impacts (Table A1.3, Appendix I). All trails have a Low impact to mammals, while vegetation and amphibians are impacted on a broader scale ranging from Moderate to Moderately High, and Low to High, respectively. However, raptors are much more impacted along trails than the other three Conservation Criteria. All but two trails (Jalachichi Oak Grove and Jalachichi Overnight) have a High impact to raptors.

When vegetation or raptors are weighted "Much More Important" than other Conservation Criteria, the ranks and impact scores vary between one another. When comparing these two criteria, the lowest impact trails for raptors are in the Jalachichi trail system, while the lowest impact trails for vegetation are in the Army Camp trail system.

When considering seasonal variation, fall and winter produce similar ranks to each other. This is due to the increased breeding sensitivity of amphibians during these seasons. However, they differ in the severity of impacts with the addition of raptor sensitivity in the winter. Seasonal ranks are the same for spring and summer. Additionally, seasonal variation changes the impacts of trails in comparison to the baseline equally weighted scenario. When all Conservation Criteria are weighted equally, the least impactful trail, Coastal Bluffs, has a Moderate impact. However, when seasonal variations are taken into account, this trail has a Low impact in fall, Moderate in winter, and a Moderately High impact in spring and summer. These seasonal variations alternate the Coastal Bluffs trail from being the best ranked trail in fall, to the worst ranked trail in spring and summer.

5.4 Discussion

The results of the Multi-Criteria Analysis are useful for determining current trail rankings and potential new trail locations on the preserve. The preserve-wide ecological impact map can be used to locate areas of low impact and focus the addition of new trails in those areas. For example, the northern end of the preserve had lower impacts than other areas. However, many of the low impact areas would be difficult to access for environmental education as they are primarily located in the northern end of the preserve, which is far away from roads.

The results of the Multi-Criteria Analysis are driven by the overlap of high impact areas for several Conservation Criteria. We can observe how these results change as we vary weights of different Conservation Criteria. This flexibility of the model will be useful as management priorities evolve at the preserve. For example, impacts to the four Conservation Criteria vary with season. In the spring when raptors are nesting and invasive plant species are going to seed, managers should weigh raptors and vegetation with higher importance due to their increased sensitivity. Managers can use the specific ranks for spring to determine the least impactful trail, in this case the Jalachichi Oak Grove. On the other hand, seasonal ranks for the fall (influenced by amphibian sensitivity), and winter (influenced by amphibian and raptor sensitivity), suggest that the entire Jalachichi trail system should be avoided, with better trail options in the Army Camp trail system and Coastal Bluffs. These varied trail ranks can be used by preserve managers to decide on trail usage throughout different times of the year, as well as in future years as management priorities and concerns change.

While the trail ranks are useful for preserve managers, it is important to understand the underlying causes of those ranks. As previously discussed, a low impact on the preserve does not necessarily mean a low impact for all Conservation Criteria. Therefore, avoiding one Conservation Criteria on the preserve may impact another. Additionally, understanding the underlying causes of trail impact scores can help to mitigate impacts on chosen trails. For example, the Jalachichi trail system goes through purple needlegrass grassland and is also suitable habitat for invasive perennial veltdgrass. To protect the sensitive species from invasive species, The Nature Conservancy can mitigate invasive spread by cleaning students' shoes from potential invasive seeds and requiring more chaperones to ensure students stay on trail. Taking this step to mitigate impacts after choosing trails with already lower overall ecological impact can further advance TNC's conservation management on the preserve. We have provided a table of identified underlying impacts to each trail to inform mitigation strategies for TNC in (Table A1.2, Appendix I).

In addition to trail rank, preserve managers should consider the distance of each trail. Our rankings provide insight into the average impacts on each trail, since the summed impact method simply predicted trail distance. However, distance is something to take into account in addition to the impacts. A longer trail means more impacts because humans will be disrupting wildlife for a longer period of time or trampling more vegetation. Therefore, if two trails are ranked similarly and have similar average impacts, such as the Jalachichi Oak Grove trail and Army Camp Loop 1 trail in the equally weighted scenario, the shorter trail will result in fewer ecological impacts.

Finally, the results of our MCA can be supplemented with on the ground species occurrence data. Our model uses predicted highly suitable habitat for the species of concern. Additional concern should be given to areas with known species presence. For example, if TNC sights a raptor nest along the Jalachichi Pond trail, they should use this knowledge to supplement the trail ranks and adjust their decision to use other trails during breeding and nesting times for that species.

CHAPTER 6: MANAGEMENT TOOL

6.1 Introduction

While our spatial analyses will help The Nature Conservancy (TNC) understand and manage the ecological impacts of environmental education on the Dangermond Preserve, they do not identify or incorporate the education opportunities that the preserve can provide. Thus, to solve our third research objective, we created an interactive management tool for TNC that allows them to select trails on the Dangermond Preserve while considering both educational opportunities and ecological impacts. This tool will allow TNC to make informed decisions about which trails to use for environmental education, both spatially and temporally.

The Dangermond Preserve supports more than 370 native plant species, and approximately 45 vegetation communities (WRA, Inc. 2017). Additionally, the unique history of the land and the eight miles of California coastline along the preserve boundary provides several scenic landmarks. Together, scenic landmarks and diversity in vegetation communities provide rich educational opportunities for students. Notably, the visual and scenic beauty of a landscape can contribute significantly to the quality of student experiences during a given program (Clay and Daniel 2000). Therefore, we identified six landmarks on the preserve that can be incorporated into a variety of environmental education lesson plans (Table 13). While we have only included scenic landmarks and vegetation communities as the educational opportunities in this management tool, the preserve can offer students a plethora of diverse curriculum benefits. This tool is both reproducible and adaptable such that TNC can add in additional benefits if they so choose.

6.2 Methods

We created this management tool using Shiny App in RStudio. Shiny uses R code to create an interactive web app with a user interface and reactive programming (Wickham 2020). Combining education constraints and opportunities, the app gives an output of trails that fit these factors, providing specific information about the trails' landmarks and vegetation opportunities along with each trails' ecological rank.

Based on literature review, we identified five education constraints that serve as the inputs in the user interface: group size, student age, trail difficulty, trail length, and travel time (Hopkins et al. 2013). The user will select their inputs, then the app will filter out and identify trails that meet their criteria. Along with each trail output, the app will identify the education opportunities available for each trail, i.e.; landmarks and vegetation communities, and the ecological impact score associated with each trail. Based on the date of the education program, the app will prepopulate the ecological impact score for that particular season. Using these final trail outputs, TNC can make informed decisions about which trails to use for environmental education.

6.2.1 Education constraints

Group Size and Student Age

The education group size and student age will be inputs provided by the school teacher. At this point these are not constraints that filter out certain trails. However, in the future if TNC determines carrying capacities for certain trails, then group size could be a filtering constraint.

Trail Difficulty

Trail difficulty was determined based on a formula used by the National Park Service (How to Determine Hiking Difficulty - Shenandoah National Park (U.S. National Park Service) 2017).

$$Difficulty = \sqrt{(Elevation\ gain\ (in\ feet) * 2) * Distance\ (in\ miles)}$$

Difficulty for each trail was calculated using elevation change from a 2-meter digital elevation model (DEM) provided by The Nature Conservancy. Numerical ratings were then grouped into five categories: Easiest, Moderate, Moderately Strenuous, Strenuous, and Very Strenuous (Table 11). One limitation to using this National Park Service equation to calculate difficulty is that it does not consider elevation gain within a short distance along a trail. Therefore, a rating could be considered “Easiest” from the equation, but due to factors such as quick elevation gain, the trail could in actuality be more difficult.

Difficulty	Easiest	Moderate	Moderately Strenuous	Strenuous	Very Strenuous
Numerical Score	<50	50-100	100-150	150-200	>200

Table 11: National Park Service Trail Ratings Used to Categorize Trail Difficulty on the Dangermond Preserve. Trail difficulty level ranging from Easiest, Moderate, Moderately Strenuous, Strenuous, and Very Strenuous. The equation used to calculate difficulties incorporates elevation gain (in feet) and distance (in miles).

Trail Length and Travel Time

Trail length and travel time were verified using the Gaia GPS mobile app and ArcGIS. We hiked each trail and tracked the distance and travel time for each segment using this app. The Gaia GPS mobile app records distance, total time, and elevation gain. The recorded distances were then cross-referenced using ArcGIS (Table 12).

Trail Name	Trail Length (miles)	Travel Time (minutes)	Trail Difficulty
Army Camp System (Including Bunker Loop)	7.00	220	Moderate
Army Camp Loop 1	4.20	140	Moderate
Army Camp Loop 2	4.60	150	Moderate
Army Camp to Bunkers	3.12	41	Easy
Coastal Bluffs	0.68	40	Easy
Jalachichi Pond	1.76	50	Easy
Jalachichi Oak Grove	2.20	60	Easy
Jalachichi Lollipop	2.80	N/A	Easy
Jalachichi Loop	1.42	90	Easy
Jalachichi Overnight Loop	2.96	90	Moderate
Water Canyon Loop	3.25	100	Moderate
Water Canyon Out and Back	2.00	45	Easy

Table 12: Trail Length, Travel Time, and Trail Difficulty for Education Trails on the Dangermond Preserve. Trail length and travel time were calculated using the Gaia GPS mobile app. Trail difficulty was determined using National Park Service ratings.

6.2.2 Education opportunities

Landmarks

Guided by TNC's staff knowledge, we established a list of landmarks on the Dangermond Preserve that offer educational opportunities for students (Table 13). In order to identify which landmarks are visible from certain trails, we created a viewshed model in ArcGIS using the Viewshed Tool. This model calculates the area of view from points along a trail and combines them to create a map of the overall viewshed of the trail. The inputs into this model included trail and elevation data for the Dangermond Preserve. The results were then used to identify landmarks that are within the viewshed of each trail. We then created a layer with the landmarks in ArcGIS and overlaid this layer with maps from our viewshed model. Looking at the viewsheds of each trail individually, we determined whether or not a landmark was located within the viewshed of the trail.

Landmark	Educational Opportunity
Point Conception	Merging of climate patterns and ocean currents; early explorers
Point Conception Lighthouse	Historical use; importance for navigation
Government Point	Direction of the coast changes from south to west-facing
Army Camp Bunkers	Historical use for defense
Army Camp Wells	Groundwater; watersheds on the preserve
Jalachichi Pond	Aquatic habitat for plants and wildlife

Table 13: Landmarks on the Dangermond Preserve that may Provide Educational Opportunities for Students. Landmarks include points of interest, historical structures, and natural features that educators can incorporate into their lesson plans.

Vegetation Communities

The Nature Conservancy provided layers of land cover on the Dangermond Preserve, which included tree-dominated, shrub-dominated, and herb-dominated communities, as well as miscellaneous land cover. We merged the layers of tree-dominated, shrub-dominated, herb-dominated communities together in ArcGIS to create one layer of vegetation cover. The layer of miscellaneous land cover was excluded from this analysis because it consisted of agricultural areas, developed areas, coastal strand, and open water.

We used the Spatial Join Tool in ArcGIS to join the layer of vegetation cover with the layer of environmental education trails on the preserve. We set the "Within a Distance" option to 10 meters, which allowed us to create a list that included all vegetation communities located within 10 meters of a trail. We assumed that all vegetation communities located within 10 meters of a trail were within the viewshed of that trail and were close enough for educators to provide an informative lesson to students.

6.3 Results

This management tool is a useful way to quickly sort through available education trails and filter out trails based on the education constraints. Since the programming for the tool results in an interactive interface, the trail output appears immediately when a user selects the education constraints. The user can then compare the education opportunities and ecological impact among the resulting trails. One example scenario that highlights these trade-offs is shown in Figure 25. The education constraints used in this scenario include: a trail difficulty of Easy, trail length of 2 miles, and travel time of 1.5 hours.

Figure 25: Example of Trail Options for a Fall Education Program on the Dangermond Preserve. The education constraints used in the management tool include a trail difficulty level of Easy, a trail length of 2 miles, and a travel time of 1.5 hours.

Based on the input selections, the app provides four available trails that meet the education constraints: the Coastal Bluffs trail, Jalachichi Loop, Jalachichi Pond, and Water Canyon Out and Back. While each trail has a similar number of vegetation communities, they vary in the available scenic landmarks. Additionally, three of the four trails have a High impact for the fall season. This is due to the fact that these trails intersect areas that are impactful to sensitive raptors and sensitive vegetation during this season. The only trail that has a Low impact is the Coastal Bluffs trail; this trail also has the most scenic landmarks available. At this stage in the decision-making process, TNC must weigh the education benefits to students with the potential ecological costs to the preserve in order to determine which trail is the most suitable for a given program. For this specific scenario, the Coastal Bluffs trail is the best option, since it has the most education opportunities and lowest ecological impact. However, changing the time of year of education programming will alter these results.

Seasonality can greatly affect the ecological impact score due to the varying sensitivities of the four Conservation Criteria throughout the year. For comparison, Table 14 shows how the impact scores change when the same education scenario mentioned above takes place in the spring.

Trail Name	**Fall Impact Score**	**Spring Impact Score**
Coastal Bluffs	Low (0.49)	Moderately High (2.69)
Jalachichi Pond	High (3.22)	Moderately High (2.47)
Jalachichi Loop	High (3.26)	Moderately High (2.48)
Water Canyon Out and Back	High (3.44)	Moderately High (2.62)

Table 14: Comparison of Spring and Fall Impact Scores for an Example Education Scenario. Ecological impact for all four education trails in this example scenario change between fall and spring. The Coastal Bluffs trail increases from Low in the fall to Moderately High in the spring, while the other three trails (Jalachichi Pond, Jalachichi Loop, Water Canyon Out and Back) each decrease from High in the fall to Moderately High in the spring.

The impact scores for each trail changes from fall to spring. For the Coastal Bluffs trail, the impact score becomes Moderately High in spring. During the fall season there is no seeding of invasive plants, which therefore reduces the risk to the sensitive vegetation communities. However, for the Jalachichi Pond trail and the Water Canyon Out and Back trail, the impact is lessened to Moderately High. The impact scores for these trails are higher in the fall due to increased sensitivity for amphibians in those areas, since the California red-legged frog breeds during fall months (California Red-Legged Frog - Amphibians and Reptiles, Endangered Species Accounts | Sacramento Fish & Wildlife Office n.d.).

6.4 Discussion

This management tool was designed to be easy for The Nature Conservancy to use for assessing the trade-offs of environmental education on the Dangermond Preserve. Furthermore, we designed this tool to be adaptable if trails or education opportunities need to be added, removed, or otherwise updated.

Our analyses have demonstrated that seasonality is extremely important when considering ecological impact and trail use. Managers on the Dangermond Preserve can utilize this tool, in conjunction with our previous spatial analyses, to plan education programming far in advance. Additionally, this tool has the ability to monitor and track trail use by allowing TNC to save the results each time a trail is selected for programming. Results are continually updated and saved into a .csv file. By monitoring trail use in this way, TNC can concurrently monitor the amount of ecological impact the education programs have on the trail systems. If TNC determines that certain trails have a carrying capacity for student use, they can update the management tool to reflect these numbers as an education constraint.

When combined with the identified knowledge of environmental education benefits and consideration of program implementation impacts, TNC will be more informed in their decision making process of how to balance these trade-offs. For example, while this tool may identify two trails that fit a given programs' needs, one trail may have more education opportunities than the second trail. However, the first trail may be more ecologically sensitive to human presence and have a higher impact score. Given this information, TNC can then decide, based on their own management priorities, which trail to use for a given program.

CHAPTER 7: CONCLUSIONS & RECOMMENDATIONS

7.1 Conclusions

The purpose of this project was to assist The Nature Conservancy in managing the impacts of environmental education at the Jack and Laura Dangermond Preserve. A managed cattle ranch for more than 100 years, the Dangermond Preserve was gifted to The Nature Conservancy in 2017 and today represents an exceptional opportunity for nature-based learning on California's Central Coast. The preserve contains a network of 12 trails that could be used to connect students from nearby Lompoc, CA with the outdoors. However, the preserve also supports a high amount of native biodiversity, including many sensitive plant and wildlife species.

Objective 1

Our first objective was to identify plant and wildlife species that are sensitive to humans and map their suitable habitat on the Dangermond Preserve. We also mapped suitable habitat for three invasive plant species to locate where invasive species are mostly likely to spread into areas with sensitive plants. We defined "sensitive" as species that are documented in scientific literature as being negatively impacted by the presence of humans. In addition, most of the species we defined as "sensitive" are listed as special-status at the federal, state, or local level.

Takeaway 1.1: In general, establishing a new education trail on the preserve would be most impactful to sensitive species if located in coastal areas or riparian habitat.

Many of the plant and wildlife species we defined as sensitive have suitable habitat near the coast and along creeks and streams on the preserve. For example, all six of the raptor species have highly suitable habitat near Government Point and along parts of Jalama Creek. The area around Government Point also provides critical habitat for Gaviota tarplant, and riparian habitat along Jalama Creek supports species such as the California red-legged frog. Notably, there is less overlap in suitable habitat for the identified sensitive species in the northern end of the preserve.

Objective 2

Our second objective was to rank each education trail on the Dangermond Preserve based on its ecological impact. We defined "ecological impact" as the cumulative impact to four Conservation Criteria: sensitive vegetation, sensitive mammals, sensitive raptors, and sensitive amphibians. Using the four Conservation Criteria and a baseline of equal weights as inputs, we performed a Multi-Criteria Analysis in ArcGIS to calculate the ecological impact of each trail. We also calculated the ecological impact of each trail using alternative weighting scenarios, such as all weight assigned to one criterion, much more weight assigned to one criterion than all others, all weight assigned to vegetation or wildlife criteria**,** weight assigned based on seasonality, and weight assigned based on Dangermond Preserve manager preferences.

Takeaway 2.1: All education trails pass through areas of both low and high ecological impact.

We found that all 12 education trails on the preserve pass through areas of both low and high ecological impact. While some trails have a higher ecological impact than others, there are not necessarily "go" or "no-go" trails. One trail that mostly avoids areas of high ecological impact is the Coastal Bluffs trail, which is a relatively short trail located near Government Point. However, this trail still passes through an area of high impact to sensitive raptors and is near an area of high impact to sensitive vegetation.

In addition, trails that avoid impact to one Conservation Criterion may impact another criterion. This is because suitable habitat for sensitive vegetation, sensitive mammals, sensitive raptors, and sensitive amphibians overlap in some areas on the preserve but not in others. For example, the Jalachichi Oak Grove trail tends to avoid impact to sensitive vegetation and sensitive mammals, but passes through areas of high impact to sensitive raptors and sensitive amphibians.

Takeaway 2.2: The education trail with the best rank, meaning the lowest ecological impact, depends on which Conservation Criteria TNC prioritizes protecting.

By running our Multi-Criteria Analysis under different weighting scenarios, we found that the ecological impact of each education trail depends largely on the underlying weights. For example, with sensitive vegetation ranked as "Much More Important" than all other Conservation Criteria, the Army Camp to Bunker trail is the least impactful trail. In contrast, with sensitive raptors ranked as "Much More Important" than all other Conservation Criteria, the Army Camp to Bunker trail has a Moderately High impact and is ranked 7th.

Notably, the trail with the lowest ecological impact often depends on the season. For example, the Jalachichi Oak Grove trail is the least impactful trail during the spring and summer. However, this trail has a Moderately High impact in the fall and winter, ranking 7th and 6th, respectively. This is in part because the Jalachichi Oak Grove trail mostly avoids areas with sensitive vegetation, which is one of the Conservation Criteria that is assigned a high weight during the spring and summer due to invasive plant seeding.

Takeaway 2.3: Of the four Conservation Criteria considered on the Dangermond Preserve, avoiding areas with sensitive raptors may be most challenging.

When all weight is assigned to sensitive raptors, all 12 trails have a Moderately High or High impact. This is because most of the preserve offers suitable habitat for raptors, and all of the trails pass within the flushing zones of at least five raptor species. In contrast, when all weight is assigned to sensitive mammals, all 12 trails are Low or Moderate impact. There are no trails that pass through suitable habitat for more than four mammal species.

In prioritizing protecting raptors, TNC managers would in many instances also be protecting the other three Conservation Criteria. However, this would leave managers with a limited number of trail options for their education programs. If protecting raptors is the primary concern, the Jalachichi trail system appears to provide the best trail options.

<u>Objective 3</u>

Our third objective was to create a management tool that The Nature Conservancy can use to select trails on the preserve that meet student needs and provide educational opportunities. We used the ShinyApp package in RStudio to create this tool, which allowed us to build a user-friendly web interface for TNC. To use this tool, a TNC manager inputs information that incorporates educational constraints: trail difficulty, trail length, and travel time. The tool then produces a list of trails that meet the educational constraints, and provides information about the ecological impact of each trail. The tool also lists the educational opportunities associated with each trail, which includes landmarks and vegetation communities.

Takeaway 3.1: Trails with a high number of educational opportunities and a low ecological impact may meet the needs of some students but not others

An example of a trail that meets the needs of some students but not others is the Coastal Bluffs trail. This trail has a Low impact in the fall and a Moderate impact in the winter, and is ranked 1st in both seasons. It offers views of landmarks such as Point Conception, and passes near vegetation communities such as Menzie's goldenbush scrub, brownheaded rush seeps, and iceplant mats. In addition, the Coastal Bluffs trail has almost no change in elevation and is less than a mile round trip. This makes the Coastal Bluffs trail an ideal option for elementary school students, individuals with disabilities, and others who need an easy trail or may not have much hiking experience.

However, the Coastal Bluffs trail may not meet the needs of middle or high school-level students that are interested in a longer, more rigorous hike. Such students may prefer the Army Camp Loop 1 trail, which is about 4.5 miles in length and passes through vegetation communities such as coast live oak woodland, California sagebrush scrub, coyote bush scrub, and non-native grassland. The trade-off in using the Army Camp Loop 1 trail rather than the Coastal Bluffs trail is that while it meets the needs of older students, it has a Moderate impact in the fall and a Moderately High impact in the winter.

A Case Study in Protected Area Management

While the Dangermond Preserve is a unique area, the takeaways from our research address trade-offs that managers of other protected areas need to be aware of when making decisions about managing access for environmental education. For example, when there are multiple conflicting criteria to protect, attempts to avoid impacts to one criterion may result in impacts to another criterion. Furthermore, a trail will often pass through areas of both low and high impact. This highlights the importance of assigning weights based on which criteria managers care most about protecting.

The methods that we used in this project, including identifying Conservation Criteria, conducting a Multi-Criteria Analysis, and creating a management tool, offer an approach that managers of other protected areas can use to inform trail management decisions. While the criteria considered important to protect will differ depending on the geographical area, concepts such as mapping hotspots where sensitive species face the highest threat from invasive species can help with assessing the ecological impact of a trail. In addition, a management tool such as the interactive web app created in this project can allow a land manager to easily compare the "costs and benefits" of a trail, and can aid in selecting trails that provide educational opportunities while reducing or avoiding ecological impacts.

7.2 Recommendations

1. *Importance of seasonality: Assign weights to all Conservation Criteria based on the time of year.*

We found that the trail with the lowest ecological impact differs depending on the weights assigned to each Conservation Criterion, meaning that weights play an important role in trail use decision-making. In addition, we found through our literature review that plant and wildlife species on the preserve differ in the timing of biological events such as leafing, seeding, breeding, nesting, and migration. This suggests that there are certain times of year when the use of a trail would be particularly impactful to one or more Conservation Criteria. For example, raptors may be more impacted during the spring and summer when they are breeding, attending to nests, and rearing young. With this in mind, we recommend that managers at the Dangermond Preserve utilize the various weighting scenarios for the Conservation Criteria that reflect the timing of biological events. This will help to account for the effect that seasonality has on species sensitivity, and will result in trail rankings that more accurately reflect the impact to native biodiversity on the preserve.

To assist The Nature Conservancy in assigning weights, we produced a table of trail rankings based on season (Table A1.3, Appendix I). This table serves as a reference that managers at the Dangermond Preserve can use to compare the ecological impact of trails at different times of the year. It is our hope that this information can be used by The Nature Conservancy to make more informed decisions about their trail management that accounts for seasonal considerations.

2. *Importance of consistent monitoring of the Conservation Criteria: Hire consultants or researchers to conduct field surveys to supplement the currently available data.*

While we have provided thorough and up-to-date information on predicted ecological impacts to the preserve, we did so using data on predicted, rather than validated, species habitat suitability. To assist TNC in making more informed management decisions on the preserve, we offer three recommendations for supplementing the data we used in our analyses.

First, field surveys should be conducted to identify and verify the location of the three invasive species in this report; iceplant, black mustard, and perennial veldtgrass. Currently, these invasive species are not in isolated data files. Instead, they are paired with other plant species in a single polygon across the preserve in such a way that it is impossible to pinpoint their true locations. Spatial data collected from field surveys would refine the ecological impact due to the spread of invasives, and provide a more accurate depiction of potential consequences due to environmental education programming.

Second, conducting field surveys in the fall and spring will ensure minimal impact to mammals, raptors, and amphibians by locating dens, nests, and breeding habitat, respectively. For example, a mountain lion near Army Camp could pose a serious safety risk to environmental education groups if the lion has cubs nearby and feels threatened. The presence of humans may cause a lioness to flee the area (Smith et al. 2017), which could result in a lower probability of survival for her offspring, depending on their age (Elbroch and Quigley 2013), due to reduced hunting success in less suitable habitats. Similarly, raptor flushing behavior is known to decrease their nesting success (Richardson and Miller 1997). For this reason, it is crucial that field surveys are conducted to locate nests of the raptor species we have identified.

Lastly, field surveys should determine the specific breeding habitat of amphibians in order to locate the most suitable aquatic habitat and species-specific buffer distances. Location of dens, nests, and breeding habitats should be used to refine the predicted ecological impact map when deciding which trails will best minimize ecological impacts. Should a den, nest, or breeding habitat occur near an education trail, that trail should be closed until the species of concern’s breeding season has finished.

3. *Outcomes of Environmental Education: Continually monitor and evaluate education program effectiveness*

Access to the outdoors has been connected to mental and physical well-being in youths, and the Dangermond Preserve represents an exceptional opportunity to provide students in Lompoc, CA with such benefits. However, in providing students with opportunities to learn and play in nature, TNC intends to not only improve the health of students but also inspire them to become the next generation of conservation leaders. With assistance from NatureBridge, NatureTrack, and REACH, TNC is well-positioned to instill students with the knowledge, curiosity, and appreciation for nature that can promote pro-environmental attitudes and motivate students to pursue land stewardship careers as adults.

We recommend that as education programs are implemented on the preserve, TNC continually measures both the short- and long-term success of such programs. This will involve defining success and identifying ways to measure it. For example, short-term success could be defined as improvements in understanding STEM and environmental science concepts. This could be measured by comparing science test scores between students from similar backgrounds that participate in education programs on the Dangermond Preserve and those who do not. To assess long-term impacts, TNC could survey students that participated in education programs and ask about their academic and career goals. Following up with students to learn about their volunteer experiences, internships, degree programs, and jobs can help TNC assess whether its programs are providing a pipeline model that leads students into environmental careers.

In addition, we recommend that TNC regularly consult with third-party educators about whether the trails are meeting the needs of students. This project identified landmarks and vegetation communities as educational opportunities, however there may be other features on the preserve that could be incorporated into lesson plans. We suggest that TNC coordinate closely with educators to ensure that the trails are meeting curricular needs and providing students with engaging, memorable learning experiences. If educators are finding that trails with a low ecological impact do not provide sufficient educational opportunities, then depending on TNC's goals it may be advisable to take students on trails with a higher ecological impact.

4. *New Trail Development: If establishing new trails, prioritize trail development in low impact areas.*

While our general recommendation is to avoid building new trails to minimize ecological impacts, TNC may wish to expand their environmental education program in the future. In doing so, the carrying capacity of existing trails may be exceeded, and TNC would need to expand their current trail systems or build new trails. The Multi-Criteria Analysis can help guide TNC's decision-making process on siting new education trails. The MCA is flexible so that TNC can update the model with new weights as their conservation and management priorities evolve. Before siting any new trails, we recommend running the MCA with the most up-to-date management weights.

Using the weighted overlay map from the MCA, TNC can identify areas with the lowest ecological impact on the preserve. The low impact areas should be prioritized for the development of new trails. Furthermore, TNC should choose areas of low impact that are accessible from current education trails or other roads currently present on the preserve. This will minimize excess ecological damage by containing trail development to previously impacted areas.

Before designing and building new trails, it is important to identify the anticipated user groups. If TNC wants to build trails that are suitable for all student age groups, then they must design the trail to cater to the youngest age group; this is especially important in terms of trail difficulty and trail slope. Additionally, the trail needs to be wide enough to support the anticipated group size and purpose of the environmental education program. Siting of new trails should follow existing land contours to reduce erosion potential (Preserve Trail Guidelines: Resource Management Guidelines for Trails in Preserves 2018). General site assessment should evaluate up-to-date presence of vegetation and wildlife species' habitats, as well as any educational opportunities the trail may provide. If the ecological and financial costs of building and maintaining the new trail outweigh the perceived environmental benefits for students, then TNC should not build the new trail.

7.3 Next Steps & Future Research

1. *Climate Change*

As climate change increases the risk of drought and fire, managers must closely monitor the spread of invasive plant species (Keeley and Syphard 2016). In this project, perennial veltdgrass and black mustard represent two invasive plant species that are promoted by wildfire. Wildfire tends to reduce the regrowth of native plant species and allows invasives to spread into new areas (Brooks 2017; Weber 2013). This in turn may shift where sensitive vegetation hotspots are located on the preserve.

We suggest that additional analyses be conducted in MaxEnt to map the habitat suitability of invasive plant species on the Dangermond Preserve under differing climate change scenarios.

Such analyses could include both the species we examined, as well as other non-native species that occur on the preserve. For this project, we used 30-year averages of climate data from 1984 through 2014 and we did not account for changes in climate. Our MaxEnt analysis can help to inform TNC's management decisions in the short-term, but does not reflect the potential spread of invasive species under projected shifts in temperature, rainfall, and other climate variables. Therefore, additional analyses under these projected shifts can inform TNC on how to avoid using trails that may increase the spread of invasive plant species in the future.

It could also be worthwhile for TNC to consult the previous Bren School Group Project (2019) to identify how the ranges of sensitive plant species may shift in the future under different climate conditions (B. Anderson et al. 2019). This previous project modeled the habitat suitability for four plant species on the Dangermond Preserve, including coast live oak, tanoak, lemonade berry, and La Purisima manzanita. With an awareness of how sensitive species ranges may shift, managers can make more informed decisions about how to reduce or avoid impacts to such species in the long-term.

2. Risks and Safety Concerns

This project focused on protecting sensitive vegetation, sensitive mammals, sensitive raptors, and sensitive amphibians on the Dangermond Preserve. However, there are other criteria not included in this analysis that may be important to consider when deciding where to allow access for environmental education on the preserve. This includes fire risk and cattle ranching, two processes that have shaped the current vegetation cover on the preserve but were not included in our Multi-Criteria Analysis.

Identifying and mapping areas of high fire risk on the preserve would be valuable, as such areas represent where human-caused ignitions could be most consequential. The heat from the undercarriage of a vehicle used to transport students or supplies also has the potential to start a wildfire if it comes in contact with dry vegetation. In addition, an ignition could occur during an education program that involves overnight camping with the use of lighters and cook stoves. During seasons of increased fire risk, and on days with high temperatures, high winds, and low humidity, it is advisable to avoid hiking and camping in high risk fire zones.

Cattle grazing represents an additional criterion that may be important to consider when deciding where to take students. To avoid human-cattle interactions, we recommend avoiding trails located in the areas where livestock are actively grazing. Coordinating with ranchers about their grazing schedules, in addition to mapping fences and other barriers on the preserve, can help to inform decisions that keep students and cattle spatially separated.

Other safety concerns that may be important to consider include proximity to roads in case of an emergency, presence of poison oak, and distance to steep slopes and cliffs.

3. *Costs and Benefits of Environmental Education*

While this project focused on the ecological costs of implementing environmental education programs on the Dangermond Preserve, TNC should also consider the associated financial costs. These costs should then be weighed against the environmental education benefits for students in order to establish optimal land management strategies, such as a carrying capacity for each education trail. Furthermore, these costs and benefits should be preemptively evaluated for differing scales of environmental education programs on the preserve (i.e. as student visitor numbers, frequency, and length of visitation increase). Identifying each education trail's carrying capacity can allow TNC to prepare for budget, staffing, and management adjustments associated with the varying infrastructure needs. Therefore, TNC should explore the costs and benefits associated with different program scales**.**

A Cost-Benefit Analysis (CBA) should be used to more precisely quantify the complete ecological and financial costs and benefits associated with the preserve's programs. We have identified three potential additional costs to consider:

1. Costs associated with hiring additional staff to assist in any program logistics.
2. Costs that increased vehicle use may incur, specifically by TNC staff. These costs include the financial cost of gasoline, as well as the environmental cost of increased greenhouse gas emissions.
3. Costs for trail maintenance or restoration associated with increased trail use.

Additionally, a CBA should quantify the benefits of the environmental education programming on the Dangermond Preserve. Conducting pre- and post-program student surveys and evaluations can aid in capturing the benefits that students experience during a given program. With these costs and benefits quantified, TNC can weigh the trade-offs and identify the appropriate scaling of future programming on the preserve that meets both their conservation management and financial goals

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APPENDIX I. OVERVIEW OF TRAILS

A1.1 Qualitative Description of Education Trails.

This table provides a qualitative description of each trail to help The Nature Conservancy plan education programming.

Trail Name	Description of Trail
Bunker Out and Back	Many curricular opportunities for students throughout the trail system. However, there are several steep spots that may be more difficult for some students or docents.
Army Camp Loop 1	There is a somewhat steep incline at the beginning of the trail starting from Cojo Gate, and a few more later in the loop. This may be difficult for some docents and younger children.
Army Camp Loop 2	There are good views of the ocean most of the way back down towards Cojo Gate. There are a few steep portions of the trail, which may take students longer to hike up.
Army Camp to Bunker	There is no shade on this trail, though the trail is mostly flat the entire way. Great views of the ocean, Point Conception, and Government Point. The army bunkers are a great curriculum opportunity for students.
Coastal Bluffs	This trail is mostly flat the entire way. Potentially accessible for student in a wheel chair. Trail is wide enough for lesson setups and programming.
Jalachichi Pond	The gate to the pond is about a 25 minute to walk. Hiking to the pond is mostly downhill the whole way - it would take longer to hike back up; the slope seems manageable though. There is shade 0.3 miles in as well.
Jalachichi Lollipop	*Needs to be assessed*
Jalachichi Loop	*Needs to be assessed*
Jalachichi Oak Grove	This is a great easy hike, particularly for younger students. There are several curriculum opportunities. When you approach the Oak Grove, there is a single track that leads to another shaded oak grove, which could be used for a lesson or lunch. This is a good turning around point. The first shady spot is just over half a mile in. There is quite a bit of poison oak in this shady spot next to the trail, so TNC should keep an eye on that. The slope is gradual and very accessible. There are great viewpoints along the trail.
Jalachichi Overnight	Not suitable for a day trip or younger students. The trail that connects the pond to the brown trail goes through a pasture area and is very steep; there is no noticeable trail. It would need to be mowed and a clear trail created in this space. Could be a great hike for an overnight trip (but students still camp at Jalama Corrals, maybe Army Camp).

Water Canyon Loop	When starting the trail from the horse corral, there are a couple short steep ascents, though they would be manageable for most school groups. On the second half of the loop there is a steep descent. This would be a very difficult slope to hike up if coming from the other direction, so we recommend starting this trail from the horse corral. There are a few places that would be good for quick lessons. There is not much shade, but the spots that are shaded are well spaced out. There are a couple gate crossings a group would need to do. One of the gates that you go through for the loop is the 3rd gate marker on the Avenza map. Realistically, this hike would take about 2 to 2 1/2 hours for high schoolers if they are stopping to do lessons
Water Canyon Outback	This is an easy flat trail that starts at the Water Canyon gate and ends near the culvert. There are not many curricular opportunities on this trail, though students could learn about invasive species. There is a lot of Black Mustard on both sides of the trail for the majority of the time.

A1.2 Description of Underlying Impacts for Each Education Trail.

This table shows the identified underlying impacts of each education trail on the Dangermond Preserve. Underlying impacts were identified to raptor species, mammal species, amphibians species, sensitive vegetation communities, and sensitive plant species. Invasive plants present along each trail were also identified. Impacts to raptors were determined by overlaying education trails with potential flushing zones of each species. Impacts to mammals were determined by overlaying education trails with highly suitable habitat for each species. Impacts to amphibians were determined for each trail based on which species had documented presence within 200 meters of aquatic habitat and each trail. We also determined which trails overlap a 100 meter and/or 200 meter aquatic habitat buffer. Impacts to sensitive vegetation communities and sensitive plant species were determined by overlaying education trails with polygons for the sensitive vegetation communities and sensitive plant species.

Table on following page

Trail	Raptors	Mammals	Amphibians (documented presence within 200 meters of habitat and trail)	Aquatic habitat buffer (within 200m)	Aquatic habitat buffer (within 100m)	Sensitive Vegetation Communities	Sensitive Plant Species	Invasive Plant Species with Highly Suitable Habitat	Non-native/Invasive Plants Already Present
Army Camp Loop 1	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk, Osprey	bobcat, mountain lion, coyote, gray fox, badger, mule deer	Arboreal salamander	Y	Y	N/A	Gaviota Tarplant	Black Mustard, Iceplant, Perennial Veldtgrass	Non-native grassland
Army Camp Loop 2	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk, Osprey	bobcat, mountain lion, coyote, gray fox, badger, mule deer	Arboreal salamander	Y	Y	N/A	Gaviota Tarplant	Black Mustard, Iceplant, Perennial Veldtgrass	Non-native grassland
Army Camp to Bunker	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk, Osprey	bobcat, mountain lion, coyote, gray fox, badger, mule deer	N/A	Y	Y	N/A	Gaviota Tarplant	N/A	Non-native grassland
All Bunker	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk, Osprey	bobcat, mountain lion, coyote, gray fox, badger, mule deer	Arboreal salamander	Y	Y	N/A	Gaviota Tarplant	Black Mustard, Iceplant, Perennial Veldtgrass	Non-native grassland
Coastal Bluffs	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk, Osprey	badger	N/A	N	N	Brownheaded Rush Seeps	Gaviota Tarplant	Black Mustard, Iceplant, Perennial Veldtgrass	Iceplant
Jalachichi Lollipop	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk	bobcat, coyote, gray fox, badger, mule deer	California red-legged frog, Pacific chorus frog	Y	Y	N/A	N/A	Perennial Veldtgrass	Non-native grassland
Jalachichi Loop	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk	gray fox, badger, mule deer	California red-legged frog, Pacific chorus frog	Y	Y	N/A	N/A	Perennial Veldtgrass	Non-native grassland
Jalachichi Oak Grove	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk	bobcat, coyote, gray fox, badger, mule deer	N/A	Y	Y	Purple Needlegrass Grassland	N/A	N/A	Non-native grassland, semi-natural herbaceous stands
Jalachichi Overnight	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk	bobcat, mountain lion, coyote, gray fox, badger, mule deer	California red-legged frog, Pacific chorus frog	Y	Y	La Purissima Manzanita Chaparral, Purple Needlegrass Grassland	La Purissima Manzanita	Perennial Veldtgrass	Non-native grassland, semi-natural herbaceous stands
Jalachichi Pond	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk	bobcat, gray fox, badger, mule deer	California red-legged frog, Pacific chorus frog	Y	Y	Purple Needlegrass Grassland	N/A	Perennial Veldtgrass	Non-native grassland
Research Loop	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk, Osprey	bobcat, mountain lion, coyote, gray fox, badger, mule deer	California red-legged frog	Y	Y	Sawtooth Golden Bush Scrub	N/A	Black Mustard, Iceplant	Non-native grassland, semi-natural herbaceous stands
Water Canyon Loop	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk, Osprey	bobcat, coyote, gray fox, badger, mule deer	N/A	Y	Y	Sawtooth Golden Bush Scrub	N/A	Black Mustard, Iceplant	Non-native grassland, semi-natural herbaceous stands
Water Canyon Outback	Cooper's hawk, Peregrine falcon, Golden eagle, American kestrel, Red-tailed hawk, Osprey	bobcat, coyote, gray fox, badger, mule deer	N/A	Y	Y	N/A	N/A	Black Mustard, Iceplant	Non-native grassland, semi-natural herbaceous stands

A1.3 Table of Complete Weighting Schemes for Education Trails.

This table shows ranks and impact scores of education trails at the Dangermond Preserve. Scores were calculated based on the following weighting scenarios: TNC's Criteria-level & Species-level preferences, TNC's Criteria-level preferences, a baseline of equal weights for the Conservation Criteria, weight assigned to one criterion, much more weight assigned to one criterion than all others, all weight assigned to vegetation or wildlife criteria**,** and weight assigned based on seasonality. Trails were ranked from 1 to 12 based on the impact score determined in each weighting scheme. Ranks are provided with each impact score in parentheses. **Bold** represents the best 4 trails for each weighting scheme, and *italics* represents the worst 4 trails for each weighting scheme. Impact scores were used to categorize trails to have Low (0-1), Moderate (1-2), Moderately High (1-3), and High (3-4) impact. Green denotes a Low impact, yellow denotes a Moderate impact, orange denotes a Moderately High impact, and red denotes a High impact.

Table on following page

Trail Name	Criteria-level & Species-level	Criteria-level	Baseline equal-weights	Amphibians Only	Mammals Only (Species-level)	Mammals Only	Raptors Only (Species-level)	Raptors Only	Vegetation Only	Wildlife Only	Amphibians Much More Important	Mammals Much More Important	Rapotrs Much More Important	Vegetation Much More Important	Fall	Winter	Spring	Summer
Army Camp to Bunker	1(1.46)	1(1.35)	2(1.59)	2(1.23)	3(0.86)	7(0.44)	12(4.00)	9(3.55)	1(1.13)	2(1.74)	2(1.36)	6(0.82)	7(2.89)	1(1.27)	2(1.36)	2(2.23)	3(2.18)	3(2.18)
Army Camp Loop 2	2(1.62)	5(1.56)	6(1.89)	4(1.84)	5(0.93)	12(0.99)	12(4.00)	8(3.55)	3(1.22)	6(2.11)	5(1.87)	12(1.25)	9(2.99)	4(1.45)	5(1.87)	5(2.53)	7(2.29)	7(2.29)
Army Camp Loop 1	3(1.63)	6(1.57)	5(1.88)	5(1.84)	2(0.83)	11(0.99)	12(4.00)	7(3.48)	4(1.25)	5(2.08)	4(1.86)	11(1.24)	8(2.94)	5(1.46)	4(1.86)	4(2.50)	5(2.27)	5(2.27)
Bunker Out and Back	4(1.63)	2(1.51)	3(1.74)	3(1.68)	4(0.93)	10(0.70)	12(4.00)	6(3.35)	5(1.28)	3(1.89)	3(1.71)	8(1.00)	6(2.81)	3(1.43)	3(1.71)	3(2.36)	4(2.19)	4(2.19)
Water Canyon Loop	5(1.71)	3(1.56)	7(1.97)	6(2.64)	7(1.32)	9(0.53)	12(4.00)	10(3.58)	2(1.15)	7(2.23)	6(2.40)	9(1.01)	10(3.04)	2(1.41)	6(2.40)	7(2.87)	6(2.28)	6(2.28)
Coastal Bluffs	6(1.75)	7(1.75)	1(1.50)	1(0.00)	1(0.00)	1(0.00)	12(4.00)	12(4.00)	9(2.00)	1(1.33)	1(0.49)	1(0.49)	11(3.16)	9(1.83)	1(0.49)	1(1.90)	12(2.69)	12(2.69)
Jalachichi Oak Grove	7(1.96)	4(1.56)	4(1.84)	7(3.30)	12(1.90)	5(0.13)	12(4.00)	1(2.59)	6(1.28)	4(2.01)	7(2.84)	2(0.69)	1(2.33)	6(1.46)	7(2.84)	6(2.73)	1(1.91)	1(1.91)
Water Canyon Out and B	8(1.99)	9(1.91)	12(2.46)	12(3.92)	6(1.19)	8(0.53)	12(4.00)	11(3.98)	7(1.34)	12(2.81)	12(3.44)	10(1.20)	12(3.46)	7(1.72)	12(3.44)	12(3.65)	11(2.62)	11(2.62)
Jalachichi Overnight	9(2.15)	8(1.82)	8(2.09)	8(3.62)	10(1.81)	6(0.26)	12(4.00)	2(2.84)	8(1.58)	8(2.25)	8(3.11)	7(0.88)	2(2.58)	8(1.74)	8(3.11)	8(3.00)	2(2.18)	2(2.18)
Jalachichi Lollipop	10(2.42)	10(2.12)	11(2.23)	11(3.84)	8(1.52)	4(0.05)	12(4.00)	4(3.00)	10(2.03)	11(2.29)	11(3.29)	5(0.76)	5(2.73)	10(2.09)	11(3.29)	11(3.17)	8(2.45)	8(2.45)
Jalachichi Loop	11(2.45)	12(2.16)	10(2.22)	10(3.8)	9(1.58)	2(0.00)	12(4.00)	3(3.00)	12(2.10)	10(2.26)	10(3.26)	3(0.73)	4(2.73)	12(2.13)	10(3.26)	10(3.15)	10(2.48)	10(2.48)
Jalachichi Pond	12(2.47)	11(2.15)	9(2.21)	9(3.74)	11(1.82)	3(0.01)	12(4.00)	5(3.00)	11(2.09)	9(2.25)	9(3.22)	4(0.74)	3(2.73)	11(2.13)	9(3.22)	9(3.13)	9(2.47)	9(2.47)

0 -1 green - Low
1-2 yellow - Moderate
2-3 orange - Moderately High
3-4 red - High

APPENDIX II. TECHNICAL APPENDIX

A2.1 VEGETATION

A2.1.1 Data Preparation for MaxEnt

Species Presence Points

The Excel files were converted to comma separated value files (.csv) to prepare for data cleaning in RStudio. Within R, the datasets were filtered to include the date collected, longitude, and latitude for observations collected in the year 2000 and onward. Observations collected prior to 2000 were excluded due to uncertainty in consistent data collection and reporting methods. The .csv's were then added to ArcGIS to convert the latitude and longitude coordinates from decimal degrees into meters, which ensured that the presence points were in the same projection as the rest of the input data.

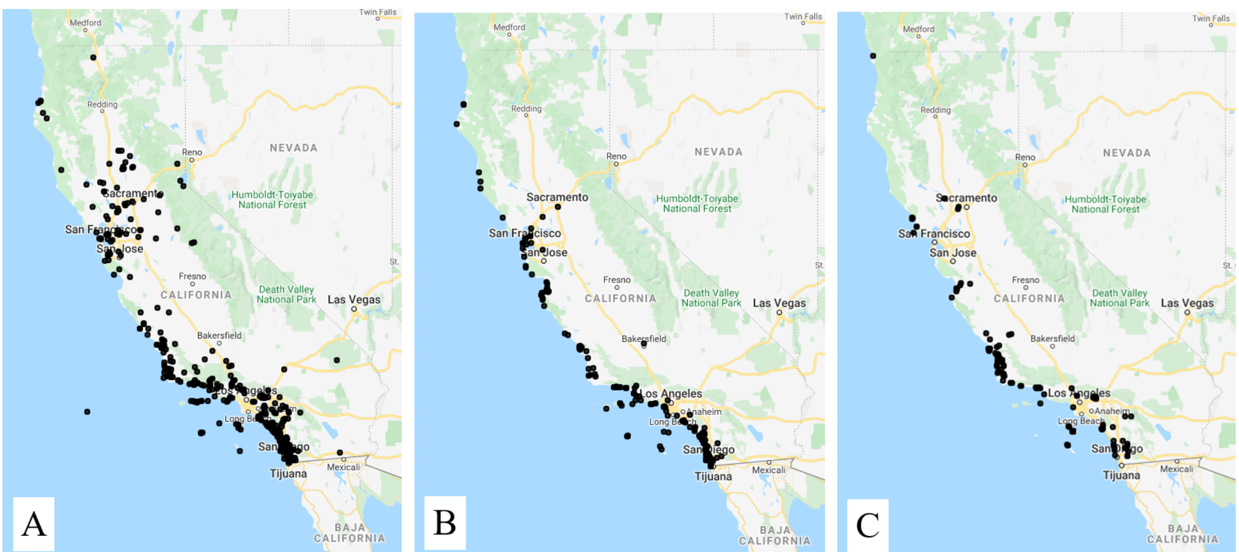

Figure A2.1: Species Presence Points for Three Invasive Plant Species in California from 2000-2019, A) Black Mustard (*Brassica nigra*), B) Iceplant (*Carpobrotus edulis*), and C) Perennial Veldtgrass (*Ehrharta calycina*). Data source: Consortium of California Herbaria, UC Berkeley.

Climate Data

This dataset was downloaded as a Raster Layer GeoTIFF (.tif file) from the California Climate Commons website, then reprojected into the NAD 1983 2011 California Teale Albers projection with a cell size of 30x30. The raster was then clipped to the California extent and converted to an ASCII file (.ascii) in preparation for MaxEnt.

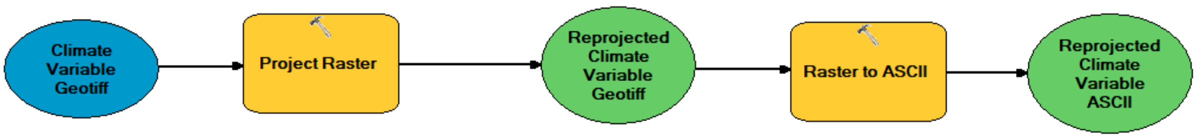

Figure A2.2: Model used to prepare climate data for MaxEnt analysis.

Soil Data

These attributes were selected based on the completeness of the data and usefulness for modeling species distributions of plants. The STATSGO2 dataset was originally downloaded as a Feature Layer shapefile. The soil texture and soil drainage class attributes were then converted to rasters, reprojected from WGS84 to NAD 1983 2011 California Teale Albers, clipped to the California extent and cell size (30x30), and converted to an ASCII file (.ascii).

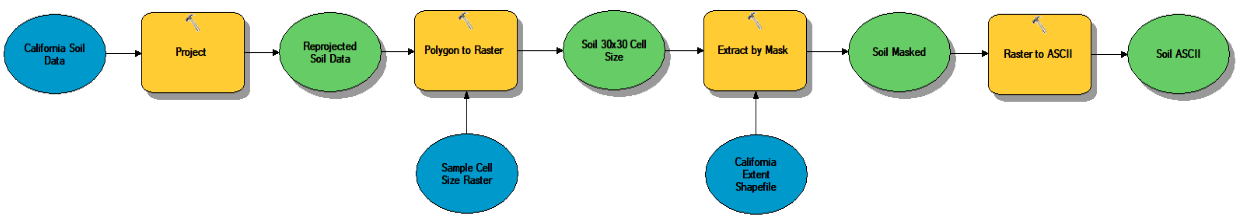

Figure A2.3: Model used to prepare soil data for MaxEnt analysis.

Elevation Data

Open Topography does not have a California-wide 30-meter DEM, and therefore elevation data was downloaded for three different regions in California and then clipped together using the Mosaic to New Raster Tool in ArcGIS. The DEM was then reprojected from WGS84 to NAD 1983 2011 California Teale Albers, clipped to the California extent and 30x30 cell size, and converted to an ASCII file (.ascii).

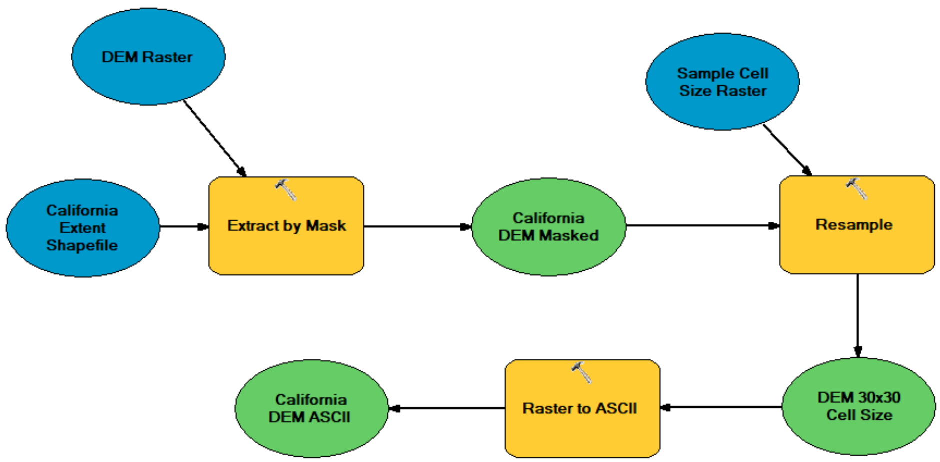

Figure A2.4: Model used to prepare DEM data for MaxEnt analysis.

Presence Point Data

The species presence point data was projected into NAD83 2011 California Teale Albers. The attribute table was converted to an Excel spreadsheet (.csv).

Figure A2.5: Model used to reproject invasive species presence points for MaxEnt analysis.

A2.1.2 MaxEnt Analysis

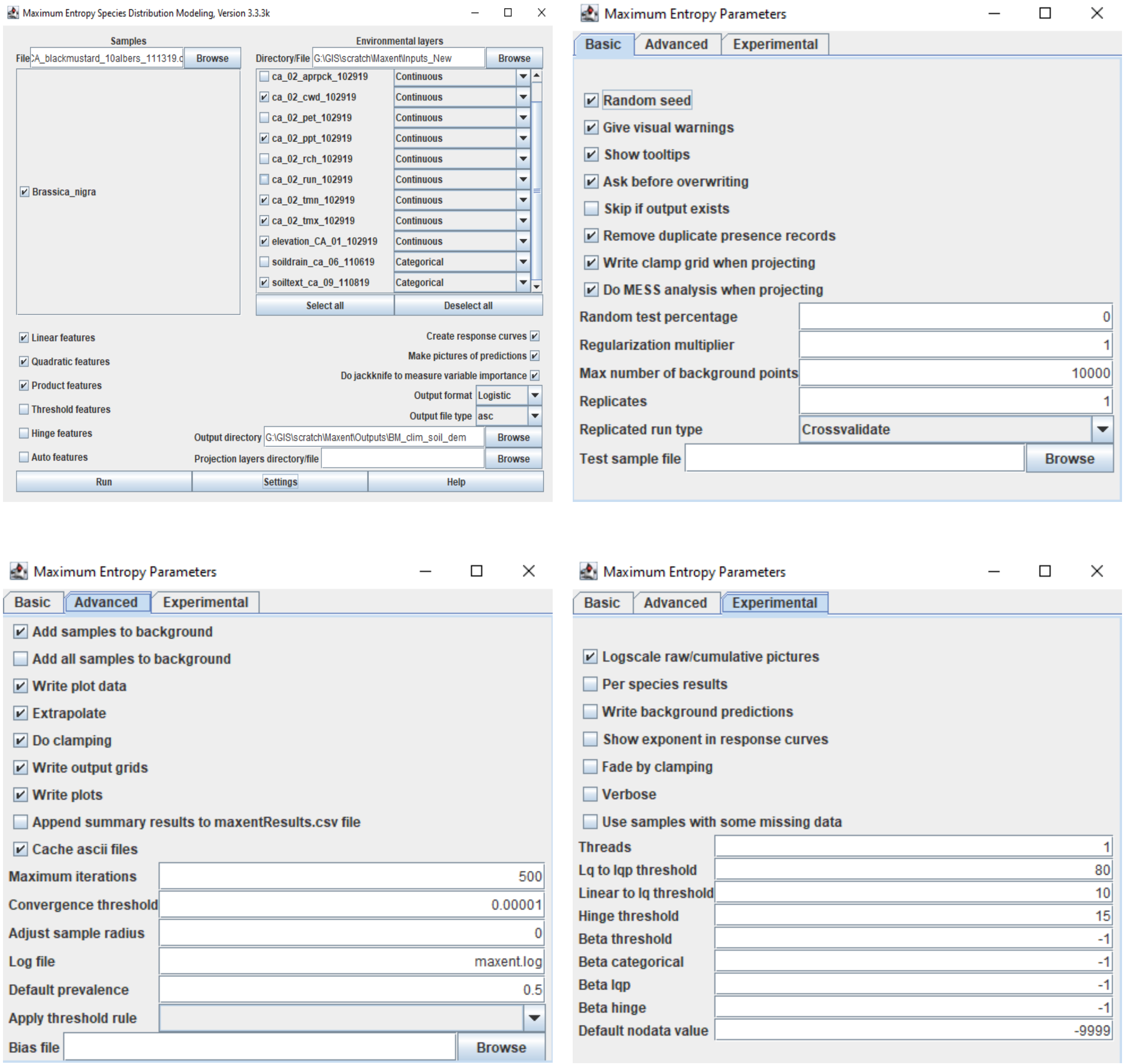

Figure A2.6: MaxEnt parameters used to model the habitat suitability for three invasive plant species on the Dangermond Preserve.

Table A2.1: Climate variables considered for MaxEnt analysis to model the habitat suitability for three invasive plant species on the Dangermond Preserve. Data source: 2014 California Climate Commons Basin Characterization Model (BCM).

Climate Data	Source	Selected
Actual Evapotranspiration	BCM	No
April 1 Snowpack	BCM	No
Climate Water Deficit	BCM	Yes
Maximum Monthly Temperature	BCM	No
Minimum Monthly Temperature	BCM	Yes
Potential Evapotranspiration	BCM	No
Precipitation	BCM	Yes
Recharge	BCM	No
Runoff	BCM	No

Table A2.2: Soil variables considered for MaxEnt analysis to model the habitat suitability for three invasive plant species on the Dangermond Preserve. Data source: State Soil Geographic Database (STATSGO2).

Soil Data	Source	Selected
Dominant soil series	STATSGO2	No
Series, family, etc.	STATSGO2	No
Dominant drainage class	STATSGO2	No
B horizon modifying suffix	STATSGO2	No
Soil taxonomic group	STATSGO2	No
Soil order	STATSGO2	No
Soil great group	STATSGO2	No
Dominant texture	STATSGO2	Yes
Dominant mineralogy	STATSGO2	No
Salt accumulations	STAGSGO2	No
Soil climate regime	STATSGO2	No

Variable	Percent contribution	Permutation importance
ca_02_tmn_102919	39.4	29.5
soiltext_ca_09_110819	27.4	1.6
elevation_CA_01_102919	19.8	46.2
ca_02_cwd_102919	8.9	7.5
ca_02_ppt_102919	4.2	14.8
ca_02_tmx_102919	0.4	0.3

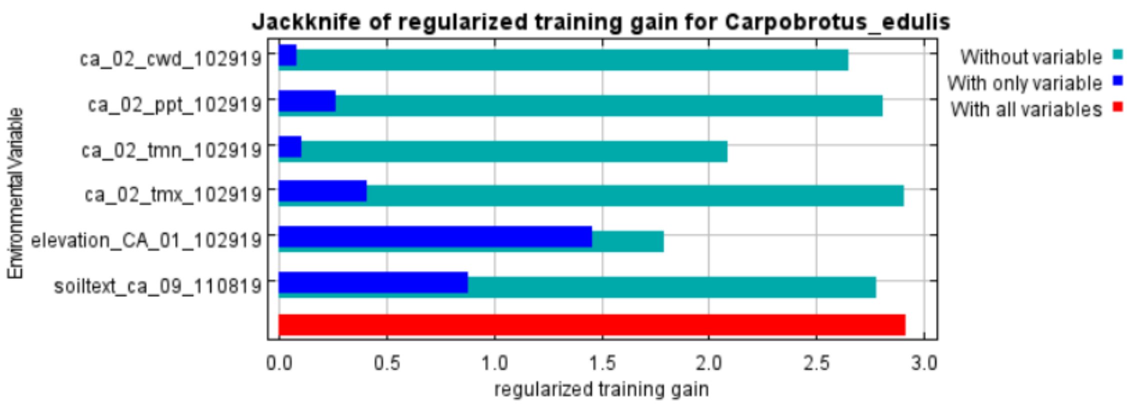

Figure A2.7: Jackknifing Results from MaxEnt Analysis for Iceplant (*Carpobrotus edulis)*.

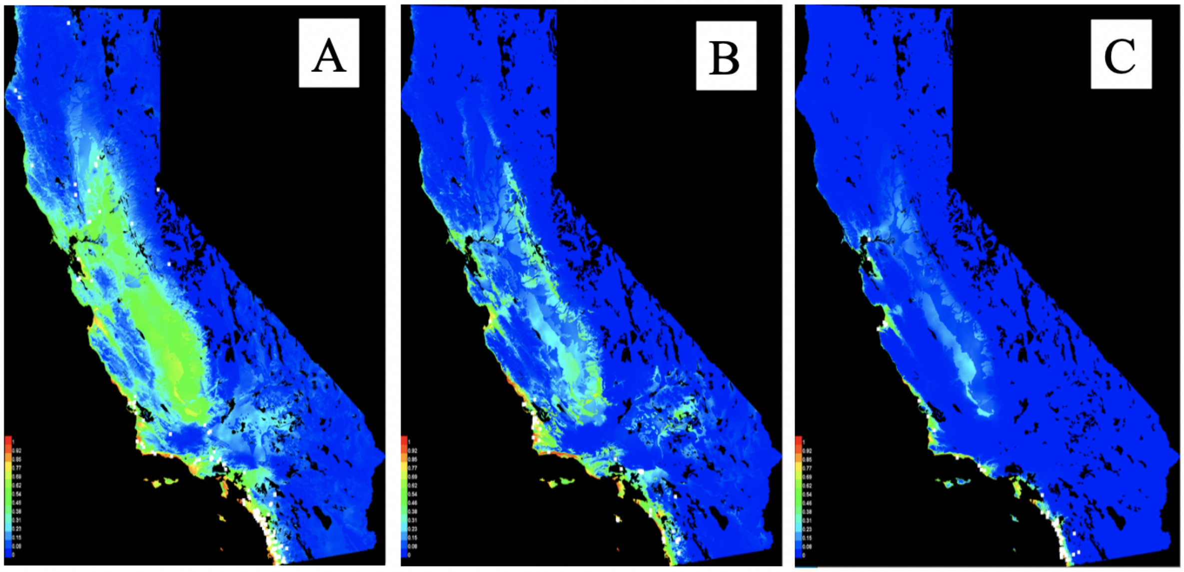

Figure A2.8 MaxEnt outputs for three invasive plant species in California, A) black mustard (*Brassica nigra*), B) iceplant (*Carpobrotus edulis*), and C) perennial veldtgrass (*Ehrharta calycina*). The habitat suitability for all three invasive plant species tends to be highest near the south and central coast of California (red), and lowest in inland and high elevation areas (blue).

A2.1.3 - Hotspot Analysis

Table A2.3: Sensitive vegetation communities on the Dangermond Preserve. Data source: WRA, Inc. 2017

Baltic and Mexican Rush Marshes	Giant Coreopsis Scrub
Bishop Pine Forest	Giant Wild Rye Grassland
Brownheaded Rush Seeps	Holly Leaf Cherry Chaparral
Bush Monkeyflower Scrub	La Purisima Manzanita Chaparral
California Brittle Bush Scrub	Lemonade Berry Scrub
California Walnut Groves	Purple Needlegrass Grassland
Cattail Marshes	Sand Dune Sedge Swaths
Creeping Ryegrass Turfs	Sawtooth Golden Bush Scrub
Tanoak Forest	

Table A2.4: Special-status plant species on the Dangermond Preserve. Data source: WRA, Inc. 2017

California Spineflower (*Mucronea californica*)	La Purisima Manzanita (*Arctostaphylos purissima*)
Cliff Aster (*Malacothrix saxatilis*)	Late-flowered Mariposa Lily (*Calochortus fimbriatus*)
Dune Ragwort (*Senecio blochmaniae*)	Nuttall's Milkvetch (*Astragalus nuttallii*)
Gaviota Tarplant (*Deinandra increscens ssp. villosa*)	Southern California Black Walnut (*Juglans californica*)
Surf Thistle (*Cirsium rhothophilum*)	

A hotspot analysis was run for each species separately to get three different outputs. The invasive species habitat suitability was the MaxEnt output map in ASCII format. This was converted to a raster using the ASCII to Raster tool. This raster was then reclassified to find the top 30% of suitable habitat, which served as the threat layer. Within the Reclassify tool, all points lower than the top 30% were changed to NoData values, and the top 30% was given a value of 1. The sensitive vegetation layer was converted from a polygon to a raster. Using the Raster Calculator tool, the invasive species threat layer was intersected with the sensitive vegetation raster. The final output displays vegetation hotspots where the top 30% of suitable habitat for each invasive species intersects with habitat for sensitive plants.

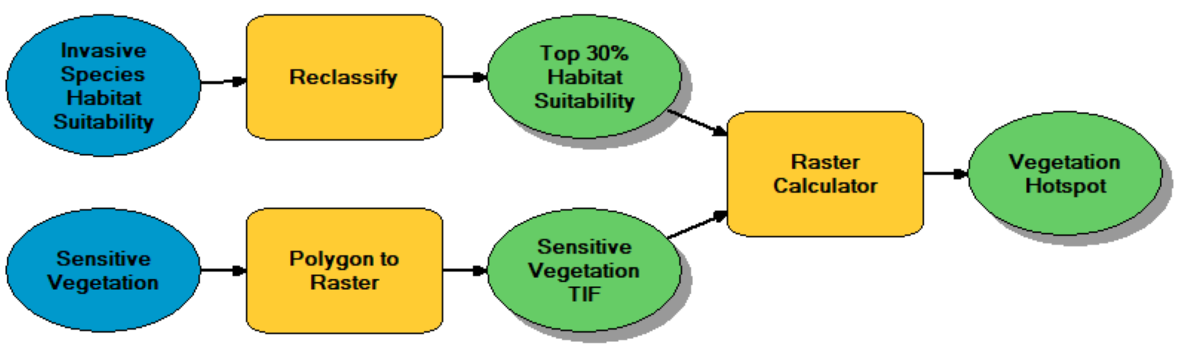

Figure A2.9: Model used to identify vegetation hotspots on the Dangermond Preserve.

A2.2 WILDLIFE

A2.2.1 Sensitive Raptor Analyses

Sensitive Raptor Highly Suitable Habitat Model
Predicted suitable habitat for selected raptor species was downloaded from the California Department of Fish and Wildlife. Each raster layer was projected into NAD 1983 2011 California Teale Albers using the Project Raster tool. Next, each layer was reclassified to filter out to select for only highly suitable habitat (having a suitability of 0.66-1). Finally, the layer was converted into a polygon to be used in subsequent analyses. This model, shown below, can also be used for mammal species.

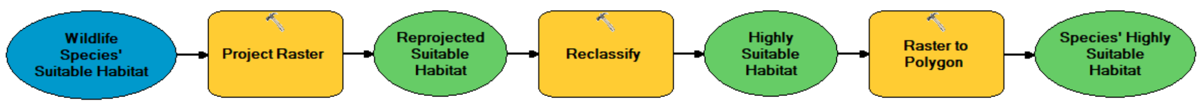

Figure A2.10: Sensitive Wildlife Highly Suitable Habitat Schematic. Highly suitable habitat (66-100%) for each sensitive wildlife species followed the above model. This model applies to sensitive raptors and sensitive mammals.

Sensitive Raptor Ecological Impact Score
The next step was to overlay the highly suitable habitat of each raptor species to determine impact levels across the preserve. The first step in this process was to add buffers to the highly suitable habitat for raptors that corresponds with each species flushing potential. These buffered habitat polygons were then converted into rasters and overlayed using Raster Calculator. Rasters of each species were added together to determine impact levels based on how many species would have the potential to flush from a given raster cell. The reclassify was tool was used to score the impact levels on a scale of 0-4 with 0 representing 0-2 raptor species flushing, 1 representing 3 raptor species flushing, 2 representing 4 raptor species flushing, 3 representing 5 raptor species flushing, and 4 representing 6 raptor species flushing. Finally, Extract by Mask was used to clip the impact bins to the extent of the Dangermond Preserve. This model and maps of each species' highly suitable habitat and flushing zones can be seen below.

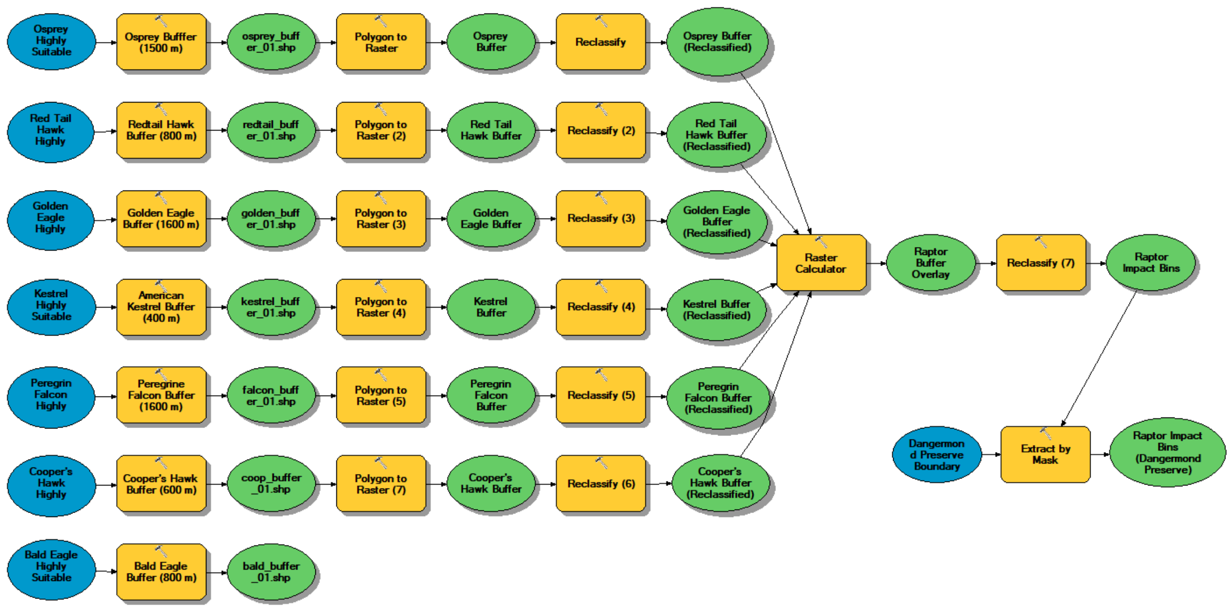

Figure A2.11: Sensitive Raptor Ecological Impact Score Schematic. This model shows the steps for overlaying the highly suitable habitat of each raptor species to determine impact levels across the preserve.

Sensitive Raptor Highly Suitable Habitat and Flushing Zone Maps

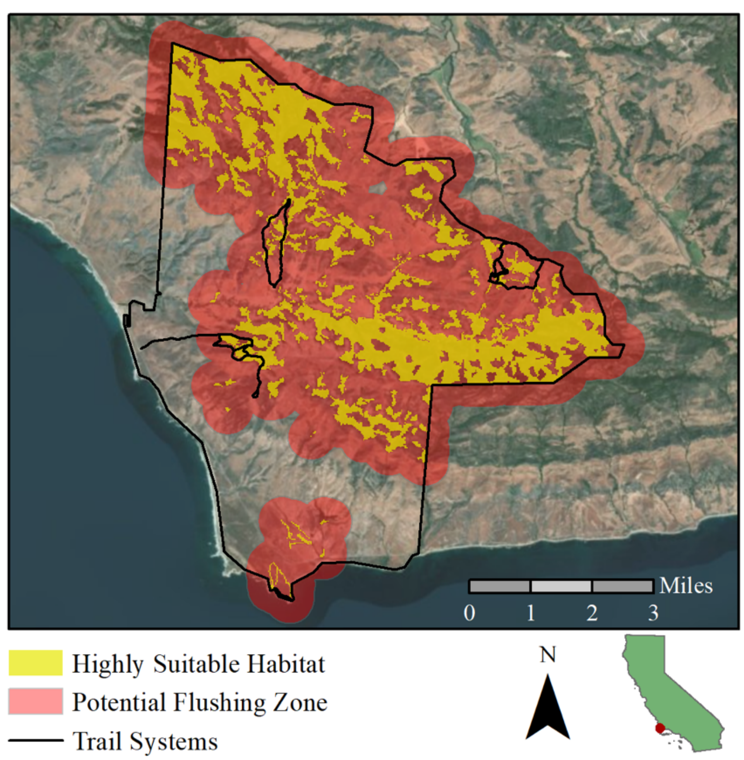

Figure A2.12: Highly Suitable Habitat and Potential Flushing Zones for the Cooper's Hawk (*Accipiter cooperii*) on the Dangermond Preserve.

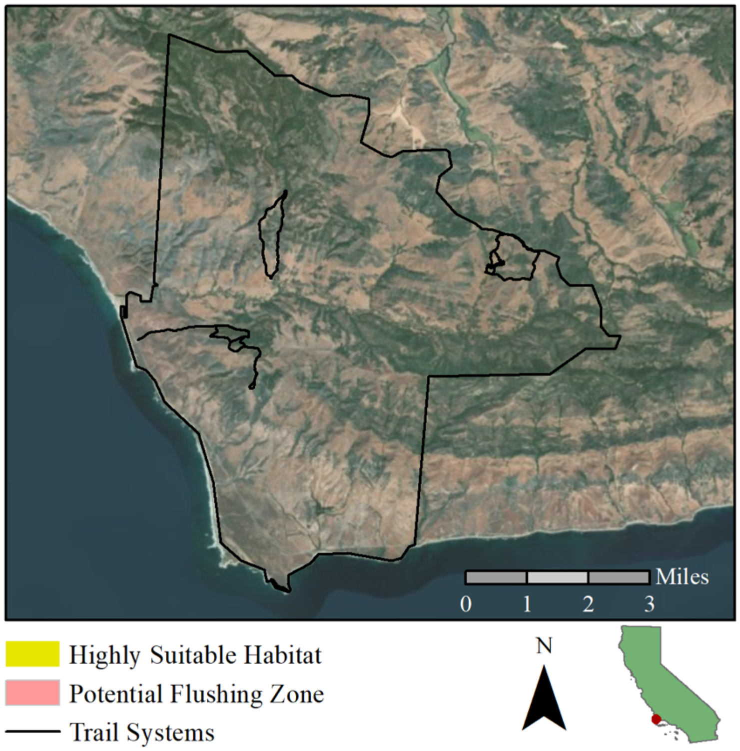

Figure A2.13: Highly Suitable Habitat and Potential Flushing Zones for the Bald Eagle (*Haliaeetus leucocephalus*) on the Dangermond Preserve.

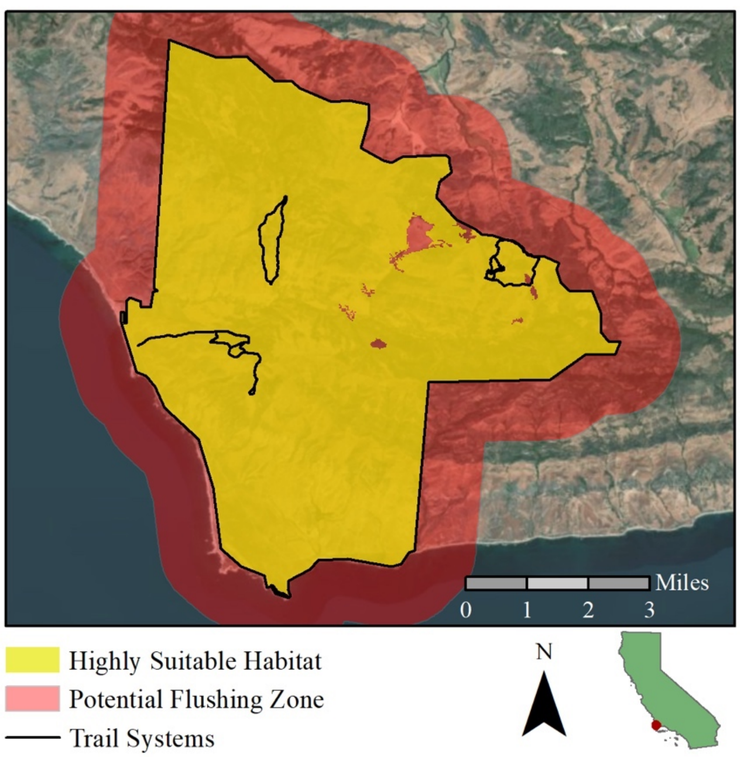

Figure A2.14: Highly Suitable Habitat and Potential Flushing Zones for the Peregrine Falcon (*Falco peregrinus*) on the Dangermond Preserve.

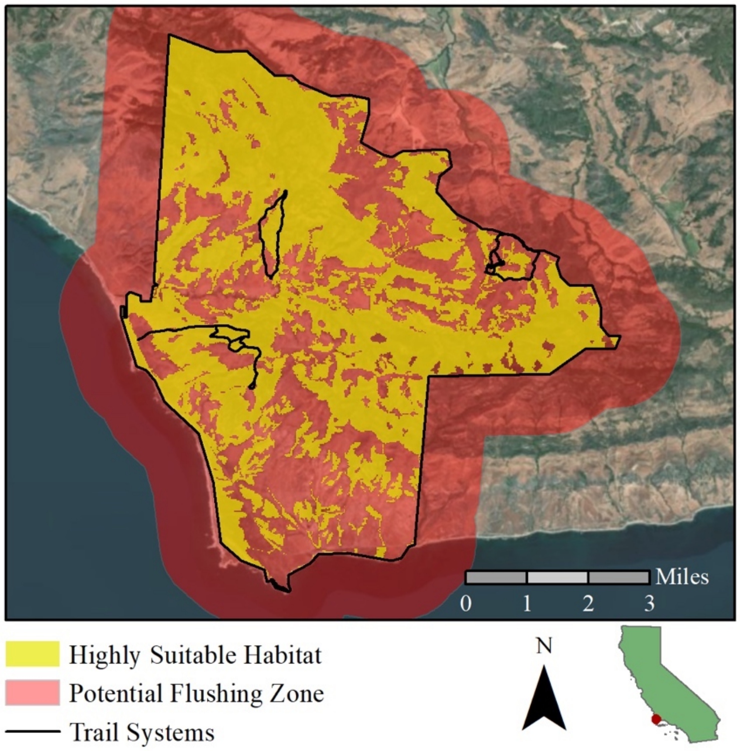

Figure A2.15: Highly Suitable Habitat and Potential Flushing Zones for the Golden Eagle (*Aquila chrysaetos*) on the Dangermond Preserve.

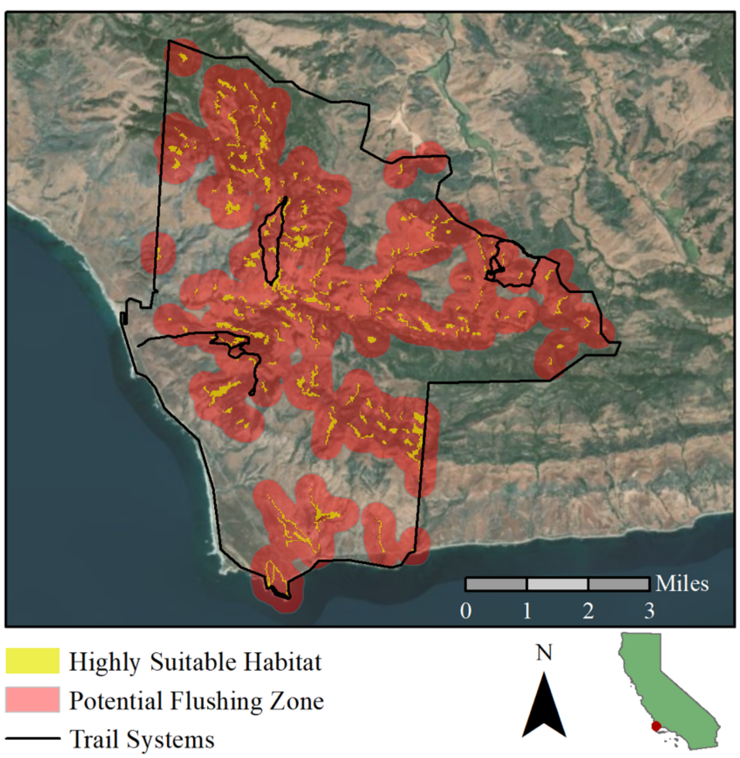

Figure A2.16: Highly Suitable Habitat and Potential Flushing Zones for the American Kestrel (*Falco sparverius*) on the Dangermond Preserve.

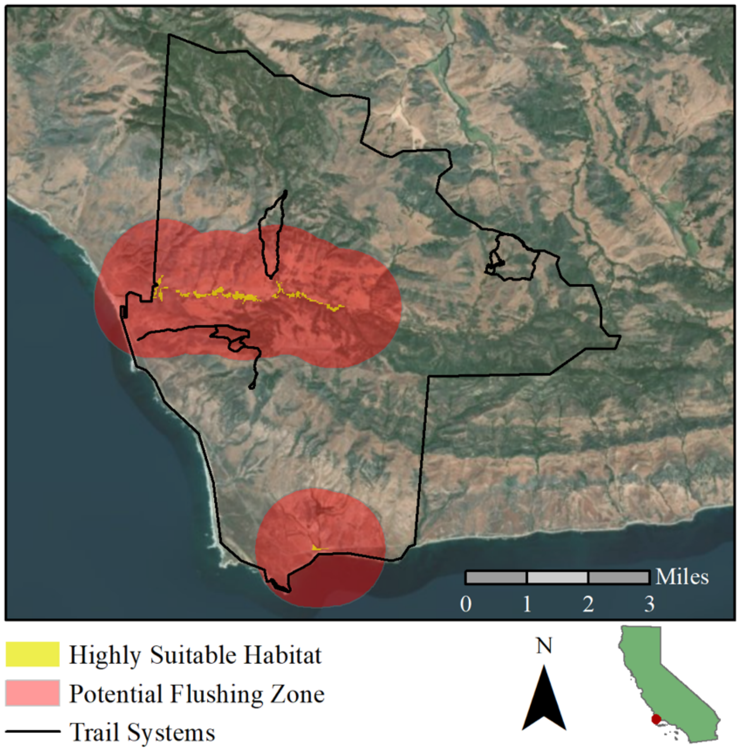

Figure A2.17: Highly Suitable Habitat and Potential Flushing Zones for the Osprey (*Pandion haliaetus*) on the Dangermond Preserve.

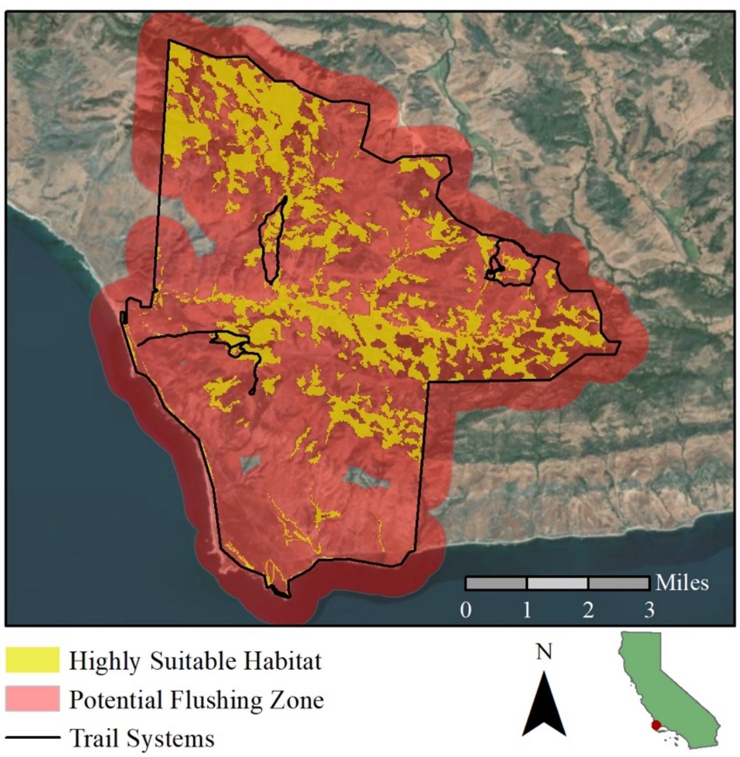

Figure A2.18: Highly Suitable Habitat and Potential Flushing Zones for the Red-tailed Hawk (*Buteo jamaicensis*) on the Dangermond Preserve.

A.2.2 Sensitive Mammals

The same model used to select for highly suitable habitat for raptors was used for mammals. Each mammal species' highly suitable habitat was then overlayed using Raster Calculator. Rasters of each species were added together to determine impact levels based on how many species had highly suitable habitat in a given raster cell. The reclassify was tool was used to score the impact levels on a scale of 0-4 with 0 representing 0-2 mammal species flushing, 1 representing 3 mammal species flushing, 2 representing 4 mammal species flushing, 3 representing 5 mammal species flushing, and 4 representing 6 mammal species flushing. Finally, Extract by Mask was used to clip the impact bins to the extent of the Dangermond Preserve. This model and maps of each species' highly suitable habitat can be seen below.

Sensitive Mammals Ecological Impact Score Model

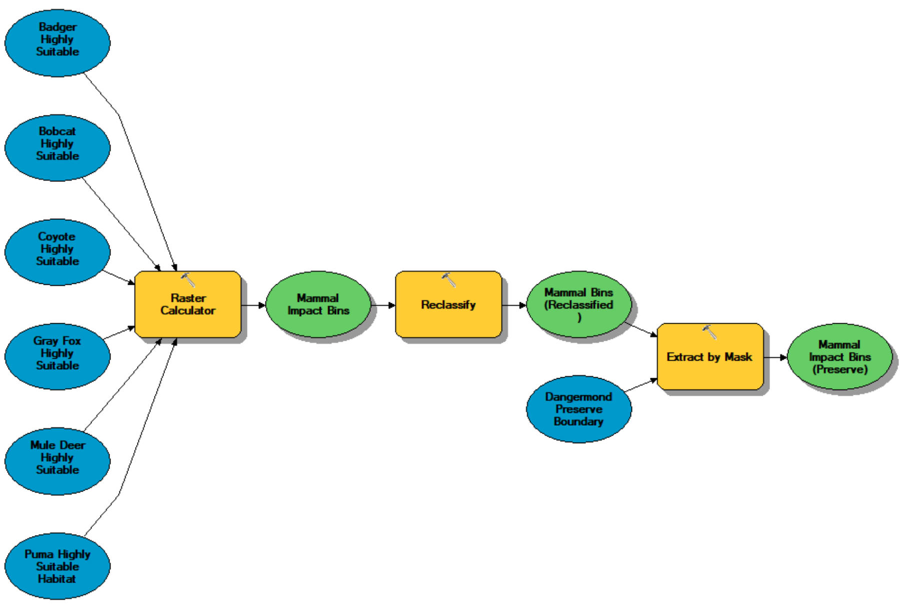

Figure A2.19: Sensitive Mammals Ecological Impact Model Schematic. This model shows the steps for overlaying the highly suitable habitat of each mammal species to determine impact levels across the preserve.

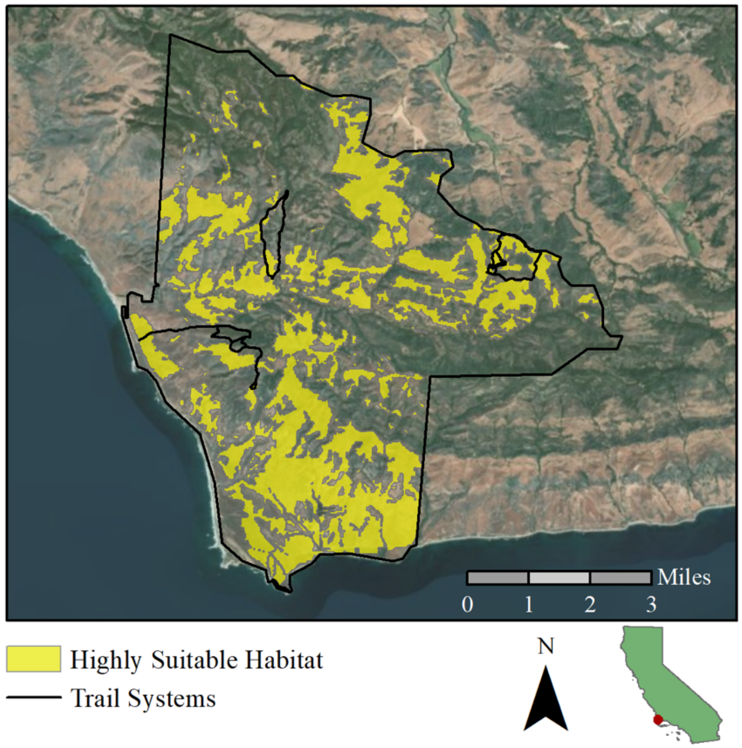

Figure A2.20: Highly Suitable Habitat for the American Badger (*Taxidea taxus*) on the Dangermond Preserve. This map shows the highly suitable habitat (0.66-1) for the American badger, as described by CWHR.

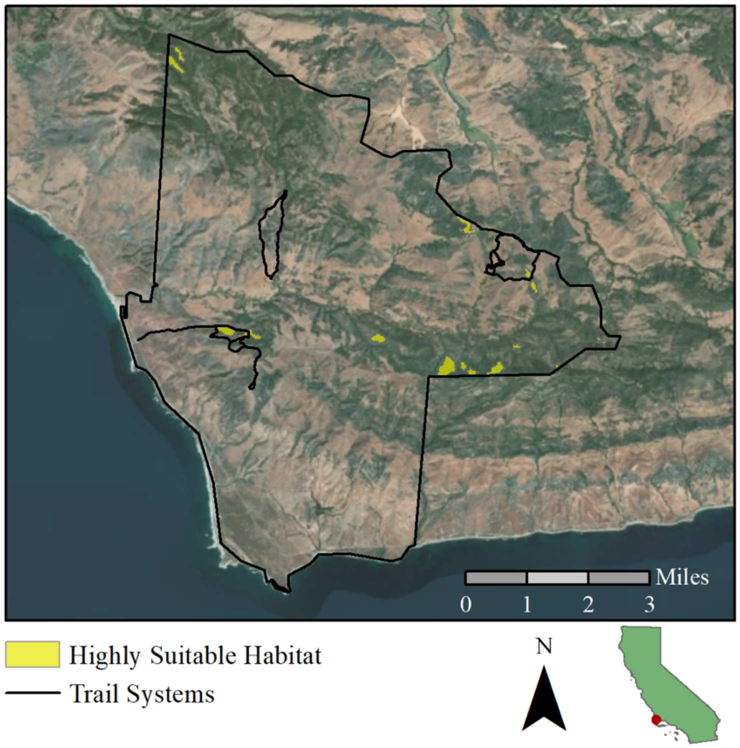

Figure A2.21: Highly Suitable Habitat for the Mountain Lion (*Puma concolor*) on the Dangermond Preserve. This map shows the highly suitable habitat (0.66-1) for the mountain lions, as described by CWHR.

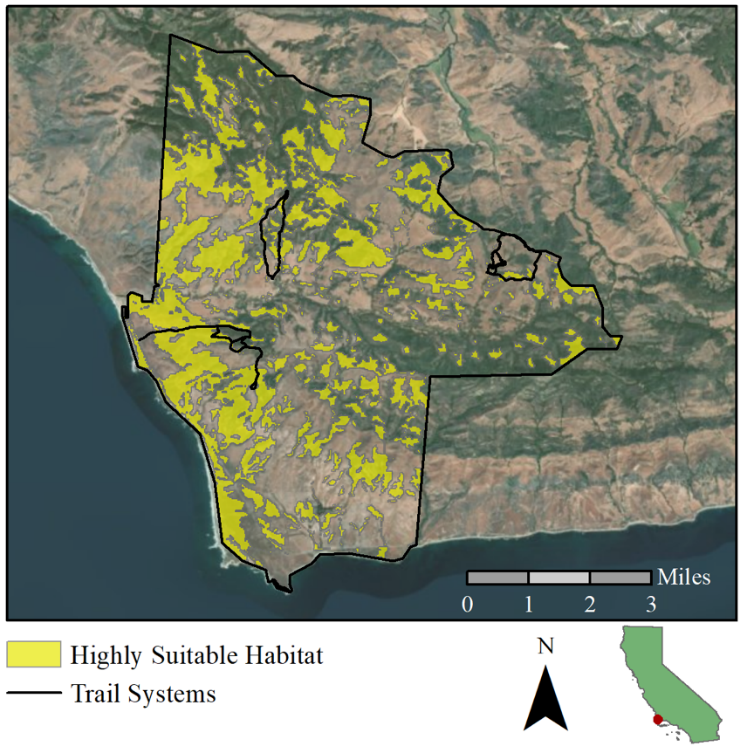

Figure A2.22: Highly Suitable Habitat for the Bobcat (*Lynx rufus*) on the Dangermond Preserve. This map shows the highly suitable habitat (0.66-1) for bobcats, as described by CWHR.

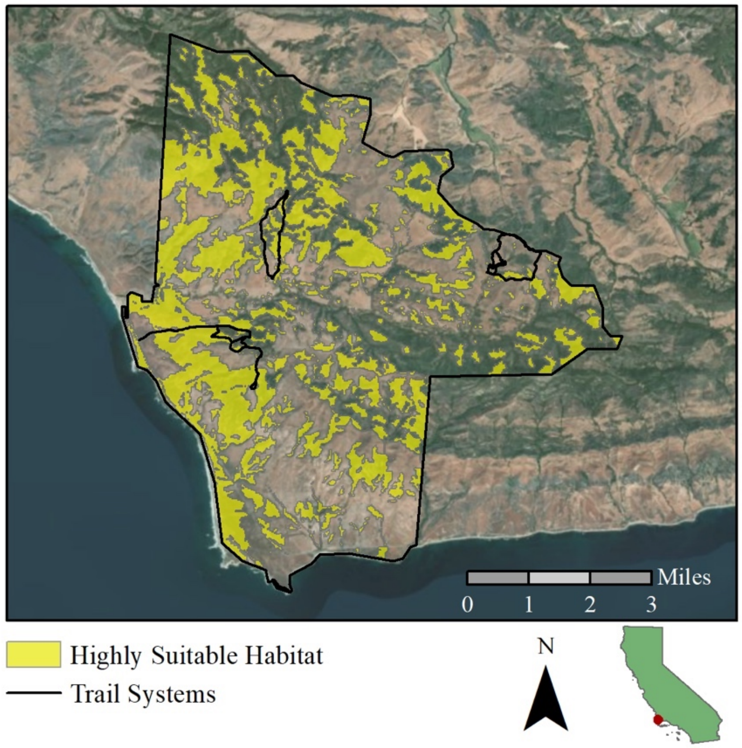

Figure A2.23: Highly Suitable Habitat for the Gray Fox (*Urocyon cinereoargenteus*) on the Dangermond Preserve. This map shows the highly suitable habitat (0.66-1) for the gray fox, as described by CWHR.

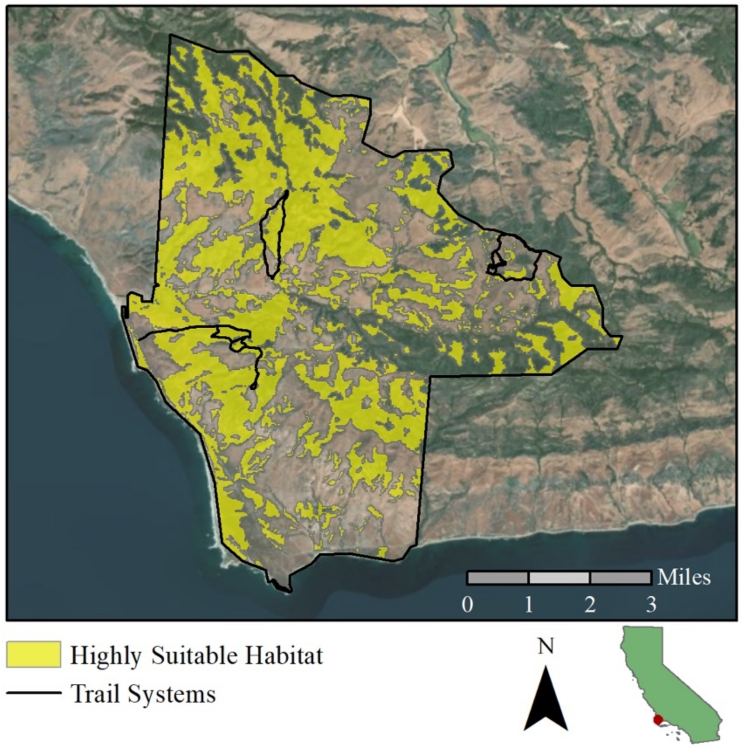

Figure A2.24: Highly Suitable Habitat for the Mule Deer (*Odocoileus hemionus*) on the Dangermond Preserve. This map shows the highly suitable habitat (0.66-1) for mule deer, as described by CWHR.

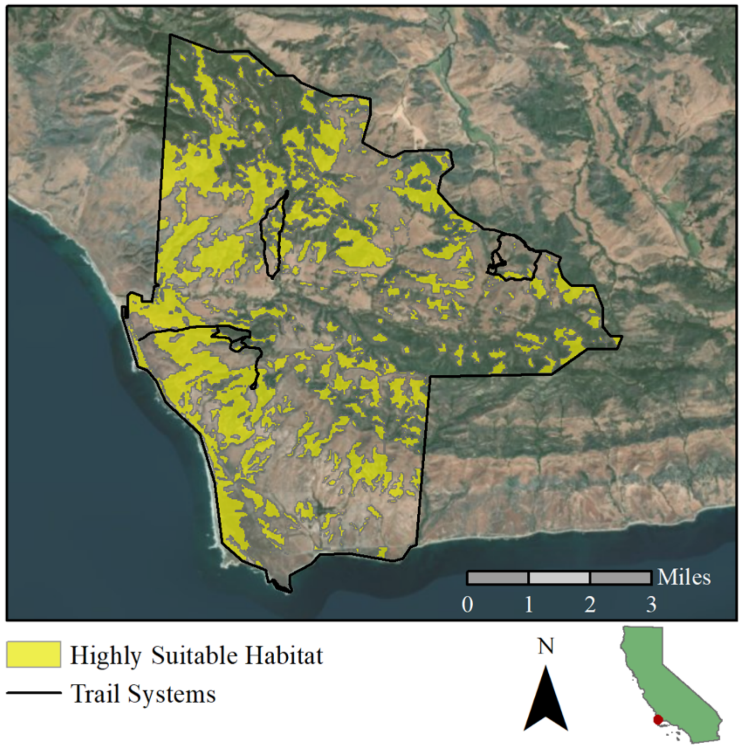

Figure A2.25: Highly Suitable Habitat for the Coyote (*Canis latrans*) on the Dangermond Preserve. This map shows the highly suitable habitat (0.66-1) for coyotes, as described by CWHR.

A.2.3 Sensitive Amphibians

For amphibians, highly suitable habitat was proxied by available stream, trough, and stock pond spatial data. The Multiple Ring Buffer tool was used to create a 100 meter, and 200 meter buffer around each aquatic feature. These buffered features were then merged together, and then dissolved into single features based on buffer distance. This layer, that represents impact levels to amphibians with a smaller buffer distance representing higher impact) was then converted into a raster, and reclassified to score the impact levels on a scale of 0-4 with 0 representing areas at least 200 meters from aquatic habitat, 2 representing areas 100 - 200 meters from aquatic habitat, and 4 representing areas within 100 meters of aquatic habitat. Finally, Extract by Mask was used to clip the impact bins to the extent of the Dangermond Preserve. This model and maps of each species' highly suitable habitat (where available) and presence points can be seen below.

Sensitive Amphibian Ecological Impact Score Model

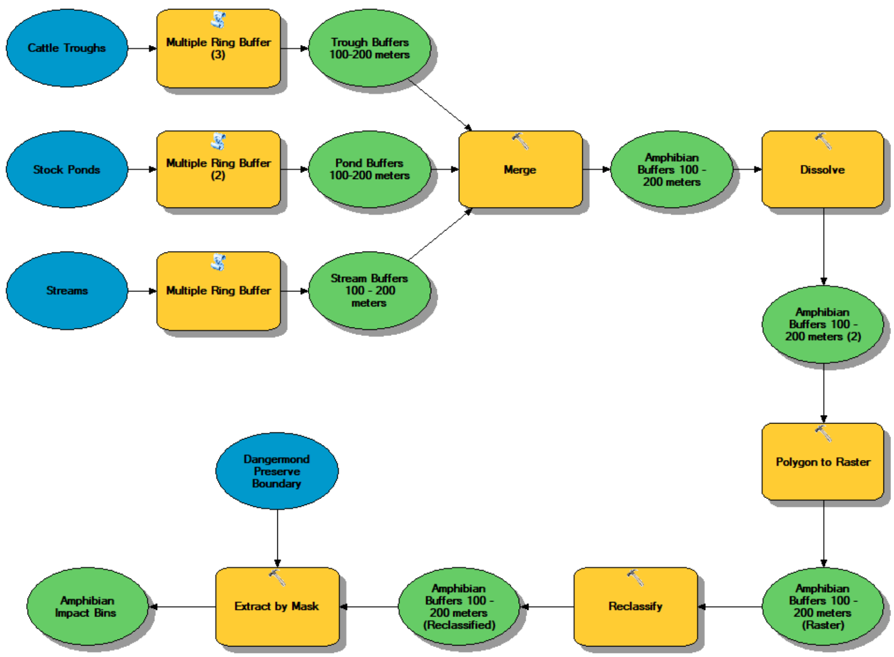

Figure A2.26: Sensitive Amphibians Ecological Impact Model Schematic. This model shows the steps for creating a 100 meter and 200 meter buffer around suitable habitat for sensitive amphibians and then creating an ecological impact layer.

Sensitive Amphibian Highly Suitable Habitat Maps

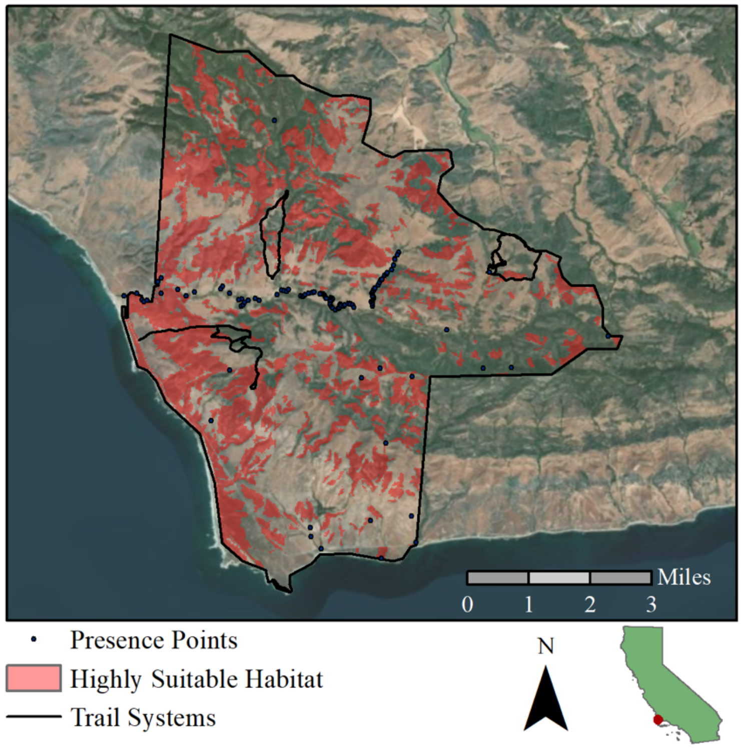

Figure A2.27: Species Presence Points and Highly Suitable Habitat for the California Red-Legged Frog (*Rana draytonii*) on the Dangermond Preserve. This map shows the highly suitable habitat (0.66-1) for the California red-legged frog, as described by CWHR.

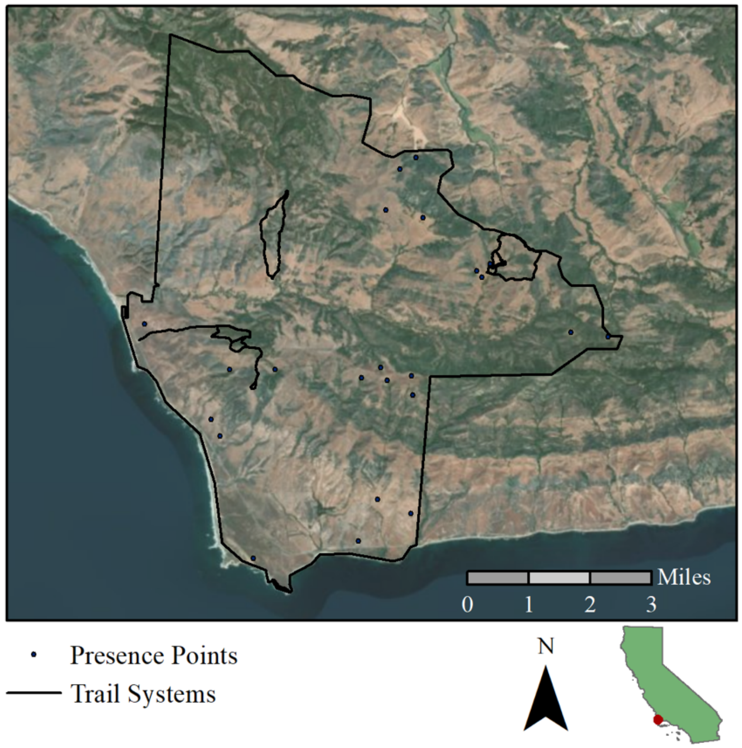

Figure A2.28: Species Presence Points for the Pacific Chorus Frog (*Pseudacris regilla*) on the Dangermond Preserve. This map shows the highly suitable habitat (0.66-1) for the Pacific chorus frog, as described by CWHR.

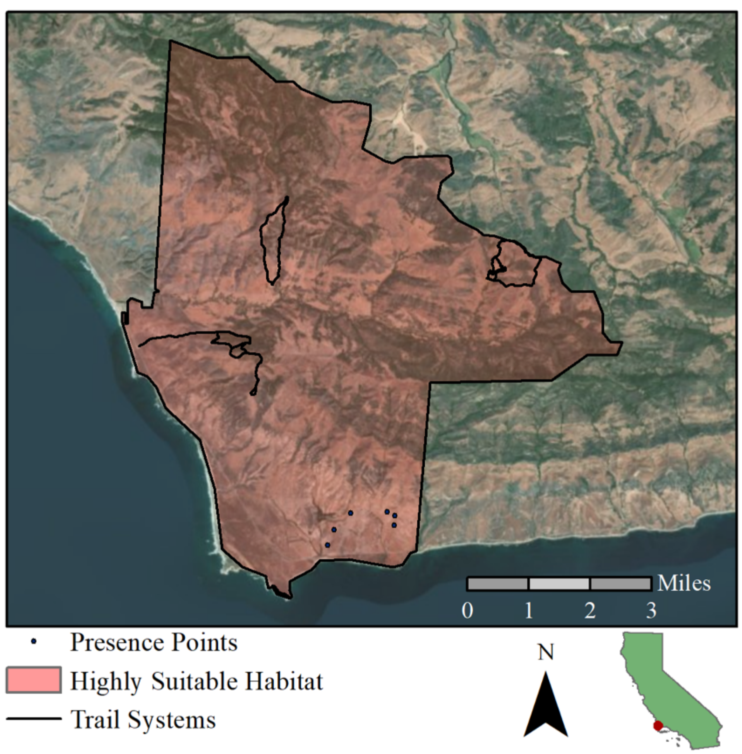

Figure A2.29: Species Presence Points and Highly Suitable Habitat for the Western Toad (*Anaxyrus boreas*) on the Dangermond Preserve. This map shows the highly suitable habitat (0.66-1) for the American badger, as described by CWHR.

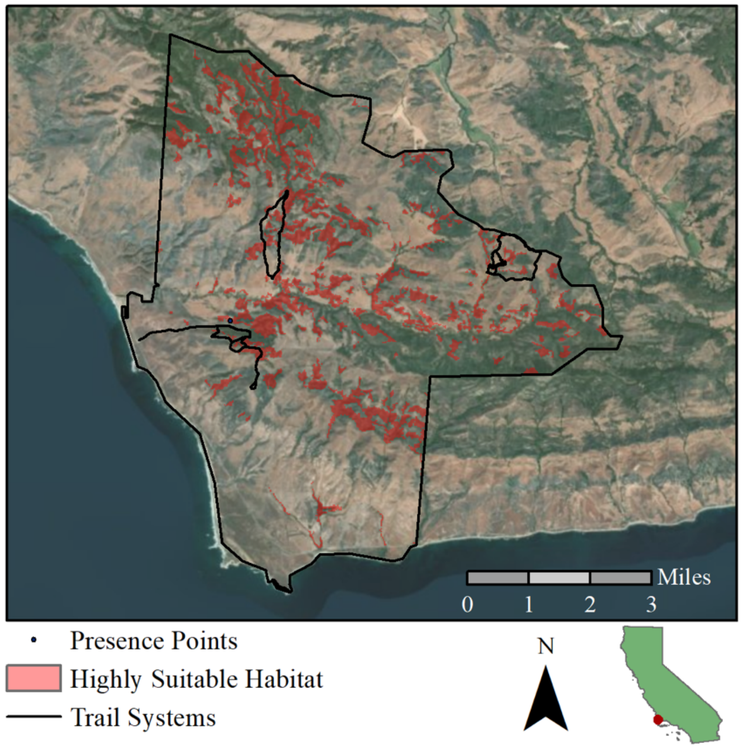

Figure A2.30: Species Presence Points and Highly Suitable Habitat for the Arboreal Salamander (*Aneides lugubris*) on the Dangermond Preserve. This map shows the highly suitable habitat (0.66-1) for the arboreal salamander, as described by CWHR.

A2.3 ANALYTICAL HIERARCHY PROCESS

2.3.1 Conservation Criteria-Level AHP and Associated Survey

The following two pages are the exact survey and technical appendix we sent to staff at The Nature Conservancy, to evaluate their conservation preferences among the Conservation Criteria we included in this project.

Instructions: We are trying to understand the conservation priorities of The Nature Conservancy on the Dangermond Preserve. Please compare the relative importance of the conservation criteria below from the management perspective of the preserve; not as a private individual. Please indicate your responses by circling or highlighting the option you select. *If you have questions as to how we will evaluate these conservation criteria, we've attached a technical description for your reference.*

1. Is it more important to protect sensitive and special-status vegetation or sensitive raptors?

Much more important to protect vegetation than raptors	More important to protect vegetation than raptors	Equally important	More important to protect raptors than vegetation	Much more important to protect raptors than vegetation

2. Is it more important to protect sensitive raptors or sensitive amphibians?

Much more important to protect raptors than amphibians	More important to protect raptors than amphibians	Equally important	More important to protect amphibians than raptors	Much more important to protect amphibians than raptors

3. Is it more important to protect sensitive amphibians or sensitive mammals?

Much more important to protect amphibians than mammals	More important to protect amphibians than mammals	Equally important	More important to protect mammals than amphibians	Much more important to protect mammals than amphibians

Please continue on following page

4. Is it more important to protect sensitive mammals or sensitive and special-status vegetation?

Much more important to protect mammals than vegetation	More important to protect mammals than vegetation	Equally important	More important to protect vegetation than mammals	Much more important to protect vegetation than mammals

5. Is it more important to protect sensitive and special-status vegetation or sensitive amphibians?

Much more important to protect vegetation than amphibians	More important to protect vegetation than amphibians	Equally important	More important to protect amphibians than vegetation	Much more important to protect amphibians than vegetation

6. Is it more important to protect sensitive mammals or sensitive raptors?

Much more important to protect mammals than raptors	More important to protect mammals than raptors	Equally important	More important to protect raptors than mammals	Much more important to protect raptors than mammals

Technical appendix on following pages

Table A2.5. Criteria and associated scores used to identify areas of impact on the Dangermond Preserve. A low score signifies low impact.

Criteria	Attributes	Description	Score
Protecting sensitive and special-status vegetation	Sensitive vegetation hotspot	Sensitive vegetation overlapping with high habitat suitability (70-100%) for one or more invasive plant species	4
	Sensitive vegetation present but not a hotspot	Sensitive vegetation not overlapping with high habitat suitability (70-100%) for one or more invasive plant species	3
	High potential for spread of invasive plant species, but no sensitive vegetation present	High habitat suitability (70-100%) for one or more invasive plant species	2
	Moderate potential for spread of invasive plant species, but no sensitive vegetation present	Moderate habitat suitability (30-70%) for one or more invasive plant species	1
	Low potential for spread of invasive plant species, and no sensitive vegetation present	Low habitat suitability (0-30%) for all three invasive plant species	0
Protecting Sensitive Raptor Populations	Potential for all raptor species to be affected	Overlapping flushing zones for 6 raptor species	4
	Potential for high number of raptor species to be affected	Overlapping flushing zones for 5 raptor species	3
	Potential for moderately high number of raptor species to be affected	Overlapping flushing zones for 4 raptor species	2
	Potential for moderate number of raptor species to be affected	Overlapping flushing zones for 3 raptor species	1

	Potential for low number of raptor species to be affected	Overlapping flushing zones for 0-2 raptor species	0
Protecting Sensitive Mammal Populations	Potential for all mammal species to be affected	Overlapping highly suitable habitat (66-100%) for 6 mammal species	4
	Potential for high number of mammal species to be affected	Overlapping highly suitable habitat (66-100%) for 5 mammal species	3
	Potential for moderately high number of mammal species to be affected	Overlapping highly suitable habitat (66-100%) for 4 mammal species	2
	Potential for moderate number of mammal species to be affected	Overlapping highly suitable habitat (66-100%) for 3 mammal species	1
	Potential for low number of mammal species to be affected	Overlapping highly suitable habitat (66-100%) for 0-2 mammal species	0
Protecting Sensitive Amphibian Populations	High impact to amphibians	Within 0-100m buffer zone around aquatic habitat	4
	Moderate impact to amphibians	Within the 100-200m buffer zone around aquatic habitat	2
	Low to no impact to amphibians	Outside of the 200m buffer zone around aquatic habitat	0

2.3.2 Species-level AHP and Associated Survey: Mammals

The following two pages are the exact survey and technical appendix we sent to staff at The Nature Conservancy, to evaluate their conservation preferences for the mammals we included in the sensitive mammal criterion.

Instructions: We are trying to understand the conservation priorities of The Nature Conservancy on the Dangermond Preserve. Please compare the relative importance of the species below from the management perspective of the preserve; not as a private individual. Please indicate your responses by circling or highlighting the option you select. *If you have questions as to how we will evaluate these conservation criteria, we've attached a technical description for your reference.*

1. How important is the conservation of Badgers?

Somewhat important	Very important	Extremely important

2. How important is the conservation of Mountain Lions?

Somewhat important	Very important	Extremely important

3. How important is the conservation of Bobcats?

Somewhat important	Very important	Extremely important

4. How important is the conservation of Coyotes?

Somewhat important	Very important	Extremely important

5. How important is the conservation of Gray Foxes?

Somewhat important	Very important	Extremely important

6. How important is the conservation of Mule Deer?

Somewhat important	Very important	Extremely important

Technical appendix on following pages

Table A2.6. Criteria and associated scores used to identify areas of ecological impact on the Dangermond Preserve. A low score signifies low impact.

Criteria	Attributes	Description	Score
Protecting Sensitive Mammal Populations	High ecological impact to mammal species	Combined AHP weight of 0.80 – 1.00	4
	Moderately high ecological impact to mammal species	Combined AHP weight of 0.60 – 0.80	3
	Moderate ecological impact to mammal species	Combined AHP weight of 0.40 – 0.60	2
	Moderately low ecological impact to mammal species	Combined AHP weight of 0.20 – 0.40	1
	Low ecological impact to mammal species	Combined AHP weight of 0.00 – 0.20	0

2.3.3 Species-level AHP and Associate Survey: Raptors

The following two pages are the exact survey and technical appendix we sent to staff at The Nature Conservancy, to evaluate their conservation preferences for the raptors we included in the sensitive raptor criterion.

Instructions: We are trying to understand the conservation priorities of The Nature Conservancy on the Dangermond Preserve. Please compare the relative importance of the species below from the management perspective of the preserve; not as a private individual. Please indicate your responses by circling or highlighting the option you select. *If you have questions as to how we will evaluate these conservation criteria, we've attached a technical description for your reference.*

1. How important is the conservation of Cooper's Hawks?

Somewhat important	Very important	Extremely important

2. How important is the conservation of Golden Eagles?

Somewhat important	Very important	Extremely important

3. How important is the conservation of Kestrels?

Somewhat important	Very important	Extremely important

4. How important is the conservation of Ospreys?

Somewhat important	Very important	Extremely important

5. How important is the conservation of Red-tailed Hawks?

Somewhat important	Very important	Extremely important

6. How important is the conservation of Peregrine Falcons?

Somewhat important	Very important	Extremely important

Technical appendix on following pages

Table A2.7. Criteria and associated scores used to identify areas of impact on the Dangermond Preserve. A low score signifies low impact.

Criteria	Attributes	Description	Score
Protecting Sensitive Raptor Populations	High ecological impact to raptor species	Combined AHP weight of 0.80 – 1.00	4
	Moderately high ecological impact to raptor species	Combined AHP weight of 0.60 – 0.80	3
	Moderate ecological impact to raptor species	Combined AHP weight of 0.40 – 0.60	2
	Moderately low ecological impact to raptor species	Combined AHP weight of 0.20 – 0.40	1
	Low ecological impact to raptor species	Combined AHP weight of 0.00 – 0.20	0

Table A2.8: Criteria and associated scores used to identify areas of impact on the Dangermond Preserve. A low score signifies low impact. This table is the combination for the Criteria-level & Species-level Analytical Hierarchy Process.

Criteria	Attributes	Description	Score
Protecting sensitive and special-status vegetation	Sensitive vegetation hotspot	Sensitive vegetation overlapping with high habitat suitability (70-100%) for one or more invasive plant species	4
	Sensitive vegetation present but not a hotspot	Sensitive vegetation not overlapping with high habitat suitability (70-100%) for one or more invasive plant species	3
	High potential for spread of invasive plant species, but no sensitive vegetation present	High habitat suitability (70-100%) for one or more invasive plant species	2
	Moderate potential for spread of invasive plant species, but no sensitive vegetation present	Moderate habitat suitability (30-70%) for one or more invasive plant species	1
	Low potential for spread of invasive plant species, and no sensitive vegetation present	Low habitat suitability (0-30%) for all three invasive plant species	0
Protecting Sensitive Raptor Populations	High ecological impact to raptor species	Combined AHP weight of 0.80 – 1.00	4
	Moderately high ecological impact to raptor species	Combined AHP weight of 0.60 – 0.80	3
	Moderate ecological impact to raptor species	Combined AHP weight of 0.40 – 0.60	2
	Moderately low ecological impact to raptor species	Combined AHP weight of 0.20 – 0.40	1

	Low ecological impact to raptor species	Combined AHP weight of 0.00 – 0.20	0
Protecting Sensitive Mammal Populations	High ecological impact to mammal species	Combined AHP weight of 0.80 – 1.00	4
	Moderately high ecological impact to mammal species	Combined AHP weight of 0.60 – 0.80	3
	Moderate ecological impact to mammal species	Combined AHP weight of 0.40 – 0.60	2
	Moderately low ecological impact to mammal species	Combined AHP weight of 0.20 – 0.40	1
	Low ecological impact to mammal species	Combined AHP weight of 0.00 – 0.20	0
Protecting Sensitive Amphibian Populations	High impact to amphibians	Within 0-100m buffer zone around aquatic habitat	4
	Moderate impact to amphibians	Within the 100-200m buffer zone around aquatic habitat	2
	Low to no impact to amphibians	Outside of the 200m buffer zone around aquatic habitat	0

2.3.4 Analytical Hierarchy Process Calculations

Analytical Hierarchy Process Work Flow

Figure 2.31: Work Flow Schematic for Obtaining Conservation Criteria Weights. This schematic shows the steps we took to determine the weights for each Conservation Criterion. First, we sent surveys out to staff at The Nature Conservancy. We then ran their responses through an Analytical Hierarchy Process, that produced the weights (Goepel 2018).

Analytical Hierarchy Process Survey & Values

1. Is it more important to protect sensitive and special-status vegetation or sensitive raptors?

Much more important to protect vegetation than raptors (9)	More important to protect vegetation than raptors (5)	Equally important (1)	More important to protect raptors than vegetation (5)	Much more important to protect raptors than vegetation (9)

Figure 2.32: Survey Questionnaire and Associated Numerical Values for the Analytical Hierarchy Process. This figure shows the value associated with each potential response from the multiple surveys we sent to staff at The Nature Conservancy. Depending on the answer selected, we then input those values into an online calculator (Goepel 2018).

A2.4 MULTI-CRITERIA ANALYSIS

Once weights were determined by the Analytical Hierarchy Process, the four Conservation Criteria were combined in a weighted overlay using the Raster Calculator tool. This gave a preserve wide impact raster. This raster was multiplied by 100 to preserve decimal places when converting values to integers. The raster was then converted to a polygon layer of preserve impact. This was intersected with a layer of trails. The result was trails divided up into pieces of different impact scores. The length of each impact along a trail was calculated to determine the average impact of a trail.

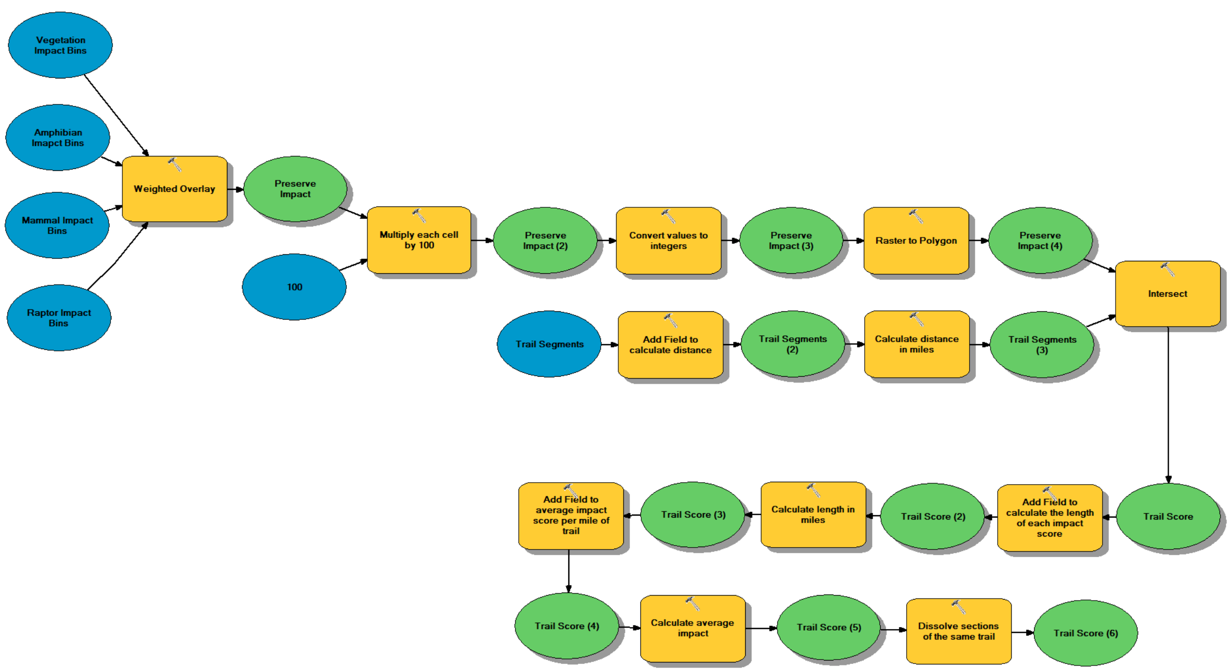

Figure A2.33: Multi-Criteria Analysis Schematic. The model workflow for the Multi-Criteria Analysis to determine trail ranks and ecological impact scores.

A2.5 TRAIL DIFFICULTY

Trail difficulty was determined based on a formula used by the National Park Service (How to Determine Hiking Difficulty - Shenandoah National Park (U.S. National Park Service) 2017).

$$\text{Difficulty} = \sqrt{(Elevation\ gain\ (in\ feet) * 2) * Distance\ (in\ miles)}$$

The Add Surface Information tool was used to determine minimum and maximum elevation of each trail from a 2-meter digital elevation model (DEM) provided by The Nature Conservancy. This was used to determine the elevation gain for the difficulty calculation. A new attribute field was created for the difficulty calculation. Numerical ratings were then classified into five categories: Easiest (0-50), Moderate (50-100), Moderately Strenuous (100-150), Strenuous (150-200), and Very Strenuous (>200).

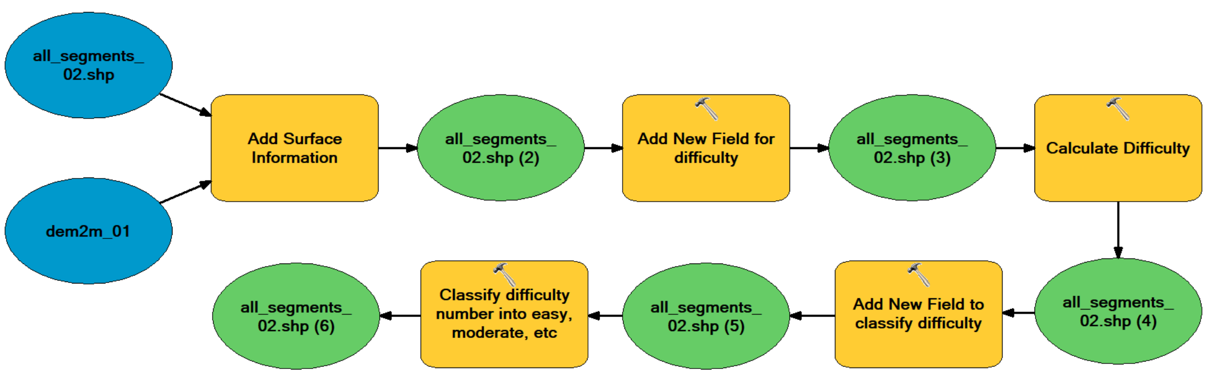

Figure A2.34: Education Trail Difficulty Schematic. This model shows the steps used to calculate the difficulty ranking for each education trail.

A2.6 MANAGEMENT TOOL

The following is the Shiny code used to create the Management Tool. This code can be run using Rstudio.

```
########################################################
######## The Dangermond Preserve Management Tool #######
########################################################

# Created by:
# Tess Hooper and Keene Morrow
# Bren School of Environmental Science & Management
# Winter 2020

########################################################
################ Prepare Workspace & Data ##############
########################################################

#### Attach Packages ####
library(shiny)
library(tidyverse)

## ── Attaching packages ───────────────────────────────────
───────────────── tidyverse 1.3.0 ──

## ✓ ggplot2 3.2.1     ✓ purrr   0.3.3
## ✓ tibble  2.1.3     ✓ dplyr   0.8.3
## ✓ tidyr   1.0.0     ✓ stringr 1.4.0
## ✓ readr   1.3.1     ✓ forcats 0.4.0

## ── Conflicts ────────────────────────────────────────────
───────────── tidyverse_conflicts() ──
## ✖ dplyr::filter() masks stats::filter()
## ✖ dplyr::lag()    masks stats::lag()

library(shinydashboard)

##
## Attaching package: 'shinydashboard'

## The following object is masked from 'package:graphics':
##
##     box

library(janitor)
```

```
##
## Attaching package: 'janitor'

## The following objects are masked from 'package:stats':
##
##     chisq.test, fisher.test

library(chron)

## NOTE: The default cutoff when expanding a 2-digit year
## to a 4-digit year will change from 30 to 69 by Aug 2020
## (as for Date and POSIXct in base R.)

library(lubridate)

##
## Attaching package: 'lubridate'

## The following objects are masked from 'package:chron':
##
##     days, hours, minutes, seconds, years

## The following object is masked from 'package:base':
##
##     date

library(dplyr)

#### Read in Data ####
trails <- read_csv("all_trail_info.csv") %>%
  janitor::clean_names() %>%
  rename(length_miles = length) %>%
  mutate(travel_time = sub(":\\d{2}", "", times((travel_time_mins%/%60
+  travel_time_mins%%60 /3600)/24))) %>%   # make col with HH:MM forma
t for trail travel time
  pivot_longer(7:10, names_to = "season", values_to = "impact_score")

## Parsed with column specification:
## cols(
##   `Trail Name` = col_character(),
##   Length = col_double(),
##   `Travel Time (mins)` = col_double(),
##   Difficulty = col_character(),
##   Landmarks = col_character(),
##   `Vegetation Communities` = col_character(),
##   Fall = col_character(),
##   Winter = col_character(),
##   Spring = col_character(),
```

```
##   Summer = col_character()
## )

######################################################
################### User Interface ##################
######################################################

ui <- dashboardPage(
  dashboardHeader(title = "Dangermond Preserve Trail Management"),

  # Create navigation sidebar
  dashboardSidebar(
    sidebarMenu(
      menuItem("Introduction", tabName = "intro", icon = icon("leaf"))
,
      menuItem("Definition of Terms", tabName = "def", icon = icon("bo
ok-open")),
      menuItem("School Group Information", tabName = "group", icon = i
con("pencil-alt")),
      menuItem("Program Options", tabName = "program", icon = icon("je
di")),
      menuItem("Trail Selection", tabName = "decision", icon = icon("b
alance-scale"))
    )),

  # Create Content Body
  dashboardBody(
    tabItems(
      tabItem(
        tabName = "intro",
        fluidRow(
          # Introduction
          img(src = "live_oaks_dp.jpg", height = 300, width = 500),
          box(width = 300,
              title = strong("Introduction"),
              p("The purpose of this web app is to serve as a decision
-making tool for The Nature Conservancy (TNC) and the preserve manager
s at The Jack and Laura Dangermond Preserve. Through this app, TNC wil
l be able to identify education trails that fit program criteria while
also identifying the ecological impact scores and education opportunit
ies associated with each given trail.", style = "font-family: 'times'
; font-si16pt"),
              br(),
              p("There are five education constraints that have been i
dentified: group size, student age, trail difficulty, trail length, an
d travel time. Based on the user selection, the app will filter out an
```

```
d identify trails that meet the specific program criteria needs. Along
with providing an output of each trail that fits those criteria, the a
pp will also identify the ecological impact score associated with each
trail and the education opportunities available along each trail. The
education opportunities have been identified as landmarks and vegetati
on communities. Scenic landmarks and diversity in vegetation communiti
es can provide rich curricular opportunities for students.", style = "
font-family: 'times' ; font-si16pt"),
              br(),
              strong("How to Use this Tool:"),
              p("The user can toggle between the app windows via the s
idebar menu on the left. Below is an explanation of each tab.", style
= "font-family: 'times' ; font-si16pt"),
              p("1. Definition of Terms: This tab provides information
about the education constraints, education opportunities, and ecologic
al impact score.", style = "font-family: 'times' ; font-si16pt"),
              p("2. School Group Information: This is the first tab wh
ere the user will input information into the web app. The user will in
put the School Group Name, Program Date, Number of Students, and Numbe
r of Teachers/Chaperones.*Note: The Program Date input will prepopulat
e the resulting trail table with the associated seasonal impact score.
", style = "font-family: 'times' ; font-si16pt"),
              p("3. Program Options: This is where the user can change
the criteria for the education program. This includes Trail Difficulty
, Trail Length, Travel Time, Season, and Impact Score.", style = "font
-family: 'times' ; font-si16pt"),
              p("4. Trail Selection: This final tab is where the user
will ultimately select the trail to use for a given environmental educ
ation program after exploring the program options. There is a “Save’'
button on the right side of the tab that will export all of the web ap
p information into a .csv file called “group_info.csv”. This action ca
n be used to monitor how many students & programs take place on each t
rail." , style = "font-family: 'times' ; font-si16pt"),

          )
        )
      ),

      # Definition of Terms
      tabItem(
        tabName = "def",
        fluidRow(
          box(width = 300,
              title = strong("Definition of Terms"),
              strong("Group Size and Age:"),
              p("The education group size and student age will be inpu
```

```
ts provided by the school teacher. At this point these are not constra
ints that filter out certain trails. However, in the future if TNC det
ermines carrying capacities for certain trails, then group size could 
be a filtering constraint.", style = "font-family: 'times' ; font-si16
pt"),
              br(),
              strong("Trail Difficulty:"),
              p("Trail difficulty was determined based on a formula us
ed by the National Park Service for Shenandoah National Park. Difficul
ty for each trail was calculated using elevation change from a 2-meter
digital elevation model (DEM) provided by TNC. Numerical ratings were 
then grouped into five categories: Easiest, Moderate, Moderately Stren
uous, Strenuous, and Very Strenuous. One limitation to using this Nati
onal Park Service equation to calculate difficulty is that it is an av
erage, the equation does not consider elevation gain within a short di
stance along a trail. Therefore, a rating could be considered "Easiest
" from the equation, but due to factors such as quick elevation gain, 
the trail could in actuality be more difficult.", style = "font-family
: 'times' ; font-si16pt"),
              br(),
              strong("Trail Length and Travel Time:"),
              p("Trail length and travel time was verified using the G
aia GPS mobile app and ArcGIS. The Gaia GPS mobile app records distanc
e, total time, and elevation gains. The recorded distances were then c
ross-referenced using ArcGIS.", style = "font-family: 'times' ; font-s
i16pt"),
              br(),
              strong("Landmarks:"),
              p("Scenic landmarks were identified from well-known loca
tions on the Dangermond Preserve. These include Point Conception, Poin
t Conception Lighthouse, Government Point, Army Camp Bunkers, Army Cam
p Wells, and Jalachichi Pond. ", style = "font-family: 'times' ; font-
si16pt"),
              br(),
              strong("Vegetation Communities:"),
              br(),
              p("The vegetation communities include tree-dominated, sh
rub-dominated, and herb-dominated communities on the preserve.", style
= "font-family: 'times' ; font-si16pt"),
              br(),
              strong("Ecological Impact Score:"),
              p("The ecological impact score for each trail was determ
ined using a Multi-Criteria Analysis in ArcGIS. The score refers to th
e ecological impact to four Conservation Criteria: Sensitive Vegetatio
n, Sensitive Raptors, Sensitive Mammals, and Sensitive Amphibians. The
score that is shown in this interactive app reflects the seasonal sens
```

```
itivities of each criteria.", style = "font-family: 'times' ; font-si1
6pt"),
              br(),
              em("**For full methodology, please see the research repo
rt from the group of students at The Bren School for Environmental Sci
ence & Management (University of California, Santa Barbara).** ")
          )
        )
      ),

      # Group Information
      tabItem(
        tabName = "group",
        fluidRow(
          ## Group: Left Side
          box(title = "School Group Information",
              textInput(inputId = "group_name",
                        label = "School Group Name",
                        value = ""),
              dateInput(inputId = "date",
                        label = "Program Date"),
              textInput(inputId = "grade_level",
                        label = "School Grade Level",
                        value = ""),
              numericInput(inputId = "students",
                           label = "Number of Students",
                           value = ""),
              numericInput(inputId = "chaperones",
                           label = "Number of Teachers/Chaperones",
                           value = "")
          )#,
          # box(textOutput(outputId = "date1"))
        )
      ),

      # Program
      tabItem(
        tabName = "program",
        fluidRow(
          ## Program: Left Side
          box(width = 4,
              title = "Program Options",
              checkboxGroupInput(inputId = "trail_diff",
                                 label = "Select trail difficulty:",
                                 choices = c("Easy",
                                             "Moderate",
```

```
                                                "Difficult"),
                                  selected = "Easy"),
              # Trail length slider (miles)
              sliderInput(inputId = "trail_len",
                          label = "Select trail length in miles:",
                          min = 0,
                          max = 7,
                          value = c(0.5, 2.5),
                          step = 0.5,
                          round = FALSE,
                          # post = " miles",
                          ticks = TRUE,
                          animate = FALSE),

              # Travel time slider (minutes)
              sliderInput(inputId = "trail_time",
                          label = "Select travel time:",
                          min = 0,
                          max = 4,
                          value = c(0.5, 3),
                          step = .5,
                          round = TRUE,
                          post = " hours",
                          ticks = TRUE,
                          animate = FALSE),
          ),

          ## Program: Right Side
          box(width = 8,
              tableOutput(outputId = "trail_table")))
      ),

      # Trail Selection
      tabItem(
        tabName = "decision",
        fluidRow(
          ## Trail Selection: Left Side
          box(width = 3,
              title = "Trail Selection",
              radioButtons("trail_final", label = "Select:",
                           choices = c("Bunker Out and Back",
                                       "Army Camp Loop 1",
                                       "Army Camp Loop 2",
                                       "Army Camp to Bunkers",
                                       "Coastal Bluffs",
                                       "Jalachichi Pond",
```

```
                                          "Jalachichi Lollipop",
                                          "Jalachichi Loop",
                                          "Jalachichi Oak Grove",
                                          "Jalachichi Overnight",
                                          "Water Canyon Loop",
                                          "Water Canyon Out and Back"),
                            selected = "Bunker Out and Back")), # defau
lt selection of radio buttons
          ## Trail Selection: Right Side
          box(width = 9,
              # summary table
              tableOutput(outputId = "new_info"),
              # save button
              actionButton("save_csv", label = "Save")
          )
        )
      )
    )
  )
)
#### End UI ####

#######################################################
######################## Server ######################
#######################################################

server <- function(input, output, session){

  # Create table to display on the Program Options tab
  trails_group <- reactive({
    trails %>%
      # Filter table contents based on inputs
      dplyr::filter(difficulty %in% input$trail_diff,
                    length_miles >= input$trail_len[1],
                    length_miles <= input$trail_len[2],
                    travel_time_mins >= input$trail_time[1]*60,
                    travel_time_mins <= input$trail_time[2]*60,
                    season == case_when(
                      month(input$date) %in% c(09, 10, 11) ~ "fall",
                      month(input$date) %in% c(12, 01, 02) ~ "winter",
                      month(input$date) %in% c(03, 04, 05) ~ "spring",
                      month(input$date) %in% c(06, 07, 08) ~ "summer"
                    )) %>%
      # Select table contents
      dplyr::select(trail_name,
                    difficulty,
```

```r
                    length_miles,
                    travel_time,
                    landmarks,
                    vegetation_communities,
                    impact_score) %>%
      # Update the column names
      rename("Trail Name" = trail_name,
             "Difficulty" = difficulty,
             "Length (Miles)" = length_miles,
             "Travel Time" = travel_time,
             "Impact Score" = impact_score,
             "Landmarks" = landmarks,
             "Vegetation" = vegetation_communities
      )
  })

  # Prepare table for display on the Program Options tab
  output$trail_table <- renderTable({
    trails_group()
  })

  # Create table for display on the Trail Selection tab
  new_info <- reactive({
    # create data frame with input and selected information
    cbind(
      data.frame(save_date = as.Date(Sys.Date(),
                                     format = "%B %d %Y"),
                 # Group Info
                 group_name = input$group_name,
                 date = lubridate::as_date(input$date),
                 students = input$students,
                 chaperones = input$chaperones,
                 season = case_when(
                   month(input$date) %in% c(09, 10, 11) ~ "Fall",
                   month(input$date) %in% c(12, 01, 02) ~ "Winter"
,
                   month(input$date) %in% c(03, 04, 05) ~ "Spring"
,
                   month(input$date) %in% c(06, 07, 08) ~ "Summer"
                 ),
                 # Select trail
                 trail_name = input$trail_final
      ),
      # Impact score of selected trail for season of program
      filter(trails,
             trail_name == input$trail_final,
```

```
            season == case_when(
              month(input$date) %in% c(09, 10, 11) ~ "fall",
              month(input$date) %in% c(12, 01, 02) ~ "winter",
              month(input$date) %in% c(03, 04, 05) ~ "spring",
              month(input$date) %in% c(06, 07, 08) ~ "summer"
            ))[9])
  })

  # Prepare table for display on the Trail Selection tab
  output$new_info <- renderTable({
    rename(new_info(),
           "Save Date" = save_date,
           "Group Name" = group_name,
           "Program Date" = date,
           "Number of Students" = students,
           "Number of Chaperones" = chaperones,
           "Season" = season,
           "Trail" = trail_name,
           "Impact Score" = impact_score
    )
  })

  # Save input information to CSV when Save button is clicked
  observeEvent(input$save_csv, {

    # read in existing file
    info <- read_csv("group_info.csv")

    # rbind new data
    update <- info %>%
      rbind(new_info())

    # write csv, overwriting existing file
    write.csv(update, file = "group_info.csv", row.names = FALSE)

    # show save message
    showNotification(h1("Save successful."),
                     action = a(href = "javascript:location.reload();"
, "Start a new entry."),
                     duration = NULL,
                     type = "message")
  })
}
#### End Server ####

###########################################################
```

```
######################## Render App #######################
###########################################################

shinyApp(ui = ui, server = server)

## PhantomJS not found. You can install it with webshot::install_phant
omjs(). If it is installed, please make sure the phantomjs executable
can be found via the PATH variable.
```