Assessment of visitor impacts on coastal bluff erosion at Point Lobos State Natural Reserve

Sean Noble

January 2016

California State University Monterey Bay
California State Park
And
The Point Lobos Foundation

Acknowledgements

We would like to thank:

- Marsha Grand and the Richard Grand Foundation
- Point Lobos Foundation
- Stephen Bachman & California State Parks staff
- Dr. Doug Smith & the CSUMB Watershed Geology Lab
- Naval Post Graduate School Remote Sensing Center
- Elizabeth Koch

This is primarily the work of CSUMB graduate student intern Sean Noble, working under the supervision and support of State Parks staff.

Executive Summary

Point Lobos State Natural Reserve (PLSNR) is home to a diverse array of natural resources. Its iconic land and seascapes, varied ecosystems, and rich cultural history have inspired countless visitors during its 83 years as part of the California State Park System. However, with the rapidly increasing popularity of PLSNR, California has struggled to balance maintaining public access with ensuring the protection and preservation of PLSNR's sensitive resources. Starting with the 1935 Master Plan by the Olmsted Brothers, the land management goals have been to preserve the natural condition of PLSNR, and to minimize signs of human presence. The current condition of PLSNR demonstrates that these goals are not being met. With increasing visitor use, PLSNR is being "loved to death", and these fragile natural resources are being lost.

The goal of this study is to assess the vulnerability of PLSNR to human activity, survey visitor impact to the coastal areas, and to make land management recommendations based on the collected findings. To determine the vulnerability of PLSNR to human activity, we conducted a literature review and we analyzed geologic and environmental data relevant to PLSNR. We used this information combined with GIS processes to generate an erosion potential model for PLSNR.

To survey the coastal areas of PLSNR we used GPS to collect data on the location and severity of trail degradation, user created trails, and areas of vegetation and soil loss. We used this data to determine the relative density of visitor impact. The areas that had the highest relative density of user impact were the focus of more quantitative survey methods. We identified a group of trail segments as being severely degraded and surveyed them with a series of trail cross sections. Additionally, we used motion photogrammetry to survey a sample set of bluffs that had large areas of vegetation and soil loss.

These quantitative surveys revealed that there was significant levels of human impacts throughout the coastal bluffs region of PLSNR. We measured over 1,000 m of severely degraded trails, 4,700 m of user created trails, and over 2,000 m^2 of vegetation and soil loss. Of the trails surveyed through cross sections, the most severely eroded was the trail section passing next to Sand Hill Cove which had an estimated 40 m^3 of lost soil. We also found that multiple trail segments passed within close proximity to marine mammal haul outs, which the literature suggests significantly affects their behavior. Wildlife disturbance data collected by Elizabeth Koch and CA State Parks (analysis not finished as of this report), substantiated that wildlife disturbance was occurring in areas of PLSNR where trails are near (within 100 m) to marine mammal haul outs.

We used the collected information to make a number of suggestions that would help PLSNR be more sustainable while still providing public access. We used GIS to generate alternate trail routes that avoid close proximity to known marine mammal haul outs and areas with high modeled potential for erosion. Additionally, we made specific suggestions for severely impacted areas like Lower Sea Lion Point, Granite Point, Coal Shoot Point, and Weston Beach. We stressed the use of trail borders and public education, specifically on the importance of zero impact behavior. Finally, we analyzed the coastal parking areas at Bird Island, Whalers Cove, and Piney Woods for potential mitigation strategies to eliminate runoff discharge into the Area of Special Biological Significance, just off the coast of PLSNR.

Table of Contents

Acronyms

ASBS – Area of Special Biologic Concern

BMP – Best Management Practices

GIS – Geographical Information Systems

PLSNR – Point Lobos State Natural Reserve

MP – Motion photogrammetry

UCT – User created trail

DEM – Digital elevation model

Introduction

In 1933, the State of California purchased Point Lobos because of its unique assemblage of marine and natural resources. Two years later the Save the Redwoods Foundation commissioned the Olmsted Brothers to draft a master plan for the area. The Olmsted Brothers argued for the protection, preservation, and restoration of Point Lobos, citing that:

> The land embracing Point Lobos was bought for inclusion in the State Park System (a) because the very peculiar physical characteristics of the locality… (b) because it was held to be of importance to mankind, in the present and in future generations…(c) because there was obvious danger of the complete loss or serious impairment of such opportunity (by destructive changes in the physical condition on which it depends, or by exclusion of the public, or both) unless the land could be acquired and administered for the definite purpose of preserving that opportunity in perpetuity.

They also noted the value of the natural aesthetics of the area, taking care to mention its vulnerability to human impact and the importance of maintaining its natural condition wherever possible. In particular, the Olmsted Report highlighted its vulnerability to erosion, insisting that erosion should be preserved as a natural process, free of human influence. Additional concerns about the impact of over abundant trails and other human influences were also addressed. While it was stressed that the Reserve should be kept publically available, they warned that "pressure is likely to be exerted from time to time, often in perfectly good faith… to have the Reserve managed essentially as a 'drawing card' so as to boom <u>volume of attendance</u>" and that "such pressure needs to be firmly and intelligently resisted". However, it seems likely that the Olmsted Brothers underestimated the drawing power of Point Lobos and its popularity later in the century, prompting today's land managers to revisit the strategies for preserving Point Lobos.

In 1979, a General Plan was drafted that reestablished California's goals for the Point Lobos State Natural Reserve (PLSNR). The General Plan laid out guidelines and suggestions for land managers, as well as pointing out specific features of the area that were priorities for conservation. The primary goal stated in the General Plan was to manage PLSNR towards a "pristine state, that is, the state the ecosystem would have achieved if European man had not interfered". To accomplish this, it suggested that significantly impacted areas be identified and restored to historic conditions. The priorities were to preserve iconic ecosystems like the Monterey Cypress groves, coastal prairie mima mounds, and the intertidal and subtidal marine habitats. The General Plan also called for the protection of the resident marine mammals, and the preservation of the cultural history of the area. To accomplish this, the General Plan suggested closing coastal parking lots, or banning motor vehicles from PLSNR altogether. Additionally, it suggested education programs that emphasized the fragility of the area.

Despite this call to action, few of these previous management recommendations have been implemented, and the concerns of the General Plan have gone unaddressed. Meanwhile, visitor attendance has steadily increased in the past decades, magnifying the impact on PLSNR resources. Recently, there have been public meetings concerning plans to draft a new General Plan, one that will emphasize the goals of park unit land managers. Unfortunately, there is a dearth of information about the current condition of PLSNR and precisely what impacts visitors are having on the area, complicating the planning process.

Goals

The goals of this study were to:

- Identify the vulnerability of PLSNR to erosion and human impacts.
- Identify and quantify the amount of impact that visitors are having.
- Make recommendations that can be used by land managers in their conservation efforts.

We started by conducting a review of relevant literature about human impacts on protected areas. We used the results of the literature review to analyze available data on the climate, soils, and topography to determine the vulnerabilities of PLSNR to erosion and other user impacts.

To establish the impact of visitors on PLSNR resources, we conducted an initial visual assessment of the study area and mapped notable impacts using GPS. This assessment allowed us to identify areas where user impact is the most significant. We assigned a relative impact severity score to features noted in the visual survey, e.g. areas of soil loss were ranked as more severe then areas of trampled vegetation. This visual data was used to determine where we would make direct measurements of soil loss within PLSNR. We prioritized soil loss through trail and bluff erosion because of the difficulty in restoring these eroded areas. Trampled plants may regrow in a given area, or can be replanted. Alternatively, soils are naturally replenished on a geologic timescale. To restore an area of lost soil, similar soil would have to be located and transported into PLSNR, then stabilized using Best

Management Practices (BMP), and revegetated with native plants. While eroded areas can be restored by expensive processes, the adoption and implementation of BMP's can prevent the loss of this natural resource from occurring.

We combined everything we learned about PLSNR to make a number of recommendations for directing future land management decisions. These recommendations range from general advice on land management strategies to specific ideas for heavily impacted areas identified during our visual survey.

Study Area

The PLSNR is located on the central coast of California, just South of Monterey Bay (Fig. 1). This region of the California West Coast has a Mediterranean climate, featuring moderate temperatures with rains generally occurring between November and April. Alternatively, the peak visitation to PLSNR occurs during the dry summer months. The PLSNR covers approximately 536 hectares of scenic coastline

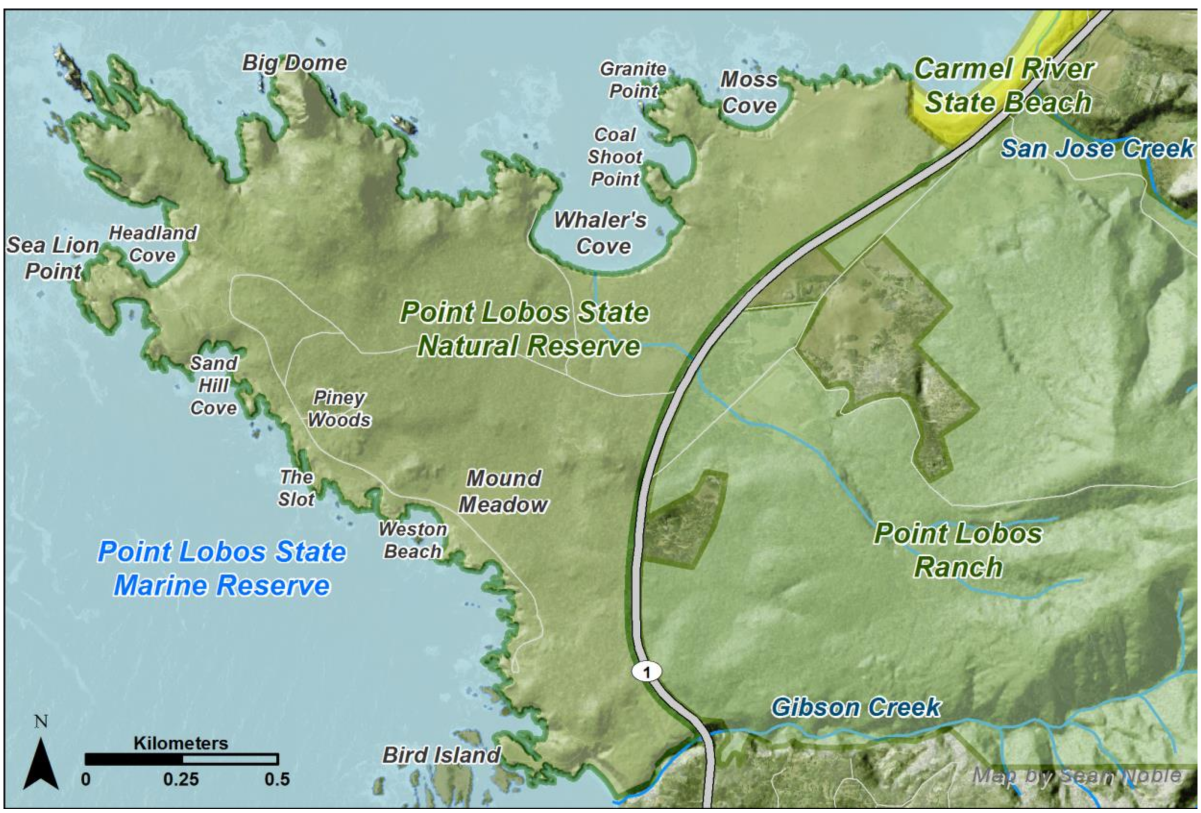


Figure 1: Point Lobos State Natural Reserve is boarded by the publically accessible Carmel River State Beach to the North, the non-accessible Point Lobos Ranch to the East across Hwy 1, and residential housing to the south across Gibson Creek.

and has been referred to as the “Crown Jewel of the State Park System” and “the greatest meeting of land and sea in the world”. PLSNR hosts many important habitats such as northern coast scrub, cypress and Monterey pine forests, and coastal chaparral plant communities. Suspended in the PLSNR soil are a number of Rumsien-Ohlone cultural sites consisting primarily of shell middens. The coastline around PLSNR is designated as an Area of Special Biological Significance (ASBS) and is enclosed in the Monterey Bay National Marine Sanctuary. Additionally, a number of protected animals are endemic to PLSNR, including southern sea otters, harbor seals, California sea lions, and black oyster catchers.

The study area for this project was limited to the coastal trails and bluffs of PLSNR. We defined this as everything from the Bird Island peninsula to the northern end of PLSNR on the seaward side of the main road (Fig. 2). The soils that make up these coastal bluffs are predominately sandy loam Mollisols with a relatively shallow (1 m) ‘A’ horizon over bedrock (Fig. 3). For our analyses and models we used sandy loam as a representative soil type for the entire area.

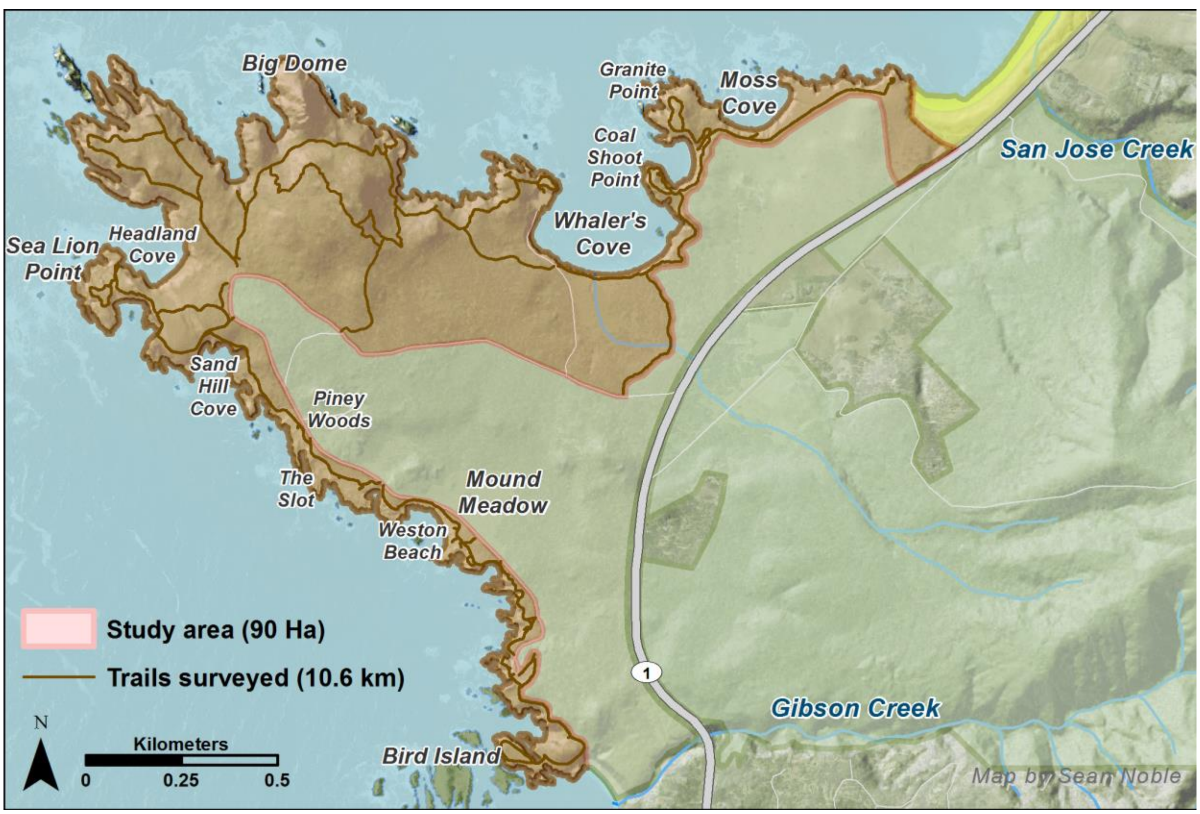


Figure 2: The trail network in PLSNR grants visitors direct access to the scenic bluffs. These trail often run directly along the bluffs edges. The major exceptions were the coastline around Big Dome and the point directly north of Moss Cove.

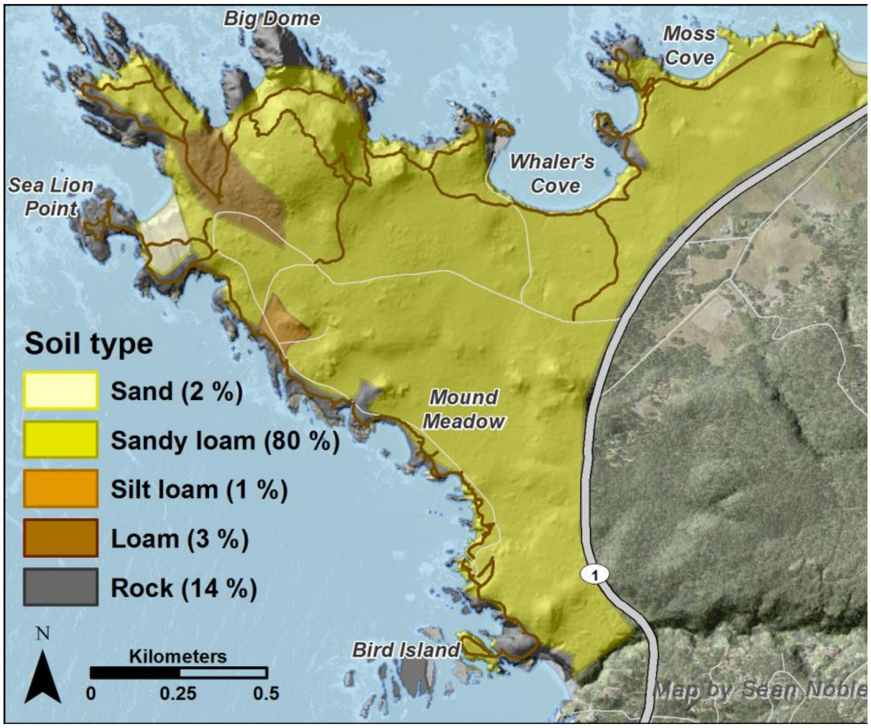


Figure 3: PLSNR soil types and land area percentage. Data based on the U.S. Dept. of Agriculture, Natural Resource Conservation Service's Soil Survey Geographic (SSURGO) database.

Literature Review

There is inherent conflict between the conservation of protected areas and the impact of the visitors who seek to enjoy them. By visiting and interacting with natural systems it is inevitable that people will have some impact. It is up to land managers to balance the goals of conservation while still allowing for visitor access (Bradford and McIntyre 2007; Snyder et al. 2008; Yang et al. 2014). This review will examine the scientific literature on how visitors might be impacting PLSNR. We will also explore studies on possible mitigation and management approaches that have been demonstrated to be effective.

User Impact

People who visit protected areas impact them in many ways. Visitors interact directly with the soils and vegetation, introduce invasive plant and animal species, and impact native wildlife behavior. Beyond degrading official trails, visitors can create unofficial, or user created trails (UCT), expanding their impact well beyond the intentions of land managers. To create a clear understanding of the factors involved in user impact at PLSNR, we started with an overview of the effect of visitors on soils and the process of erosion. We then examined the role of vegetation in mitigating erosion and how users affect vegetation. We also reviewed how visitors can effect local ecosystems, focusing on studies that pertain to habitats and species relevant to PLSNR. Finally, we examined studies on the effectiveness of managerial practices and highlighted potential BMP's that could be effective at PLSNR.

Soil

Soil erosion occurs in three steps, particle detachment, transportation, and deposition. The abiotic forces that generate erosion energy are water and air interacting with the soil surface or geology. Soil transportation occurs through wind energy or water runoff. While this movement of soil is a natural process, it can be significantly accelerated by human interactions.

Soil detachment occurs when a force is strong enough to break individual soil particles free of the soil matrix, allowing them to be transported. Direct raindrop impacts on the soil surface is a significant cause of soil detachment (Young and Wiersma 1973). It has also been demonstrated that steeper slopes are more vulnerable to erosion through raindrop detachment and runoff (Quansah 1981; Torri and Poesen 1992). Wind can also detach soil particles. In a study by Ravi and D'Odorico (2005), the sandy loam soil had the lowest wind speed threshold for particle detachment. Additionally, simply by walking over bare ground, visitors can detach a significant amount of soil making it susceptible to erosion through wind and water transportation (Cole 2004).

Parameters such as soil structure and soil moisture can have significant effects on soil erodibility and can change with the climate or through user generated impacts (Bryan 2000). Visitors cause compaction of trail surface soils, particularly in soils with more sand (Liddle and Greig-Smith 1975; Bhuju and Ohsawa 1998). Studies of sandy loam soils, like at PLSNR, indicate that compaction decreases water infiltration and increases surface runoff and erosion (Fullen 1985). Ravi and D'Odorico (2005) demonstrated that relative humidity is correlated with soil moisture. Soil moisture has been shown to be correlated with wind speed detachment thresholds, with drier soil having the lowest thresholds (Chen et al. 1996; Ravi and D'Odorico 2005). This indicates that there is probably a seasonal variability to the erodibility of the soil at PLSNR. Additionally, studies indicate that visitor trail use negatively impacts soil microbial activity which can affect the formation of aggregates and increase soil erodibility (Lucas-Borja et al. 2011).

Vegetation

Vegetation is a key component in reducing soil erodibility. There is an exponential increase in soil erosion as vegetation decreases (Gyssels et al. 2005). Vegetation provides cover and significantly reduces raindrop detachment (Ghahramani et al. 2011). Vegetation also reduces the force of the wind on the topsoil and catches air born particles, increasing deposition (Van de Ven et al. 1989; Wolfe and Nickling 1993). Additionally, plant roots help to stabilize soil, which can reduces soil erodibility.

Experiments conducted in hydraulic flumes demonstrated that grass roots in a sandy loam significantly reduce the amount of erosion from concentrated overland flow (De Baets et al. 2006). The type of vegetation also plays a role in resisting small landslides on steep slopes. A study by Fattet et al. (2011) indicates that the roots of herbaceous plants were more effective then trees in developing soil aggregates, and that the density of fine roots was a significant factor. However, this study was conducted on silt clay loams and may not directly represent how roots impact sandy loam soils. Dunaway et al. (1994) conducted a study that indicates that the percent of sand is positively correlated with root density and lower erodibility, suggesting that the pores in sandy soils are favorable for root growth. Conversely, higher sand percentages can make soils more vulnerable to compaction, which negatively affects root growth (Taylor and Burnett 1964; Bhuju and Ohsawa 1998). This highlights how visitors can impact soils through soil compaction in PLSNR and how soil compaction should be factored into determining visitor access.

There are multiple factors that can affect the density of vegetation in protected areas like PLSNR. In a study of sandy loam soils, slope thresholds were identified where plant growth was severely limited (Bochet et al. 2009). The Bochet et al (2009) study concluded that plants have difficulty growing on steep bluffs, therefore it is important to protect the existing bluff vegetation to reduce erosion. Visitors also significantly impact plants, primarily through trampling. Vegetation trampling in PLSNR takes place through lateral widening of official trails and off trail exploration i.e. UCT's. Whether a trail is official or a UCT, the impact on adjacent vegetation is similar. Trail widths tend to increase with visitor use (Dale and Weaver 1974; Wimpey and Marion 2010). Visitors can also reduce vegetation cover and alter species composition within 1 – 2 m of trails (Dale and Weaver 1974; Cole 1978). It is important to consider that different vegetation types differ in their resistance and recoverability to trampling (Cole 1995a; Cole 1995b). For example, meadows and grasses are more resistant to change then dense forested vegetation (Cole 1978). The woody stemmed shrub species found throughout PLSNR are particularly vulnerable to trampling.

Ecosystems

Visitors at PLSNR likely have significant impacts on the local ecosystem in three ways. First, erosion can have effects beyond soil loss. Second, visitors can introduce invasive plant species. Lastly, visitor presence and behavior can impact local wildlife behavior.

The impacts of soil erosion go beyond a loss of physical substrate, and the effects can ripple through the environment via the transportation and depositional processes. Air born particles can significantly impact respiratory health (Bernstein et al. 2004). Additionally, soil runoff pollution can have significant negative effects on local ecology, including marine environments (Pimentel et al. 1995).

Visitors walking on trails allows for the introduction and transportation of invasive plant species (Tyser and Worley 1992). While some studies have found that trails only effect the abundance of invasive plant species up to 15 ft from a trail, other studies have found high abundancies of invasive species persisting hundreds of feet around trails (Leung and Marion 2000). Invasive plant species can alter the native soil nutrient cycles and affect soil chemistry (Ehrenfeld 2003). In California there is a correlation between invasive plant richness and the number of 'imperiled' native plant species (Seabloom et al. 2006). These problems can be exacerbated by human disturbances such as accelerated erosion and plant trampling, which can damage native species and leave soil exposed for non-native species to take root. The spread of noxious non-native weed species can change habitat structure and function, and have real consequences for managers who may have to develop weed eradication programs at considerable expense.

Visitor presence can affect the behavior of local wildlife. This is of concern for PLSNR because it is used by marine mammals like sea otters, harbor seals, California sea lions, black oyster catchers. These species are vulnerable to harassment by people and are protected under statutes like the Marine Mammal Protection Act of 1972. In a study of harbor seals in Iceland, observers affected seal behavior from a viewing area 100 m from the haul out (Granquist and Sigurjonsdottir 2014). The number of viewers and their intensity was significant, with small numbers of calm observers having the lowest impact. Additionally, fur seals had a universally dramatic response when approached by tourists. Again, the distance to illicit a response depended on the intensity of the tourist behavior (Cassini 2001). These studies indicate that marine mammals are sensitive to disturbance from visitors, and that visitor behavior is a significant factor. Because a number of PLSNR trails, both official and user created, pass within 100 m of known haul outs, it is likely that the marine mammals endemic to the area are being impacted. If these trails are to remain in place, it is vital that visitors to PLSNR be educated on proper behavior and the potential impacts of their actions.

Management

Land managers face the difficult task of balancing visitor access with the protection of natural resources. To balance these conflicting needs, it is important to understand how intelligent trail design can limit trail degradation and reduce indirect impacts on the ecosystems. Additionally, management programs can impact visitor behavior and limit destructive practices like off trail exploration and hiking.

In an assessment of the trails in the Big South Fork National River Recreation Area, Olive and Marion (2009) identified factors that significantly affected the rate of trail degradation. Their results indicate that trails that follow the fall of the slope have significantly higher erosion rates then trails that run perpendicular to the slope. Additionally, topographic position was an important factor in trail erosion with valleys eroding more than midslopes which eroded more than ridges. The authors also identified managerial factors that effected the rate of trail erosion. Effective trail features included; tread drainage features that limited water flow down trails, the application of gravel or decomposed granite, and limitations on heavy trail use.

Other studies have indicated that the use of trail borders, even when purely symbolic, can reduced trail widening (Wimpey and Marion 2010). There is a consensus that vegetated buffer strips can reduce sediment and pesticide runoff and increase water infiltration (Dosskey 2001; Popov et al. 2006). By ensuring that trails leave vegetated buffer strips around bluffs, erosion and ecological impacts can be reduced.

Limiting off trail traffic at PLSNR should be a priority for land managers. The impact of vegetation trampling is generally not linear, with the first passes over a vegetated area causing the greatest impact (Cole 1995a). UCT’s do not benefit from professional trail design and are often located and oriented in ways that exacerbate their negative impacts on the ecosystem (Wimpey and Marion 2011). A common practice to deter off trail exploration is the placement of signs either at trail heads or in areas where off trail use is evident. Studies indicate that not all signs are equally effective at preventing off trail use. Signs that warn of citations or give a reason for staying on the trail ('Help protect the meadow by staying on trial') are more effective than signs that only ask visitors to stay on the trail ('Please stay on the trail') (Bradford and McIntyre 2007). Additionally, the signs with reasons retained their effectiveness even when placed at a trail head, away from the UCT's. It is important to note that all signs helped reduce off trail use, and that a combination of approaches could prove to be the most effective. Additionally, visitor education programs can increase visitor knowledge and alter visitor behavior (Marion and Reid 2007). It is the minority of visitors who willfully damage protected areas, so through proper trail design and visitor education, a large percentage of off trail damage can be avoided.

Methods

Vulnerability analysis

Weather analysis

We used weather data from Wunderground.com to analyze the regional weather in terms of possible impacts on erosion. We obtained daily weather summaries over multiple years (2012 -2014) from the weather station located in Carmel, just North of PLSNR. We also downloaded 5 minute weather summaries from the Lovers Point weather station in Pacific Grove. Due to the high resolution of the 5 minute data, we focused on the summer months (June – September) of the years 2012 -2015. Specifically, we looked at the daily max wind and wind gust speeds, and focused on the frequency of wind speeds surpassing 10 mph. We used 10 mph as the threshold speed required for wind to transport sandy loam soil particles in dry conditions (Ravi and D'Odorico 2005).

Topographic analysis

Topographic factors of erosion potential were determined using ArcGIS analysis on a LiDAR DEM produced by the Naval Postgraduate School (NPS) Remote Sensing Center. Based on the findings of the literature review we used the slope and topographic position index (TPI) as topographic factors for erosion potential. Because vegetation is a significant factor in erosion, and there is a threshold slope in which vegetation growth is reduced, we classified slopes above that threshold (35 degrees) more severely and referred to them as 'bluffs'. We also included areas directly upslope of bluffs as having an increased potential for erosion due to the potential for knickpoints and bluff recession. We scaled everything from 1-10, with low numbers having low erosion potential, and high numbers having increased erosion potential (Table 1). To classify TPI we used a 15 m to 30 m annulus, classifying the terrain as flat, valley, low slope, mid slope, high slope, and ridges.

Table 1: Relative impact rating given to different parameters on how they affect erosion potential. Distance from bluff was the only the upslope distance, areas directly below bluffs were not included in this category.

TPI	Slope (degree)	Distance from bluff (m)	Impact
Flat	0 - 5		0
Low Slope, high slope, ridge	5 - 10		1
Mid slope	10 - 20		2
		5 - 10	3
Valley	20 - 30	3 - 4	4
		0 - 2	5
			6
	30 - 40		7
	40 - 50		8
	50 - 60		9
	60 - 90		10

Impact Analysis

GPS Survey

We conducted a visual survey of the study area, beginning with an initial walkthrough, noting the different possible impacts visitors are having at PLSNR. We then mapped the official trails and their level of degradation, UCT's, areas of notable impact, and other important features e.g. knickpoints. Additionally, we took geotagged photos of features using a Caplio 500SE. We used a handheld Trimble Geo XT to collect GPS data, and post processed the data using GPS Pathfinder Office. Areas that were inaccessible due to the presence of sensitive fauna, soils, vegetation, or cultural resources, were mapped remotely using photographs, aerial imagery, field notes, and LiDAR. Detailed field methods and criteria can be found in Appendix C.

Official trails were identified using the visitor guide map for reference. We used GPS to create line segments for all the official trails in the study area. After post processing using GPS Pathfinder Office, we projected the data and manually adjusted lines to match notable features in the LiDAR DEM provided by NPS. This process helped features to be properly correlated with notable features in the course of later analysis.

To determine the level of trail degradation, we walked the coastal trails and rated them from 0-4, on level of incision and widening severity respectively, with zero indicating no visible issues and 4 indicating severe visible degradation. We recorded trail segments rated over zero as line segments using GPS. During post processing, we snapped these line segments to the appropriate corrected official trails.

We mapped UCT's that could be observed from walking official trails. We interviewed docents and State Parks staff familiar with PLSNR to understand what kind of UCT's exist in the park and where they are prevalent. We walked UCT's, mapping them and ranking them on a scale of 1-4 based on the level of impact and degradation. Some of the trails were not accessible, primarily due to the presence of poison oak or the high potential for impacting sensitive slopes, soils, or vegetation. These UCT's were marked using GPS and were heads up digitized using photographs, orthophotos, and field notes as references.

During our initial assessment of PLSNR, we noted large areas experiencing vegetation and apparent soil loss. These areas were identified separately from the widening of official trails or UTC's, as they had no clear direction of travel. To map out the impacted areas, we walked the perimeter using the GPS to create a polygon feature. Areas of vegetation loss were identified as areas of noticeable vegetation trampling or a complete lack of vegetation adjacent to vegetated ground with no other visible distinguishing differences e.g. no significant slope breaks or changes in soil. Areas of soil loss were defined as locations within areas of vegetation loss with exposed base rock.

While mapping trail conditions, we also noted other significant management and erosion features. Specifically, we mapped the locations and types of fencing used to designate official trails throughout PLSNR. We also noted the locations of knickpoints or headcuts, where a bluff was eroding into the boundary, or active treadway, of an official trail.

User Impact density

We used the visual survey method to identify areas where user impacts had the highest density. We assigned an individual impact density to each of the observed user impact types and severities (Table 2; Table 3). Impacts that implied a loss of soil were ranked higher then impacts that only implied losses of vegetation. We used ArcMap to generate a combined density map to help locate areas where the density of user impacts was highest.

Table 2: Level of different impact types and severities of users on PLSNR. The level of impact is a unit-less ranking based on the literature and implied importance of affected resources.

Impact type	Severity	Level of impact (per m)
Trail incision	1	1
	2	2
	3	4
	4	8
Trail widening	1	0.25
	2	0.5
	3	1
	4	2
UCT	1	1
	2	2
	3	4
	4	8

Trail Cross sections

We used trail cross sectional areas to estimated soil loss from high priority trail segments. The high priority trail segments were defined as having a constant and continuous incision rating above 2, and passed within 15 m of the ocean (Fig. 4). This classification was used to identify trails that are a possible source of sediment discharge into the ASBS. Depending on segment length, we measured 3 – 5 cross sections using methods described in Marion and Olive (2006), with the exception that we measured to the natural soil slope as opposed to the active tread width. We calculated the total soil loss by multiplying the average cross sectional area by the total length of the measured trail segment.

Table3: Level of impact of users on areas within PLSNR. The level of impact is unit-less and is based on the literature and implied importance of affected resources.

Impact type	Level of impact (per m^2)
Vegetation loss	1
Soil loss	4

Photogrammetry

By combining the data gathered through the general survey with information from interviews with land managers, we identified a number of areas that are a priority for monitoring or restoration. Priorities for these areas are to generate accurate DEMs and referenceable information, against which future degradation can be tracked and quantified. We selected three bluffs to test the effectiveness of surveying these areas using structure through motion photogrammetry (Fig. 5). We used labeled multicolor ground control points (GCP’s) distributed in a 6 m hexagonal pattern to tie the resulting data to the NAD 83 UTM zone 10 coordinate system (Fig. 6). We used ArcMap to identify the GCP locations

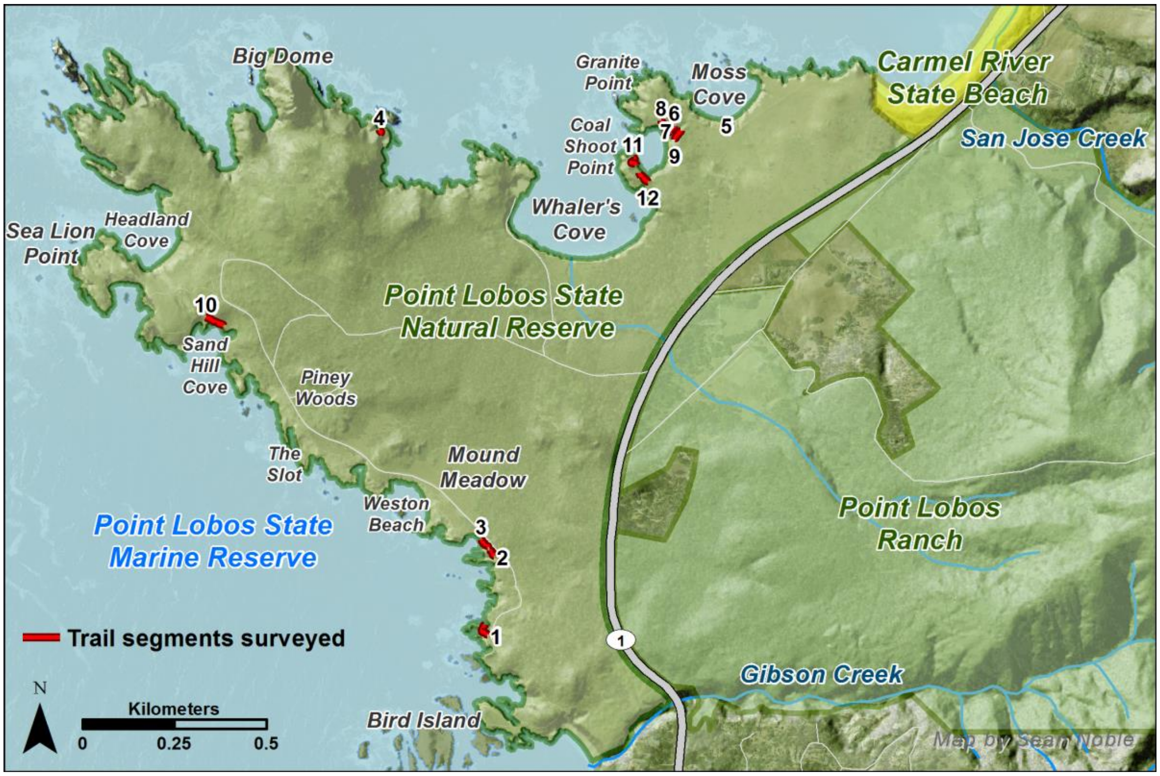


Figure 4: Trail segments surveyed using cross-sectional area measurements. Numbering is based on the order in which the trails were surveyed, which was contingent on trial availability due to visitor usage. Some trails, like the one leading to Sea Lion Point, were selected in the GIS analysis, but were not surveyed due to the chance of disturbing marine mammals.

and the Trimble Geo TX GPS unit to place them in the field. We used OPUS post corrected 3 arc-second Nikon total station RTK GPS to determine the precise position of each GCP as they were placed in the field. Additionally, we used the RTK GPS to map the edge of the bluff, defined as the predominant slope break separating the flat coastal scrub surface from the steep bluff face. We also collected RTK GPS points under vegetation in and around the survey area to compensate for the predicted inaccuracy of structure through motion photogrammetry in heavily vegetated areas. To determine the accuracy of the RTK GPS we took a series of reference points throughout the day. These points were taken at easily identifiable static features such as the cross of the “T” on a metal water pipe access lid.

To collect pictures for the photogrammetry, we attached a GoPro HERO 3 black in a Zenmuse H3-2D gimbal housing to the end of a 5 m extendable painter’s pole. The GoPro was set to take a 12 megapixel image every 2 seconds. Remote control of the gimbal was used to adjust the position of the camera to help ensure images were free of unwanted features. We slowly walked over the area with the camera pointed downward, ensuring that we covered each GCP from multiple directions. Additionally, we captured a number of images of the study areas from more oblique angles. The images

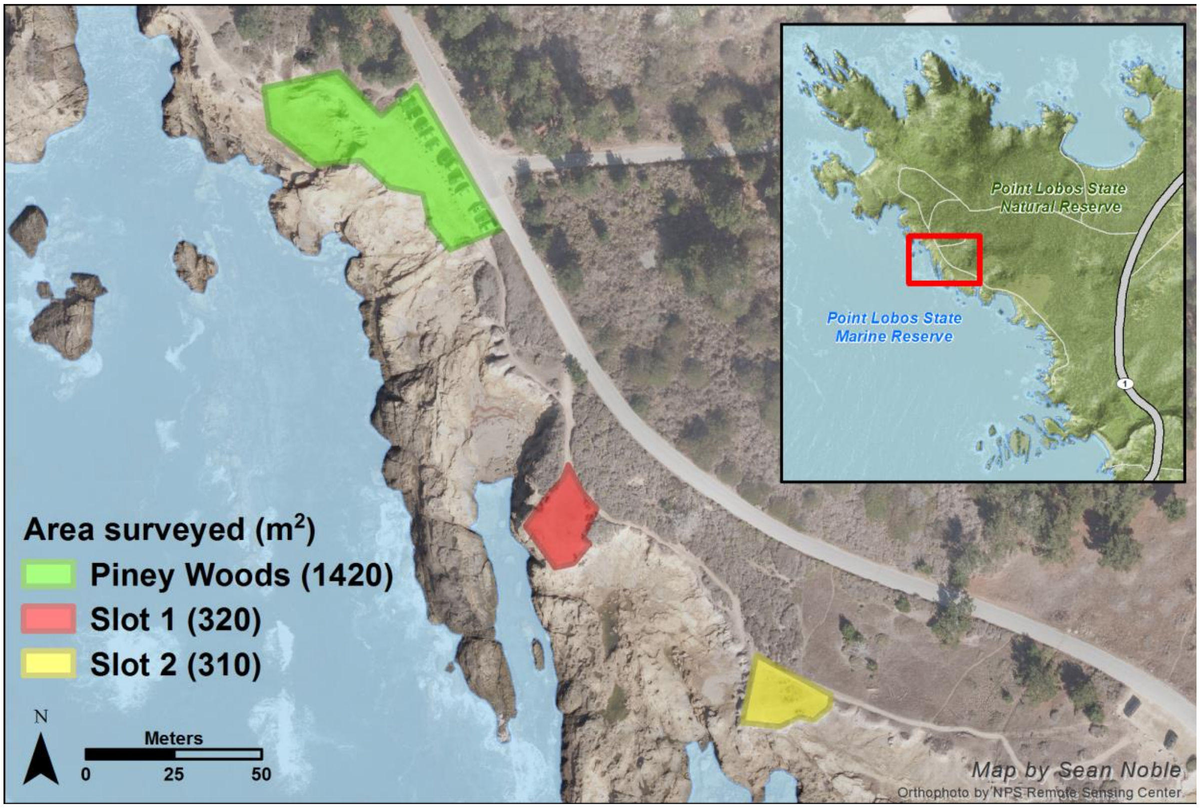


Figure 5: Bluffs surveyed using structure through motion photogrammetry.

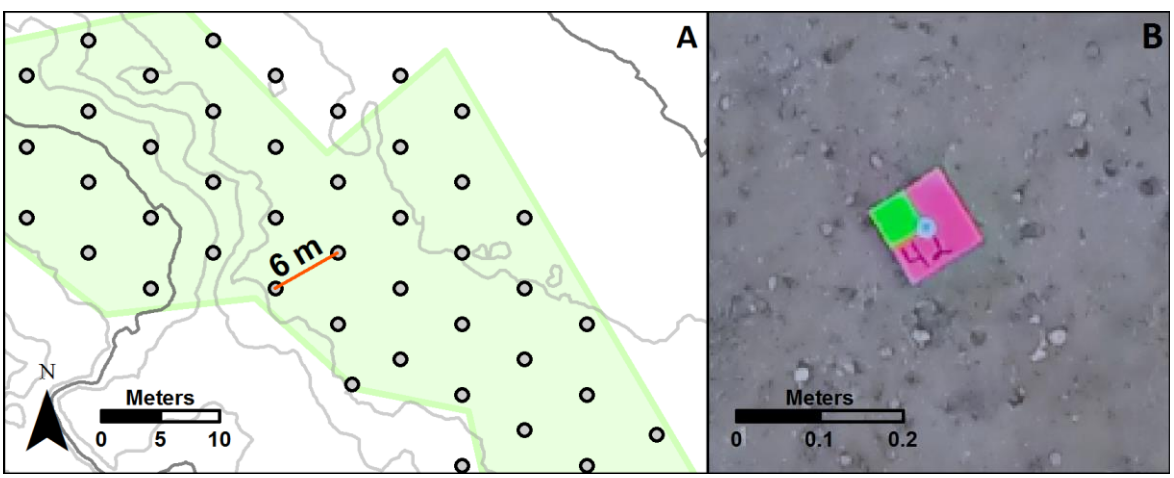


Figure 6: The planned distribution of GCP for structure through motion survey (A) and an example of one of the GCP's used (B). The spacing of the GCP's was determined through testing the viewing area from the GoPro camera from the height of the painter's pole. The multicolored pattern and numbering on the GCP's made photo identification in PhotoScan more efficient.

were processed using Agisoft PhotoScan software, which automatically adjusted for the fisheye lens of the GoPro. We selected photos to ensure that each section of the surveyed areas were covered by at least 9 images. We used medium settings when building dense point clouds and mesh surfaces.

Orthophotos, DEM's, and accuracy reports of the bluffs were the primary outputs from the PhotoScan software and surveying.

Marine Mammals

We used field observations made during the trail mapping sessions, as well as observations from other interns working at PLSNR, to identify known haul outs used by marine mammals. We then used ArcGIS to determine in which areas of PLSNR a standing person would be visible to marine mammals located at those hauls outs. To do this, we used ArcGIS view shed analysis, and assumed a marine mammal viewing height of 15 cm, and an assumed visitor height of 1.8 m (5'11"). We also used counts of hauled out marine mammals to determine a rough density of marine mammals at haul outs. This density was used to estimate the expected number of marine mammals per haul out that could be impacted by nearby visitors.

Results

Vulnerability analysis

The Wunderground.com daily summaries indicated that approximately 60% of days experience wind speeds greater than the 10 mph particle detachment threshold (Fig. 7). The analysis of the Lovers Point data for summer months revealed an average wind gust speed of 5 mph with a standard deviation of 3 mph. Wind speed generally followed a daily pattern, with the maximum wind speeds occurring in the afternoon (Fig. 8).

Most of the Reserve had a low predicted vulnerability to erosion (Fig. 9). However, the areas that did have high predicted vulnerability were near the coastal bluffs, Whalers Point, and Big Dome. Analysis of the main trail indicated that while most trail segments were in low predicted erosion areas, but there were some tail segments that crossed areas with severe predicted erosion potential (Table 4).

Impact Analysis

GPS Survey

Trail condition varied throughout PLSNR. The ADA trails around Bird Island and Sea Lion Point displayed the lowest amount of trail incision. However, these trails were newer (The Sea Lion Point ADA

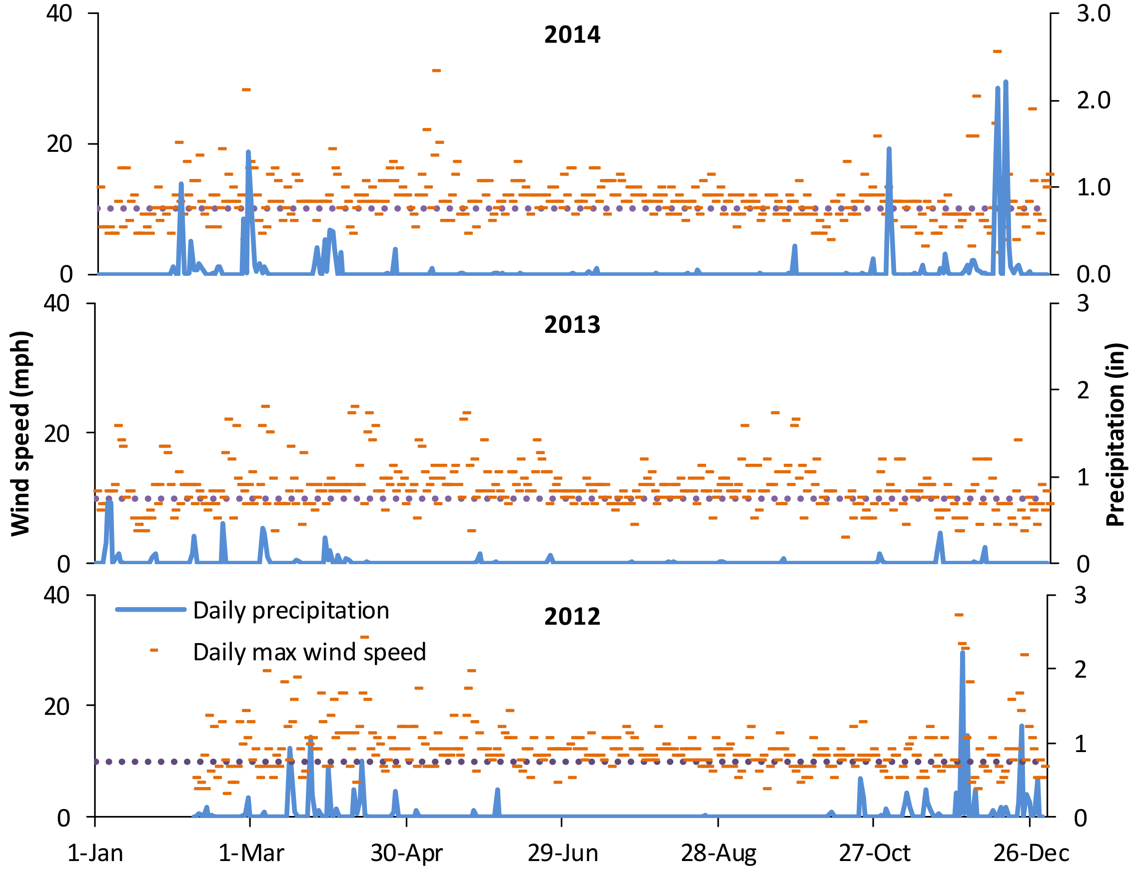


Figure 7: Daily precipitation and max wind speed for the 2012 – 2014 calendar years

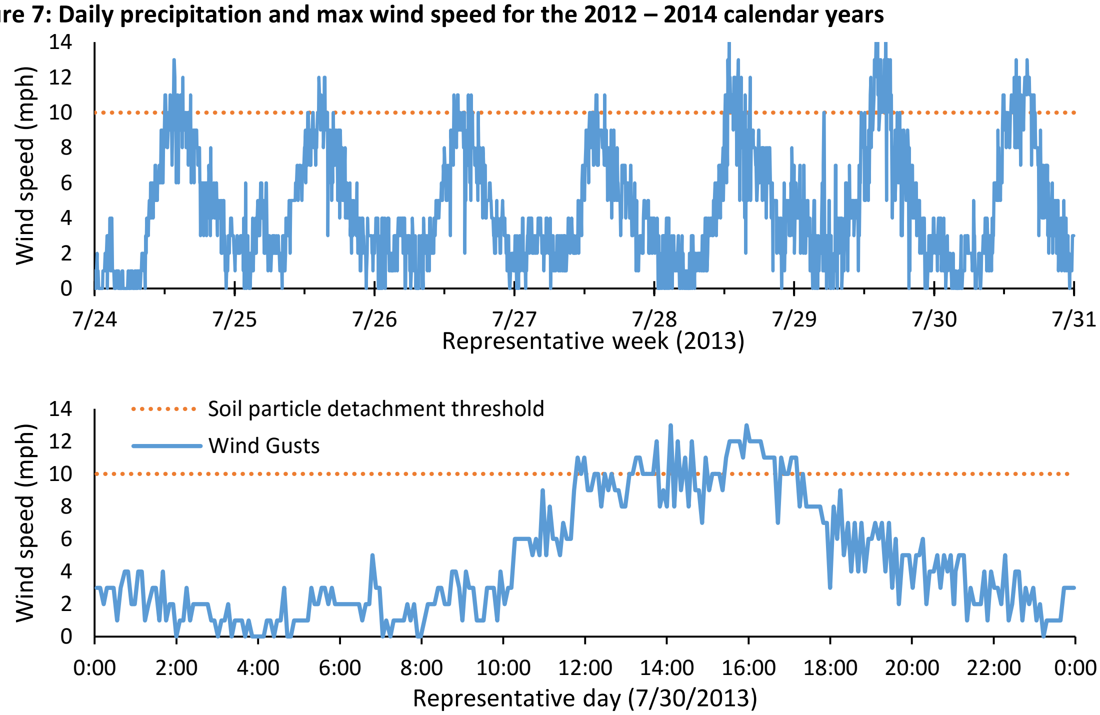


Figure 8: Wind gust speed during a representative summer week and day of 2013. We compared the wind speed average and standard deviation to the yearly data to identify representative sections.

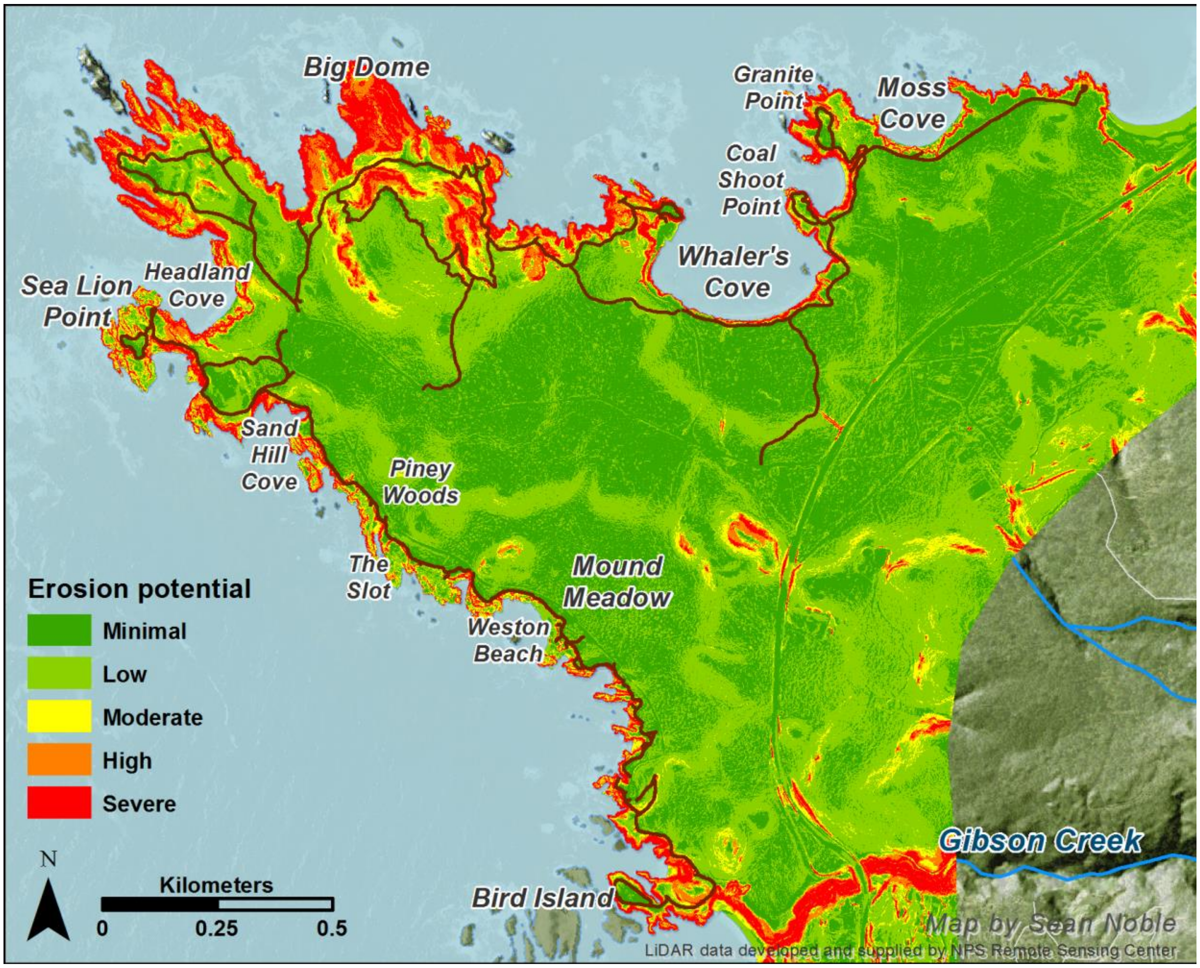


Figure 9: Erosion potential determined from topographic factors. This analysis does not account for variances in soil type or vegetation cover (Larger map available in Appendix B).

trails were installed in 2000 and the Bird Island ADA trails were installed in 2013/2014). Of the trails that did display incision, severity ratings 2 and 3 were the most common, with 1 and 4 appearing less frequently (Fig. 10). Trail widening was more evenly distributed between severity levels (Fig. 11).

Table 4: Predicted erosion potential of surveyed official trails.

Erosion potential	length (m)	Fraction of total (%)
Minimal	5729	55
Low	3133	30
Moderate	1089	10
High	375	4
Severe	156	1

User created trails are prevalent along the coast and in areas where the location of official trails was ambiguous, e.g. around granite point (Fig. 12). Lower severity UCT's trails were more prevalent then high severity UCT's, however high severity UCT's were more common on and around the bluffs. These

UCT's were commonly located on steep slopes, often oriented parallel to the slope fall increasing the rate of degradation.

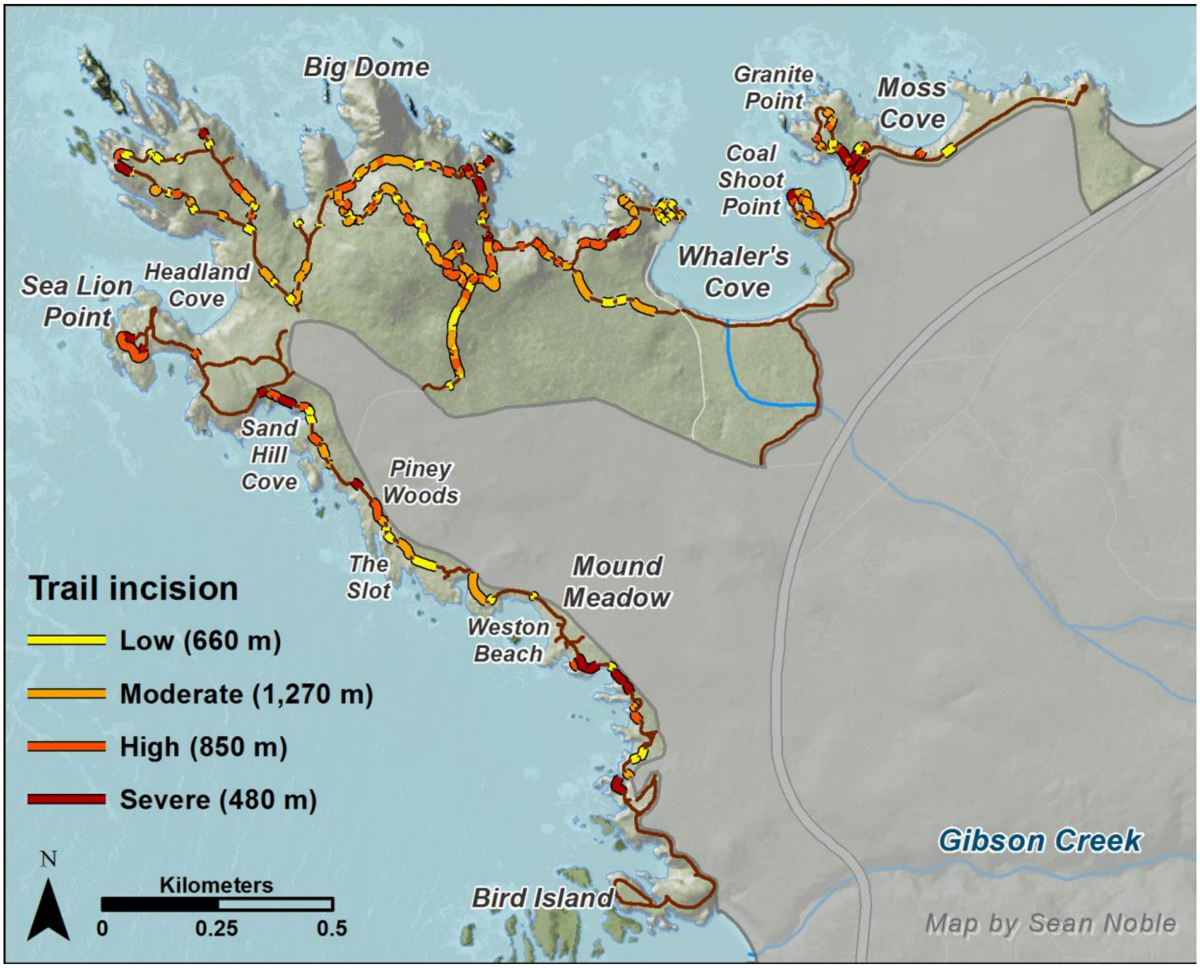


Figure 10: Trail incision on coastal trails in PLSNR determined through visual assessment (Larger map available in Appendix B).

Areas of disturbance were most common where there was an absence of fencing and were more prevalent on the Southern coast of PLSNR (Fig. 13). Wire fences were the most common regulatory feature, however they were not present on all trails (Fig. 14).

Trail Cross sections

There was a large variance in the estimated soil volume lost from sampled trail segments (Table 5). The trail segments near Sand Hill Cove had the highest predicted level of soil loss, but the trail at Moss Cove had the highest average cross sectional area, indicating the greatest soil loss per meter of trail.

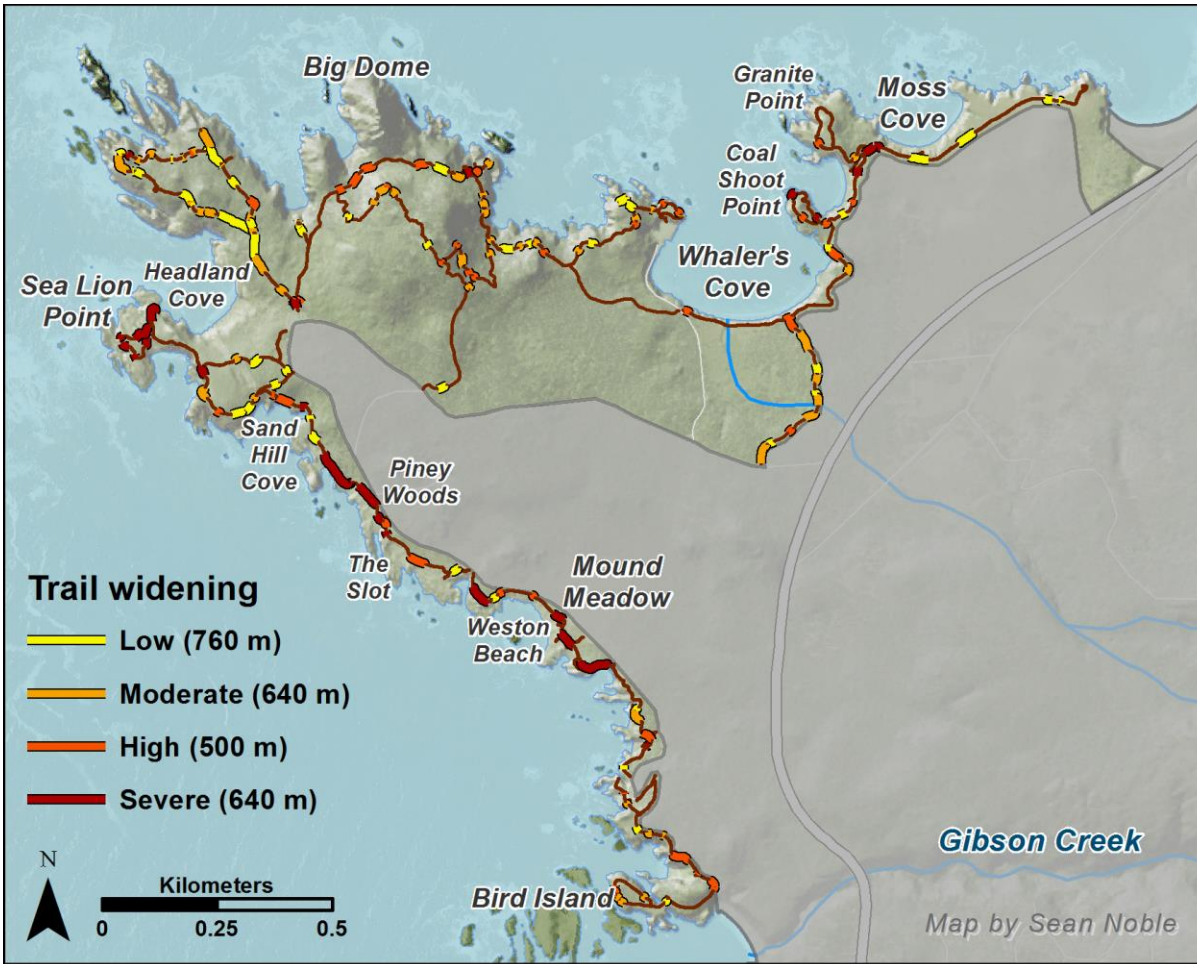


Figure 11: Trail widening on coastal trails in PLSNR determined through visual assessment (Larger map available in Appendix B).

Table 5: Calculated soil loss from trail segments.

ID	Segment location	Segment length (m)	Average CSA (m^2)	Total soil loss (m^3)
7	Granite Point/The Pit	8	0.28	2
2	Mound Meadow Trail	19	0.2	4
12	Coal Shoot Point	35	0.16	5
11	Coal Shoot Point	35	0.16	6
3	Mound Meadow Trail	30	0.18	7
6	Granite Point/The Pit	25	0.27	7
9	Granite Point/The Pit	30	0.25	8
8	Granite Point/The Pit	27	0.31	9
4	Guillemont Island	11	0.88	10
5	Moss Cove	7	2.19	13
1	Bird Island Parking Lot	37	0.33	13
10	Sand Hill Cove	53	0.68	40

Photogrammetry

According to the report generated by PhotoScan, the generated DEM from the MP survey had an accuracy of 0.029 m against the GCP's. When we compared the DEM to the points collected using the RTK GPS we calculated a standard error of 0.003 m and when we excluded points under thick vegetation the calculated standard error was 0.002 m. The calculated vertical error for the RTK GPS off of the reference points was 0.004 m.

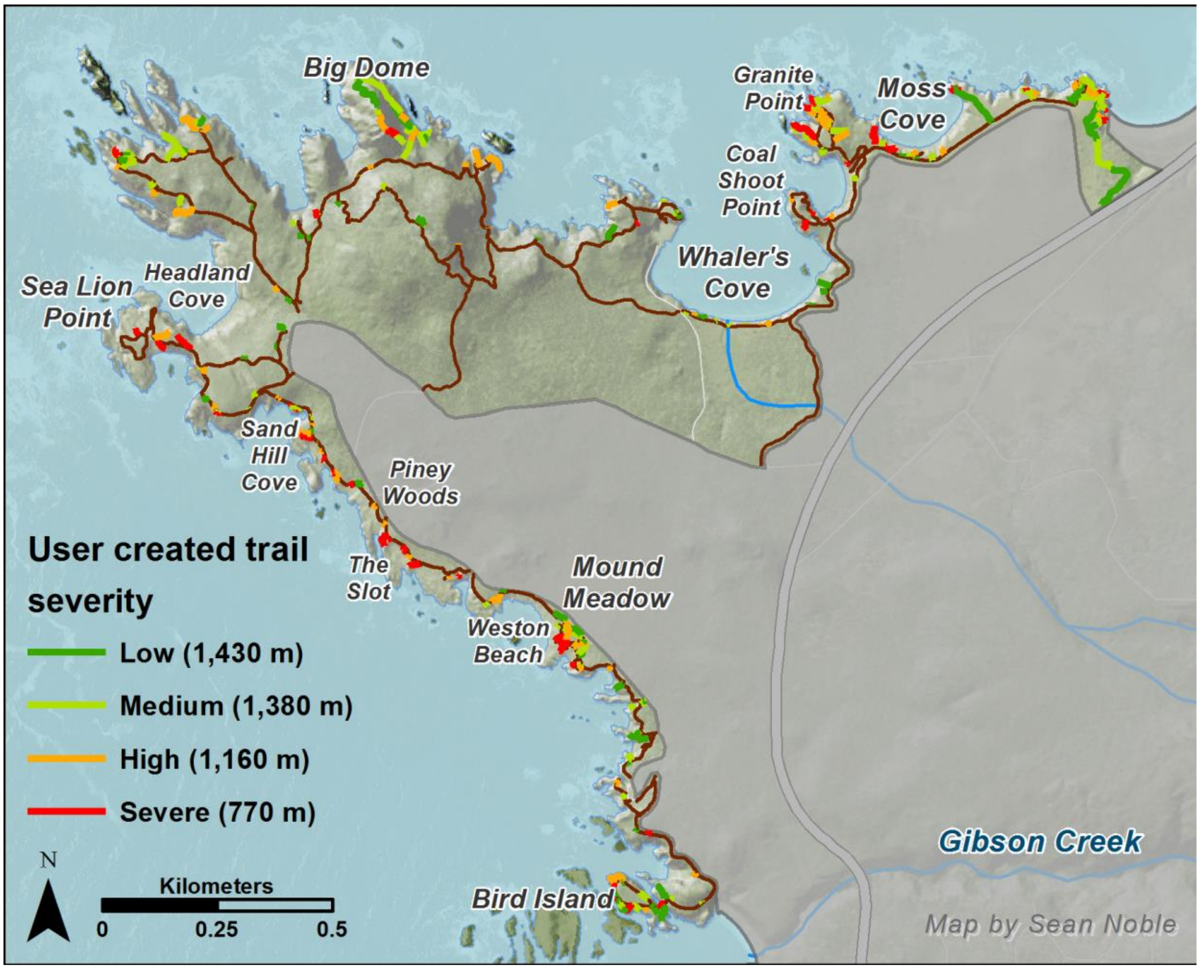


Figure 12: User created trails in the coastal region of PLSNR. Trail severity was based on level vegetation tramping, widening and incision (Larger map available in Appendix B).

Discussion

Our analysis of weather data indicates that wind speeds frequently exceed the threshold needed to transport soil particles. However, we were limited in available data sources, and the

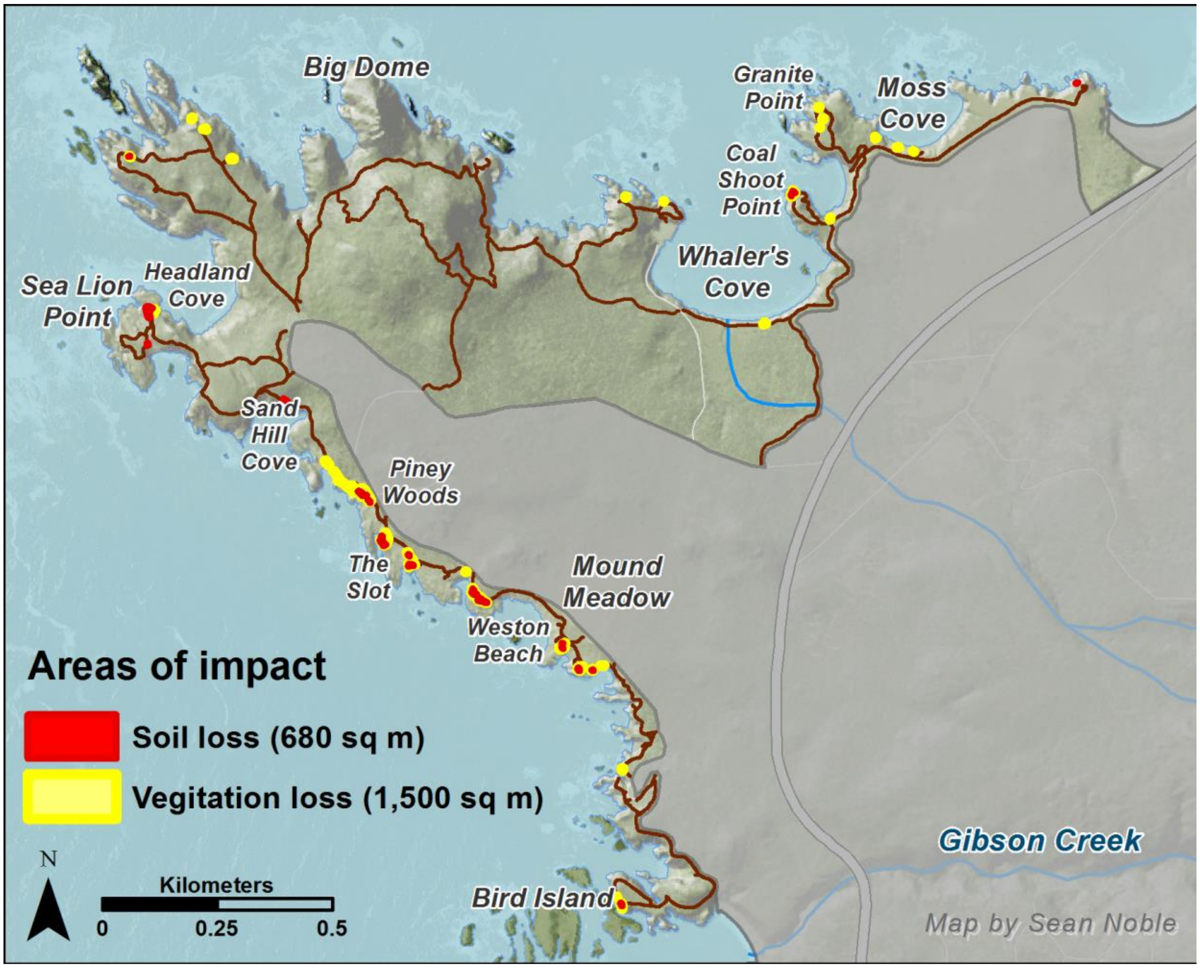


Figure 13: Areas of impact (vegetation and soil loss). The areas of impact were most common on the South section of PLSNR and on bluffs.

threshold value we used does not account for factors like soil moisture and human induced physical disturbances. The weather in Carmel may differ from that of PLSNR. Carmel is located south east of the Pacific Grove peninsula which may shelter Carmel from oceanic winds. Alternatively, the data station on Lovers Point might more closely replicate PLSNR's exposure to oceanic winds, but is further away from PLSNR. The wind speed threshold we used was based off of undisturbed, exposed sandy loam soil. However, the presence of visitors can disturb soils, which reduces the amount of energy required to transport particles, thereby making them more susceptible to erosion and transport. Additionally, we did not account for soil moisture, which can affect wind erosion. The pattern of afternoon high winds could also be significant. There is potentially less moisture in the topsoil in the afternoon making it more susceptible to transportation. If high afternoon winds coincide with high visitor traffic and lower soil moisture, the amount of soil lost to wind erosion could be significantly increased. This initial analysis of local weather conditions indicates that a significant amount of soil may be lost to wind erosion, and land management plans should consider this when making decisions.

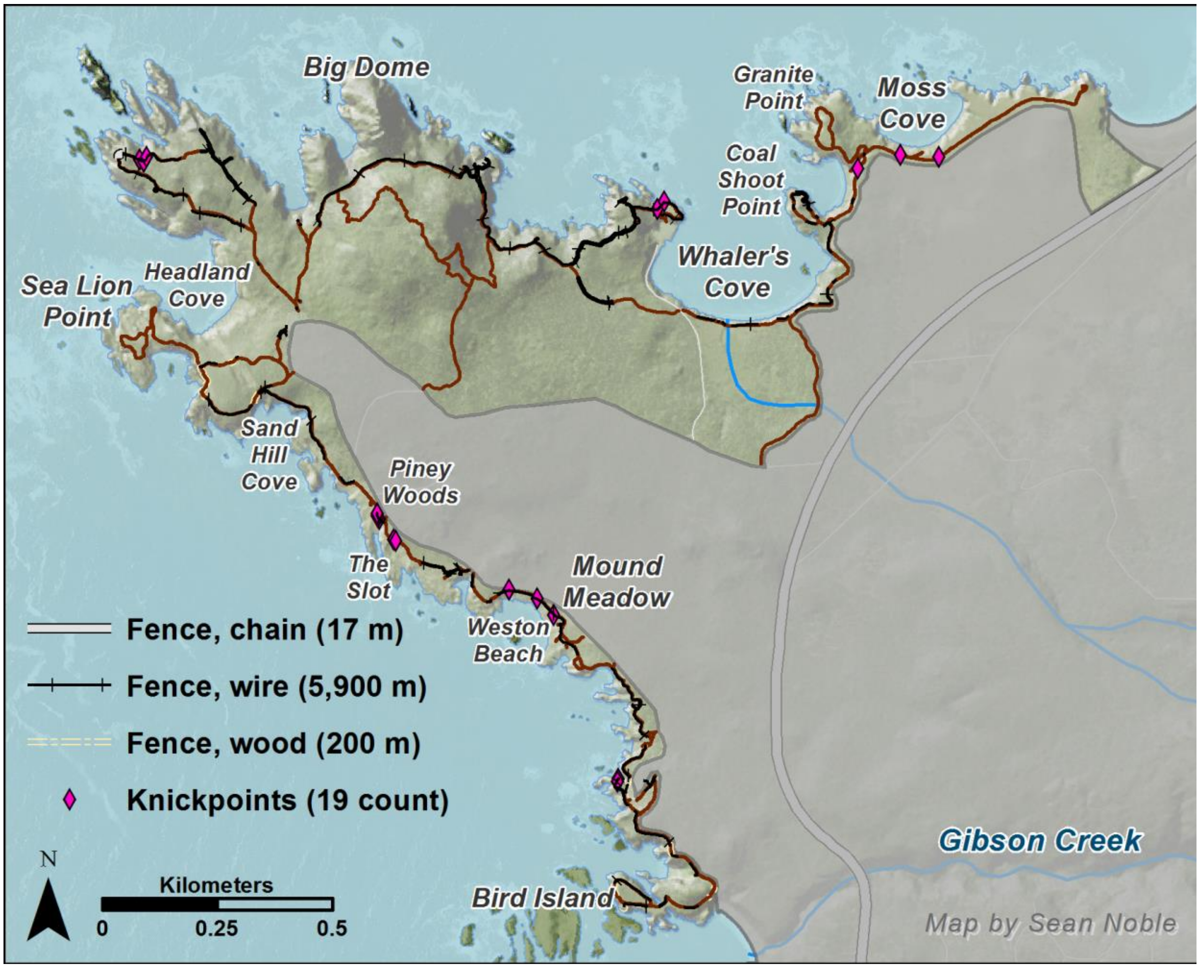


Figure 14: Fences and knickpoints along the coastal trails in PLSNR. While wire fences were common they were not present on all sections of the trails.

The erosion potential model we produced should be used as a general indicator of which areas are at a high risk of erosion, particularly if they become frequented by visitors. This model has not been thoroughly verified or ground truthed. Because of the high resolution of the LiDAR DEM, the existing trails often appear as strips traversing diagonally across a slope. This is expected in areas where the trail is properly oriented perpendicularly to the natural slope. This high resolution would also effect the estimates of the erosion potential of official trails, because the trail slope would be lower than the natural hill slope. We also expect that the trails that are more visible on the LiDAR DEM are more incised, because incision increases difference in elevation from the surrounding terrain.

Our assessment of trail degradation was limited by the definitions we laid out in our methodology and lead to some misleading data. One of our criteria for defining trail widening was based on a provision of the General Plan stating that trails within PLSNR should not exceed 1.5 m in width. However, some of the ADA trails were made to be wider than this recommendation, causing them to be indicated as widening in our survey even if they were not showing any other signs of active widening.

A significant aspect of trail degradation that was not considered in design of this project is water ponding in trails and trail ruggedness. Ponding in trails after a rain event force users to the edges of trails, where they inadvertently trample vegetation (Fig 15). Likewise, hikers will favor the vegetated trail edges if the main trail is too rugged from exposed roots and rocks. This active avoidance of official trails can lead to widening and the development of UCT's.

Figure 15: Trail ponding after rain event.

It is likely that we missed some of the UCT's during our survey, especially since it is common practice for the trail crews to use fallen branches and cuttings to obscure UCT's from the main trails. Some UCT's were visible from aerial photos that were not visible from the ground. However, it is difficult to differentiate between a deer path and a UCT in an aerial photo. On the ground we had the benefit of being able to observe footprints, foliage cover, and other clues to differentiate animal paths from UTC's. Additionally, UCT's tended to travel towards vistas, bluffs, rocky outcrops, or to ocean coves, as opposed to deer paths which often passed through thick brush. While conducting later surveys, we observed that some UCT's had been created since our initial mapping. This indicated that UCT's can be created quickly and the map should not be considered to be absolute. Managers should develop a protocol to identify and restore UCTs as they appear. Addressing UCTs as they are created would help prevent repeated use by other visitors. It is important to remember that UTC's were generated by the public exploring the area, without consideration for professional trail management and design. This causes UTC's to degrade at a rapid rate, leading to increased vegetation and soil loss.

The initial damage from people traveling off official trails is the trampling of vegetation and the exposure of the underlying soils to erosive forces. Even in the locations where the official trail is further from the coast, there are UCT's that traverse out to the bluff edges. In the example of the bluff on the north end of PLSNR, the evidence of user impact gets progressively greater as you approach the bluff (Fig. 12). This supports the idea that UCT's can be created by people seeking to get closer to the bluffs edge. On our initial walk through of PLSNR, there were some areas where it was difficult to distinguish between the official trails and the UCT's, even with the aid of the visitor map. The two areas where this issue was most prevalent was by the parking lots at Weston Beach, and at Granite Point. These UCT's are prevalent throughout PLSNR, with some extending past rod and cable fencing and signs asking for visitors to stay on the trails. Despite this, we still view rod and cable fencing as an effective tool for preventing off trail use because it reduces the severity of impact (Fig. 16).

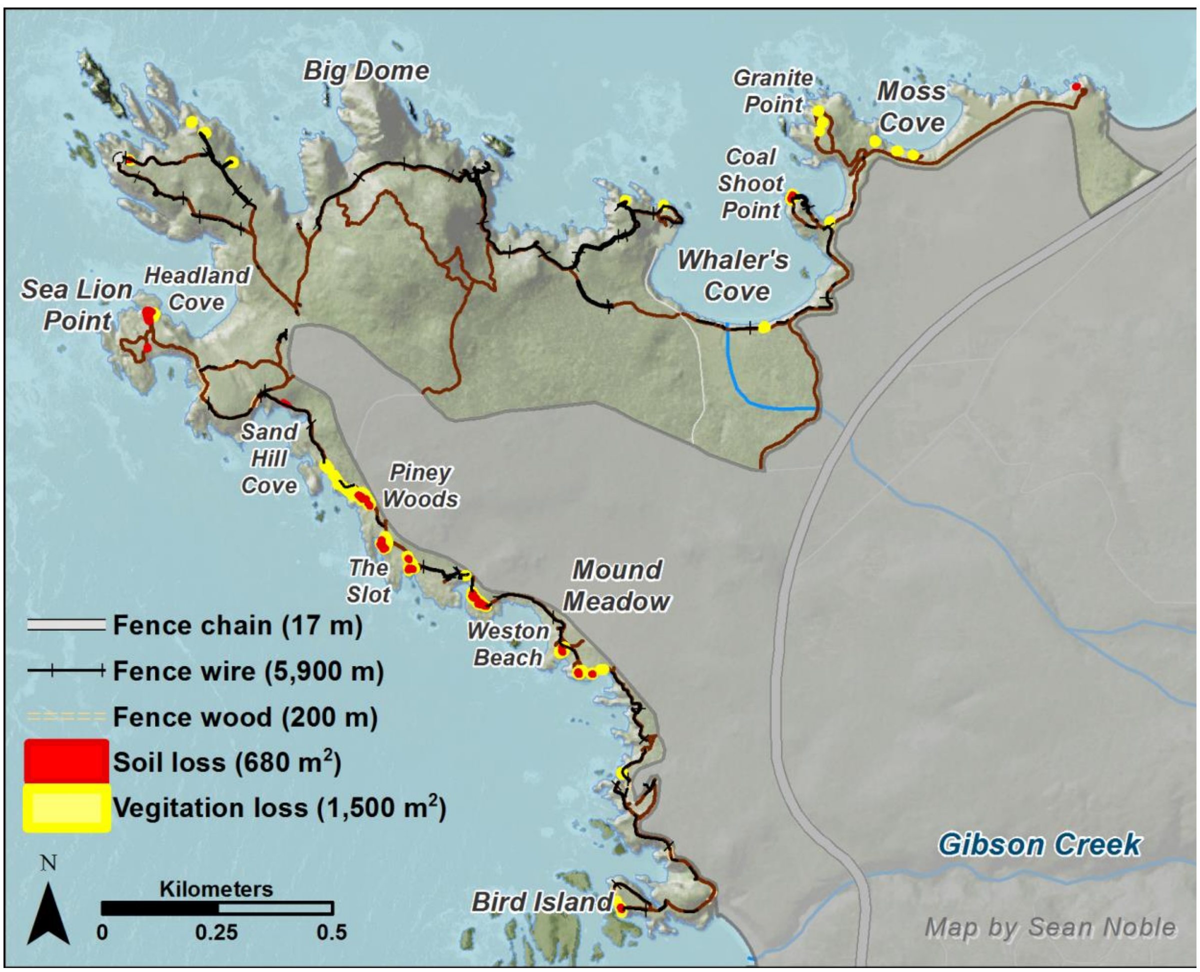


Figure 16: Areas of degradation vs the placement of fences along trails.

Evidence supports that UTC's can be created quickly by a small number of passes over a vegetated area. So, a single UCT extending past a fence could be the result of a small fraction of visitors willfully breaking park rules. In the areas without fences, we see dense networks of UCTs, or entire bluffs being completely devegetated from tramping (fig. 16). More research could build a better understanding of the interactions between visitors and managerial practices on the PLSNR.

Future research

To better understand the current state of PLSNR and how it is changing, we suggest:

- Further analysis of the effect of wind erosion on PLSNR and possible mitigation strategies.
- Ground truth erosion potential model.
- Incorporate trail orientation in suggested trail locations.
- Identify ideal vista points for trail destinations that do not compromise natural resources (soils and vegetation).
- Analyze low impact development options to capture water runoff and prevent discharge into the ASBS.
- Conduct a more thorough trail cross section survey and compare the results to the impact severities from the visual survey.
- Survey remaining bluffs, either through structure through motion photogrammetry or more traditional survey techniques.
- Analysis of what factors increase trail degradation i.e. incision and widening.
- Incorporate the area's archeological significance into analysis.
- Analyze the potential synergistic effects of sea level rise and anthropogenic impacts on PLSNR.

Recommendations

Visitors cause a number of harmful impacts to protected resources by:

- Widening trails through vegetation trampling.
- Compacting and dislodging soil particles
- Walking off trail and trampling sensitive coastal vegetation which accelerates erosion.
- Spreading invasive species
- Affecting wildlife behavior

Strategic trail design and adaptive management strategies can more effectively reduce some of these impacts. Ensuring that trails are oriented perpendicular to the terrain slope and avoiding areas of steep slopes can reduce erosion. Maintaining well established vegetated buffers around the coastal bluffs would reduce soil loss and sediment discharge into the adjacent ASBS. Vegetated buffers would also protect underlying and adjoining cultural sites. Bluff areas which have seen whole scale vegetation and soil loss should be the primary focus of restoration efforts. The restoration of fragmented bluff areas and the elimination of erosion into the adjacent ASBS would enhance habitat continuity, structure, and function along the entire coastal bluff zone. Closing redundant trails and those on unsustainable alignments would minimize total trial length, and reduce the amount of area that is exposed to visitor impacts. Additionally, trails should be located far away from sensitive wildlife to minimize visitor impact on their behavior. Counter examples of this include the Lower Sea Lion Point trail and the North Shore Trail between Guillemont Island and Whaler's Knoll Trail. However, much of this conservation effort will be lost if visitors do not stay on official trails.

The documented effectiveness of symbolic trail boarders (rod and cable fencing), trail signs, and education programs indicate that many visitors do not desire to damage protected areas. It is up to land managers to determine the best way to ensure that visitors know what conduct is appropriate to minimize their impact while visiting PLSNR. Because no method has been shown to be 100% effective, it seems logical that combining them would have the greatest effect. Education programs, like visitor guides, kiosks, and education and interpretation stations, can inform park visitors about the local habitat and the importance of proper conduct while visiting PLSNR. By ensuring that trails have at least symbolic borders (rod and cabling), visitors would easily be able to identify official trails. Well-designed education based signs can reinforce appropriate behavior and help educate visitors. Trailhead signs that remind visitors of the importance of staying on the official trials and being courteous while near wildlife have been shown to be effective. Smaller, less obtrusive signs could also be used in areas where off trail use is particularly evident. These efforts, combined with active efforts to restore UTC's as they occur, would reinforce the message of the importance of staying on official trails. For areas where symbolic fencing is not effective, park managers should consider installing more permanent wood fencing, like that at the cliff's edge at Sea Lion Point overlook. This wood fencing presents a stronger message that the area on the other side is off limits to visitors, and it weathers well in the harsh coastal environment.

We recommend that PLSNR adopt a single message to covey to visitors, and that all management strategies should be designed to reinforce that message. There should be an emphasis on the goals of PLSNR as a Reserve, and how all visitors to PLSNR should strive towards zero impact behavior. All trails should have at least symbolic borders, so visitors can easily identify official trails without consulting a guide or map. Trailheads should have signs that inform visitors about the significant features on that trail and why it is important to protect them. It should be emphasized that to protect the area, visitors must stay on official trails. Smaller signs reminding visitors of the importance of protecting the area, or of the possibility of a citation, have been shown to be effective in locations where off trail use continues. Ensuring that every visitor is exposed to this message removes the excuse of ignorance. This would allow land managers to assume that anyone participating in destructive behavior, including going off trail, is doing so purposefully, and should be subject to disciplinary action including citation by a park ranger or expulsion form PLSNR.

The trails themselves should be designed strategically with the goals of PLSNR in mind. As the Olmsted Brothers reported in their 1935 Master Plan Report Summary, “Damage by visitors is inevitable, but must not be allowed to exceed the natural restorative processes; since this would create cumulative depreciation. Moreover, this balance should be maintained at as high a level of natural values as possible”. The 1935 Olmsted Brother report also refers to coastal bluff areas and makes note that, “Because of the vulnerability of the vegetation and soil here, and because of the concentration of people, damage is considerable. Trails are therefore necessary, sufficient for the movement of the public, and people should be kept to them as closely as possible”. The 1935 Olmsted Brothers report also mentions gully erosion as being a concern as well as “volunteer trails” and makes notation of making trails less damaging and obliterating needless trails. Currently, trails trace the edges of the bluffs, which, unfortunately, maximizes the impact to the bluffs by diminishing the vegetation and increasing erosion. As a result, bluff retreat due to visitor use is of real concern. Another common trail design in PLSNR are trail loops around points e.g. Bird Island, Coal Shoot Point, and Sea Lion Point. Again, these loops maximize bluff exposure to visitor impacts. Instead of a loop, a single trail positioned along the center of a point would move the majority of the impact away from the bluffs edge. However, visitor enjoyment must be taken into account, as the draw of PLSNR is largely due to its iconic landscape and bluffs. Land managers must balance providing access and natural resource protection. UCT’s can inform land managers about which types of locations are desirable for visitors, as they are willing to travel off trail to get there. Trails should minimize visitor impact while giving them access to PLSNR’s inspirational beauty. Carefully chosen vista points at the ends of trails should be designed to accommodate groups of visitors while providing views and educational opportunities.

We used the erosion potential model and the marine mammal view shed model to create a cost map for a distance path analysis to generate an example of an alternate trail design (Fig. 17). We chose a number of locations that are currently used as vista points and generated the least cost paths to these points from the three main parking areas. This trail network reduces the 10.5 km of existing trails we surveyed to an estimated 8.5 km, while maintaining access to the iconic vista points and beaches in PLSNR. It also moves the trails further from the bluffs and marine mammal haul out areas, and avoids areas of predicted high erosion potential. We were only able to use the haul outs that we observed being used during field sessions. A more comprehensive map of favorable marine mammal haul outs could significantly alter or add to this model.

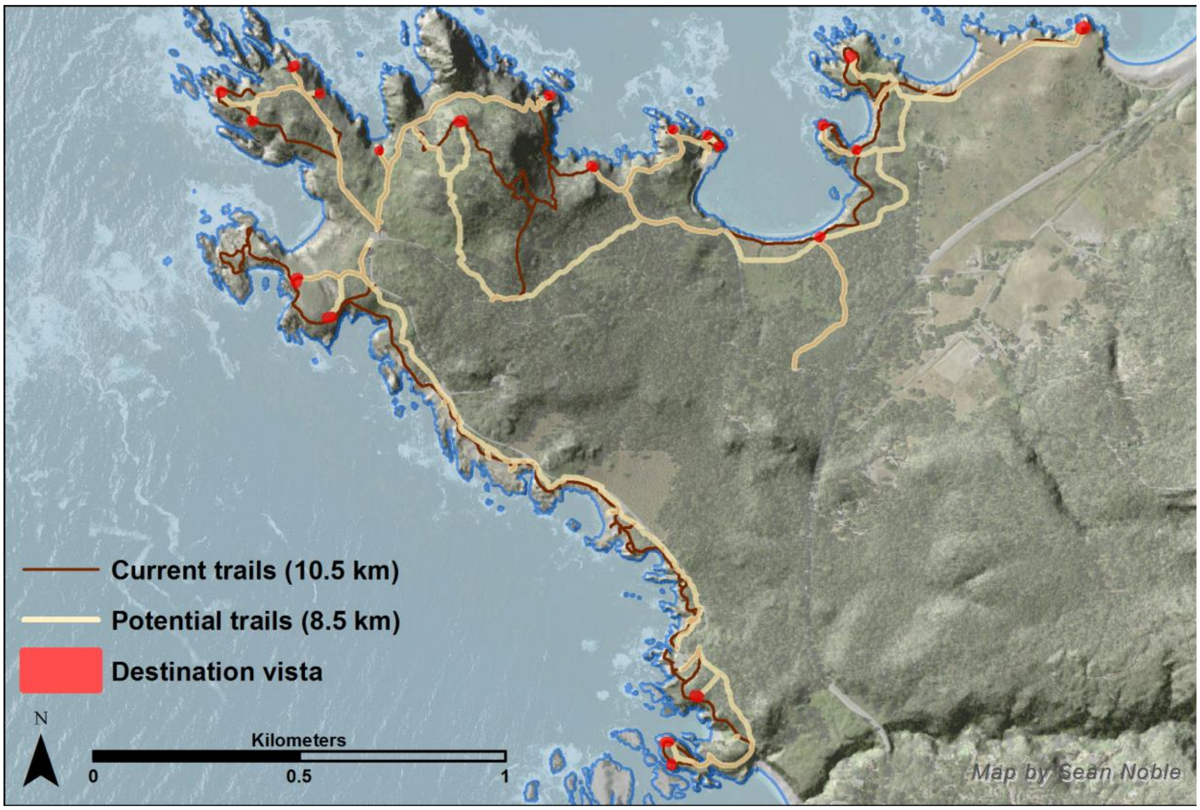


Figure 17: Alternate trail paths as determined by a least cost analysis from the parking lots to selected vista points. The vista points were selected from existing vista location and areas that were the destinations of large numbers of UCT's. These trails do not take into account the orientation in respect of the hill slope.

Specific Recommendations

We developed more detailed recommendations for some of the heavily impacted sites. These recommendations are based off the relevant literature, field observations, field measurements, and the erosion potential and marine mammal view shed models.

Granite Point

Granite Point has three main issues that are leading to increased degradation of the area. First, the main trail leading to the loop is heavily incised and located along the bluff edge. Second, the loop trail is poorly marked and often indistinguishable from UCT's. Lastly, the majority of UTC's lead to a large rock at the high spot on the point, indicating that this is a desirable destination for visitors. If there is a specific reason why land managers wish to keep visitors away from the rock, then that should be conveyed to visitors. Alternatively, if the loop is closed and a single well marked trail is provided that leads to a vista area around the rock, it is likely that much of the degradation to this location could be minimized (Appendix A, Fig. 18).

Sand Hill Cove

The trail leading down from the Sand Hill trail past Sand Hill Cove is severely degraded. It is heavily incised and shows significant widening. Additionally, the steps are undercut and in need of repair, and the trail traverses harmfully close to known marine mammal haul outs. These observations were supported by the trail cross sections which predicted that this trail had the highest volume of soil loss to erosion. Soil loss within this section of trail discharges directly into the ASBS. If this trail is rerouted the railroad tie step system should be removed, the area revegetated using native coastal scrub species, and temporary BMPs installed to arrest erosion until such time that native plants can become well established. Given the steep slope and loose soil present in this area, we recommend that this trail be relocated to the interior upland slope adjacent to the road (Appendix A, Fig. 19). A rerouted Sand Hill trail would retain excellent vistas of the ocean, coves and bluffs of this section of PLSNR, while reducing erosion and increasing the vegetated buffer between the trail and the ASBS.

Weston Beach

The trail around Weston beach is being encroached upon by a number of knickpoints which threaten the trail and can become a safety hazard (Fig 20). There is not enough room between the road and the bluff for a trail and an effective vegetated buffer. One solution would be to reduce the road down to one lane through this area (Appendix A, Fig. 21). The existing trail should be replanted to help reduce the erosion of the bluff to a more natural pace. If access to the beach is to continue, we suggest that clear access trails be provided with signs educating visitors on proper behavior at Weston Beach. Currently, there is a dense network of UCT's on the South end of Weston Beach that extend out onto

Figure 20: Knickpoint along Weston Beach.

Figure 22: Sign reading "Weston Beach" oriented so that visitors must walk off the official trail in order to read it.

the bluffs (Appendix A, Fig. 21). There is ambiguity as to what areas are appropriate for visitors to tread, a reality epitomized by a sign placed so that visitors are required to leave the trail to read it (fig. 22). The UTC's here show signs of active widening and incising and should be restored with native grasses. The remaining bluffs should be revegetated and restored using BMP's. These bluffs should be fenced on both the beach side and the trail side to eliminate ambiguity as to where visitors are supposed to be. Additionally, the two dirt parking lots in this area generate runoff that discharges into the ASBS. It would be in line with the goals of PLSNR to close these parking lots and replant them with native plants.

Coal Shoot Point

The junction area of Coal Chute Point and Granite Point trails is showing signs of moderate bluff erosion. This area should be revegetated and fenced off to prevent hiking on this steep slope (this area is immediately around the existing bluff bench). The trail leading up to and around Coal Shoot Point is showing signs of incision and widening, while the bluff at the end of the point has a large area of vegetation and soil loss. There is little vegetation at the point to prevent runoff from discharging directly into the ASBS. The extreme case would be to close off access to Coal Shoot Point and to restore the area to natural conditions. If access to the point is deemed necessary, then we recommend closing the trail on the East side of the loop, as that trail segment is experiencing the majority of the degradation, partially due to its alignment parallel to the hill slope (Appendix A, Fig. 23). Closing this trail segment has the added benefit of helping to keep visitors away from nesting great blue herons, which have taken up residence in the trees at the top of the hill, and away from hauled out seals on the rocks below the cliffs on the east side on the point. We also recommend that the point itself be restored with soils, native plants, and that erosion control BMPs be implemented to minimize soil loss and discharging soils to the ASBS. A well designed fenced vista area could be constructed to help keep visitors away from the bluffs edge, and would enable the bluff to be restored.

Lower Sea Lion Point

Visitors are causing severe impacts on the entire Lower Sea Lion Point, including soil loss and impacts on marine mammals (Appendix A, Fig 24). We recommend closing this area to visitor access and that BMP’s be implemented to restore lost bluff habitat and return incised trails to the original slope contour, with native revegetation undertaken to stabilize soils at this well exposed site. Again, replanting the areas lost due to heavy human foot traffic would help prevent further erosion, and importing soil may be necessary to restore this area. With the recommended closure of Lower Sea Lion Point, the trail that provides access to this area should likewise be subject to aggressive restoration BMP’s. The existing degraded trail poses several safety risks to people. This includes steep eroding slopes that are showing signs of active movement: headcuts working their way back to the active trail and an actively eroding bluff exposing visitors to a precipitous vertical cliff. Additionally, UTC’s in this unstable and unsafe area pass above and through a rare sand dune, which is experiencing significant soil loss as a result. Fortunately, the trail on the upper bluff provides spectacular views of this area and of the marine mammals that have reoccupied this area, while keeping visitors at a respectful distance.

ASBS Discharge

Sediment runoff from trails and parking lots into the ASBS should be minimized or prevented altogether. By increasing the distance between trails and the ocean, the amount of sediment discharged into the ASBS would be reduced. Whenever possible, vegetated buffers along the bluffs should be restored and protected.

Currently, all of the coastal parking areas within PLSNR, except Sea Lion Point parking lot, have little or no vegetated buffer and are discharging directly into the ASBS. The original General plan already recommends the closure of the coastal dirt parking lots along the road, and we support this recommendation.

If the Bird Island parking lot is to persist, then steps should be taken to stop runoff from flowing directly into the ASBS (Appendix A, Fig. 25). Possible techniques for stopping runoff are: Capturing runoff and diverting it to a percolation pond or bioswale, installing pervious pavement, or closing the seaward section of the parking lot and restoring it back coastal scrub to create an adequate vegetated buffer to capture sediment before stormwater is directed to the ASBS. A specific survey of this area should be conducted to determine the best possible solution for stopping excessive sediment discharge.

The parking lot at Whalers Cove presents the biggest challenge for stopping discharge into the ASBS. The parking lot consists of decomposed granite over substrate, is directly adjacent to the ASBS, and includes a diver access ramp. This parking lot is the access point for divers, and is an important feature to maintain PLSNR as one of the world's premier dive locations. This creates a conflict between the educational and conservation goals of PLSNR. While the General Plan states that the priority in such conflicts should be the preservation of the area, there are other potentially options to accommodate both goals, though they may require significant and disruptive work to be conducted.

One possibility would be to capture the run off into a water storage tank. Unfortunately, it would then need to be pumped to a location that can percolate or process the water appropriately. This would require significant construction and infrastructure be installed, counter to the original goals of PLSNR. Another option may be to reduce the size of the parking area, which would make capturing run off a more manageable issue. In general, parking for hikers should be located away from the ocean. By only providing enough parking for divers, the Whalers Point parking area could be drastically reduced (Appendix A, Fig. 26). Imported soil and vegetation may be able to effectively filter run off, if it is diverted appropriately. Before implementing of any plans, careful consideration should be taken to determine the amount of water that would need to be accommodated and what mitigation techniques would be most appropriate, or even possible, for this location. Repaving the road down to the parking area with pervious pavement may also significantly reduce the amount of discharge. Other studies should assess what the underlying substrate consists of i.e. is the subgrade material in the parking lot rip-rap boulders or bedrock.

Coastal bluffs

Our survey revealed that many of the southern coast bluffs of PLSNR had significant areas where the vegetation was trampled or was completely gone (Fig. 27 and Fig. 28). The lack of vegetation fragments important coastal bluff habitat, exposes the bluffs to erosion, and effects the aesthetic qualities of PLSNR. We observed that devegetated areas appeared to have less soil then areas that still had vegetation. We used the points taken with the RTK GPS to correct for error under heavy vegetation on the DEM generated from the photogrammetry survey. Cross sections of the Slot 1 bluff show that the vegetated areas have more soil then the surrounding bare ground (Fig. 29). We recommend planting

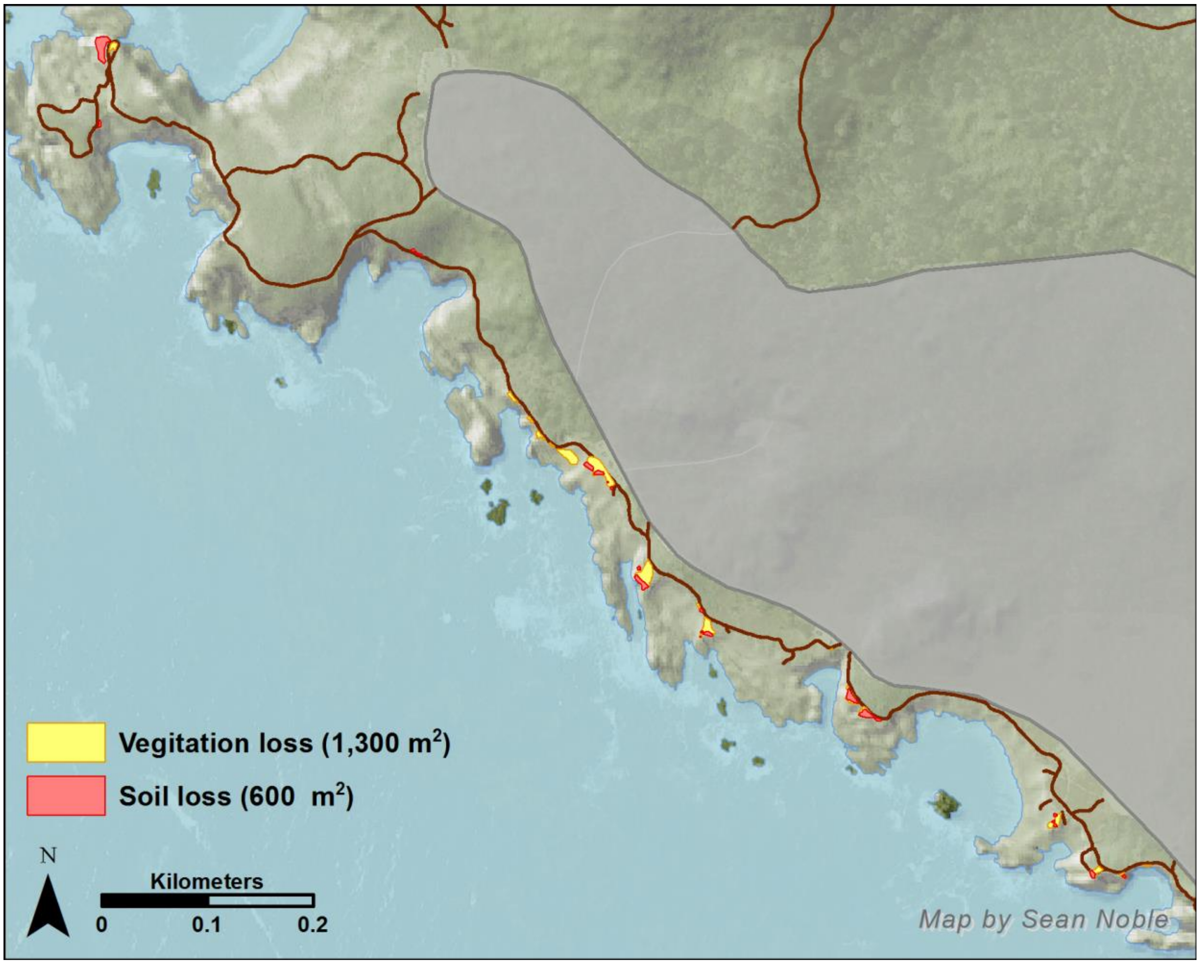


Figure 27: Areas of vegetation and soil loss on the bluffs along the southern coast of PLSNR.

new vegetation on the bluffs where soil loss is not too severe to inhibit plant growth. In locations where a significant amount of soil has already eroded, transporting new soil into PLSNR may be the best option. Additional erosion control BMPs during the plant establishment period would help assure that soils remain on site until the native plantings become well established and provide protection to the underlying soils. Restoring the vegetation to these bluffs is critical preventing further anthropogenic soil loss in PLSNR and for preserving its value as a natural resource.

Figure 28: Comparison of bluffs from coastal photographs taken in 1979 (Picture A) and 2013 (picture B), showing the reduction in vegetation. These two bluffs pictured are located just south of The Slot, and ware referred to as Slot 1 (red) and Slot 2 (yellow) in our surveys. (California Coastal Records Project *http://www.californiacoastline.org/***)**

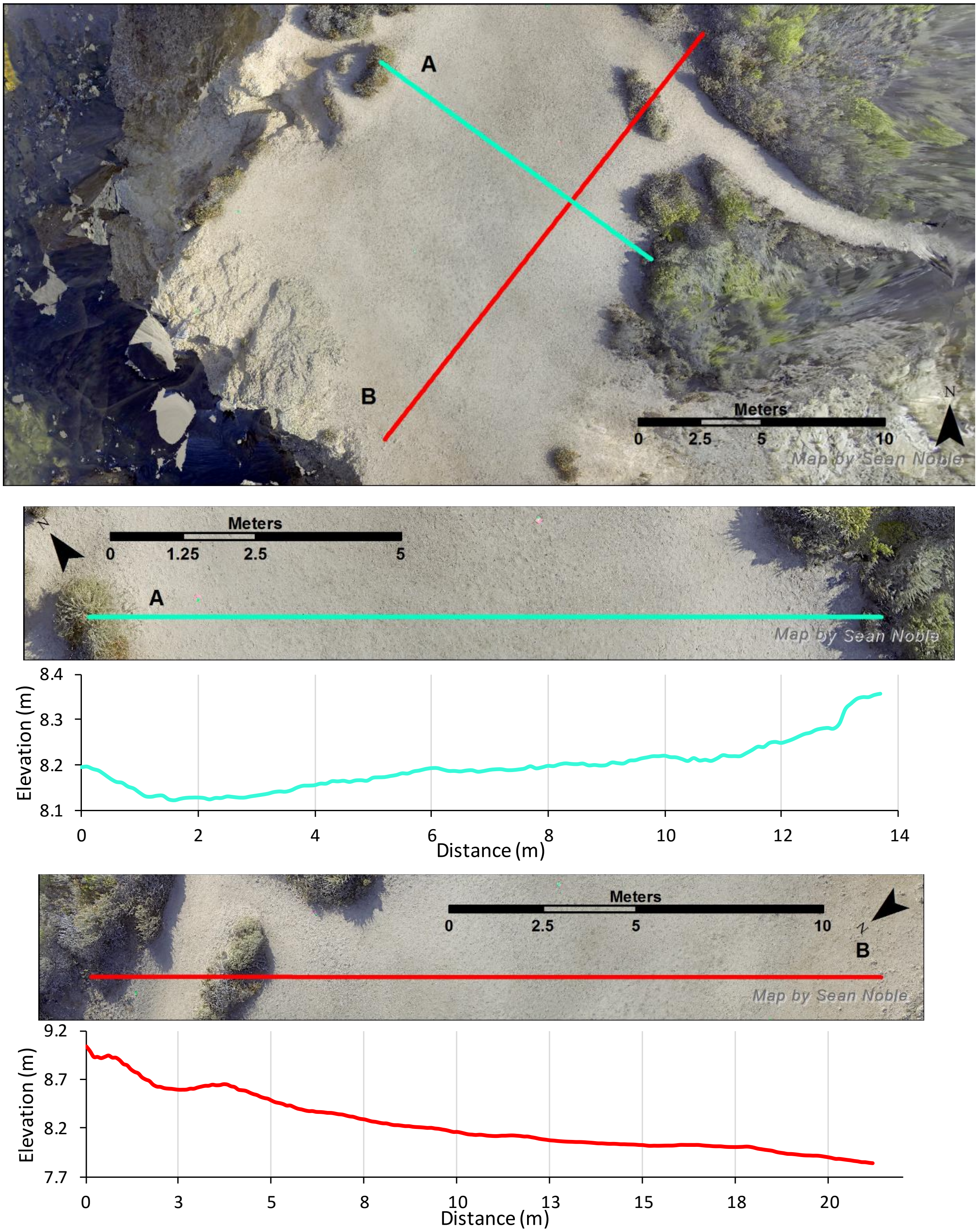


Figure 29: Cross sections of the Slot 1 bluff from the photogrammetry survey. The areas that still have vegetation were approximated 0.1 – 0.2 m higher than the adjacent devegetated areas.

References

De Baets S, Poesen J, Gyssels G, Knapen A. 2006. Effects of grass roots on the erodibility of topsoils during concentrated flow. Geomorphology 76:54–67.

Bernstein JA, Alexis N, Barnes C, Bernstein IL, Nel A, Peden D, Diaz-Sanchez D, Tarlo SM, Williams PB, Bernstein JA. 2004. Health effects of air pollution. J. Allergy Clin. Immunol. 114:1116 – 1123.

Bhuju DR, Ohsawa M. 1998. Effects of nature trails on ground vegetation and understory colonization of a patchy remnant forest in an urban domain. Biol. Conserv. 85:123–135.

Bochet E, García-Fayos P, Poesen J. 2009. Topographic thresholds for plant colonization on semi-arid eroded slopes. Earth Surf. Process. Landf. 34:1758–1771.

Bradford LE, McIntyre N. 2007. Off the beaten track: Messages as a means of reducing social trail use at St. Lawrence Islands National Park. J. Park Recreat. Adm. 25.

Bryan RB. 2000. Soil erodibility and processes of water erosion on hillslope. Geomorphology 32:385–415.

Cassini MH. 2001. Behavioural responses of South American fur seals to approach by tourists—a brief report. Appl. Anim. Behav. Sci. 71:341–346.

Chen W, Zhibao D, Zhenshan L, Zuotao Y. 1996. Wind tunnel test of the influence of moisture on the erodibility of loessial sandy loam soils by wind. J. Arid Environ. 34:391–402.

Cole DN. 1978. Estimating the Susceptibility of Wildland Vegetation to Trailside Alteration. J. Appl. Ecol. 15:281.

Cole DN. 1995a. Experimental Trampling of Vegetation. I. Relationship Between Trampling Intensity and Vegetation Response. J. Appl. Ecol. 32:203.

Cole DN. 1995b. Experimental Trampling of Vegetation. II. Predictors of Resistance and Resilience. J. Appl. Ecol. 32:215.

Cole DN. 2004. Impacts of hiking and camping on soils and vegetation: a review. Environ. Impacts Ecotourism 41:60.

Dale D, Weaver T. 1974. Trampling Effects on Vegetation of the Trail Corridors of North Rocky Mountain Forests. J. Appl. Ecol. 11:767.

Dosskey MG. 2001. Toward Quantifying Water Pollution Abatement in Response to Installing Buffers on Crop Land. Environ. Manage. 28:577–598.

Dunaway D, Swanson SR, Wendel J, Clary W. 1994. The effect of herbaceous plant communities and soil textures on particle erosion of alluvial streambanks. Geomorphology 9:47 – 56.

Ehrenfeld JG. 2003. Effects of Exotic Plant Invasions on Soil Nutrient Cycling Processes. Ecosystems 6:503–523.

Fattet M, Fu Y, Ghestem M, Ma W, Foulonneau M, Nespoulous J, Le Bissonnais Y, Stokes A. 2011. Effects of vegetation type on soil resistance to erosion: Relationship between aggregate stability and shear strength. CATENA 87:60–69.

Fullen M. 1985. Compaction, Hydrological Processes and Soil Erosion on Loamy Sands in East Shropshire, England. Soil Tillage Res. 6:17–29.

Ghahramani A, Ishikawa Y, Gomi T, Shiraki K, Miyata S. 2011. Effect of ground cover on splash and sheetwash erosion over a steep forested hillslope: A plot-scale study. CATENA 85:34–47.

Granquist SM, Sigurjonsdottir H. 2014. The effect of land based seal watching tourism on the haul-out behaviour of harbour seals (Phoca vitulina) in Iceland. Appl. Anim. Behav. Sci. 156:85–93.

Gyssels G, Poesen J, Bochet E, Li Y. 2005. Impact of plant roots on the resistance of soils to erosion by water: a review. Prog. Phys. Geogr. 29:189–217.

Leung Y-F, Marion JL. 2000. Recreation impacts and management in wilderness: A state-of-knowledge review. Vol. 5. p. 23–48.

Liddle MJ, Greig-Smith P. 1975. A Survey of Tracks and Paths in a Sand Dune Ecosystem I. Soils. J. Appl. Ecol. 12:893.

Lucas-Borja ME, Bastida F, Moreno JL, Nicolás C, Andres M, López FR, Del Cerro A. 2011. The effects of human trampling on the microbiological properties of soil and vegetation in mediterranean mountain areas. Land Degrad. Dev. 22:383–394.

Marine Mammal Protection Act of. 1972. Marine Mammal Protection Act.

Marion JL, Olive ND. 2006. Assessing and understanding trail degradation: results from big south fork national river and recreational area. Research/Resources Management Report. USDI National Park Service, Big South Fork National River and Recreation Area, Onieda, TN.

Marion JL, Reid SE. 2007. Minimising Visitor Impacts to Protected Areas: The Efficacy of Low Impact Education Programmes. J. Sustain. Tour. 15:5–27.

Olive ND, Marion JL. 2009. The influence of use-related, environmental, and managerial factors on soil loss from recreational trails. J. Environ. Manage. 90:1483–1493.

Olmsted Brothers. 1935. Point lobos Reserve Master Plan Report. [accessed 2016 Jul 2]. http://pointloboshistory.com/vaughn-report/

Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M, Crist S, Shpritz L, Fitton L, Saffouri R. 1995. Environmental and economic costs of soil erosion and conservation benefits. Sci.-AAAS-Wkly. Pap. Ed. 267:1117–1122.

Popov VH, Cornish PS, Sun H. 2006. Vegetated biofilters: The relative importance of infiltration and adsorption in reducing loads of water-soluble herbicides in agricultural runoff. Agric. Ecosyst. Environ. 114:351–359.

Quansah C. 1981. The effect of soil type, slope, rain intensity and their interactions on splash detachment and transport. J. Soil Sci. 32:215–224.

Ravi S, D'Odorico P. 2005. A field-scale analysis of the dependence of wind erosion threshold velocity on air humidity. Geophys. Res. Lett. 32. [accessed 2015 Jul 2]. http://doi.wiley.com/10.1029/2005GL023675

Seabloom EW, Williams JW, Slayback D, Stoms DM, Viers JH, Dobson AP. 2006. Human impacts, plant invasion, and imperiled plant species in California. Ecol. Appl. 16:1338–1350.

Snyder SA, Whitmore JH, Schneider IE, Becker DR. 2008. Ecological criteria, participant preferences and location models: A GIS approach toward ATV trail planning. Appl. Geogr. 28:248–258.

Taylor HM, Burnett E. 1964. Influence of Soil Strength on the Root-growth Habits of Plants. Soil Sci. 98.

Torri D, Poesen J. 1992. The effect of soil surface slope on raindrop detachment. CATENA 19:561–578.

Tyser RW, Worley CA. 1992. Alien Flora in Grasslands Adjacent to Road and Trail Corridors in Glacier National Park, Montana (U.S.A.). Conserv. Biol. 6:253–262.

Van de Ven TAM, Fryrear DW, Spaan WP. 1989. Vegetation characteristics and soil loss by wind. J. Soil Water Conserv. 44:347–349.

Wimpey JF, Marion JL. 2010. The influence of use, environmental and managerial factors on the width of recreational trails. J. Environ. Manage. 91:2028–2037.

Wimpey J, Marion JL. 2011. A spatial exploration of informal trail networks within Great Falls Park, VA. J. Environ. Manage. 92:1012–1022.

Wolfe SA, Nickling WG. 1993. The protective role of sparse vegetation in wind erosion. Prog. Phys. Geogr. 17:50–68.

Yang M, Van Coillie F, Hens L, De Wulf R, Ou X, Zhang Z. 2014. Nature conservation versus scenic quality: A GIS approach towards optimized tourist tracks in a protected area of Northwest Yunnan, China. J. Mt. Sci. 11:142–155.

Young R, Wiersma J. 1973. The Role of Rainfall Impact in Soil Detachment and Transport. Water Resour. Res. 9:1629–1639.

Appendix A: Recommendation Figures

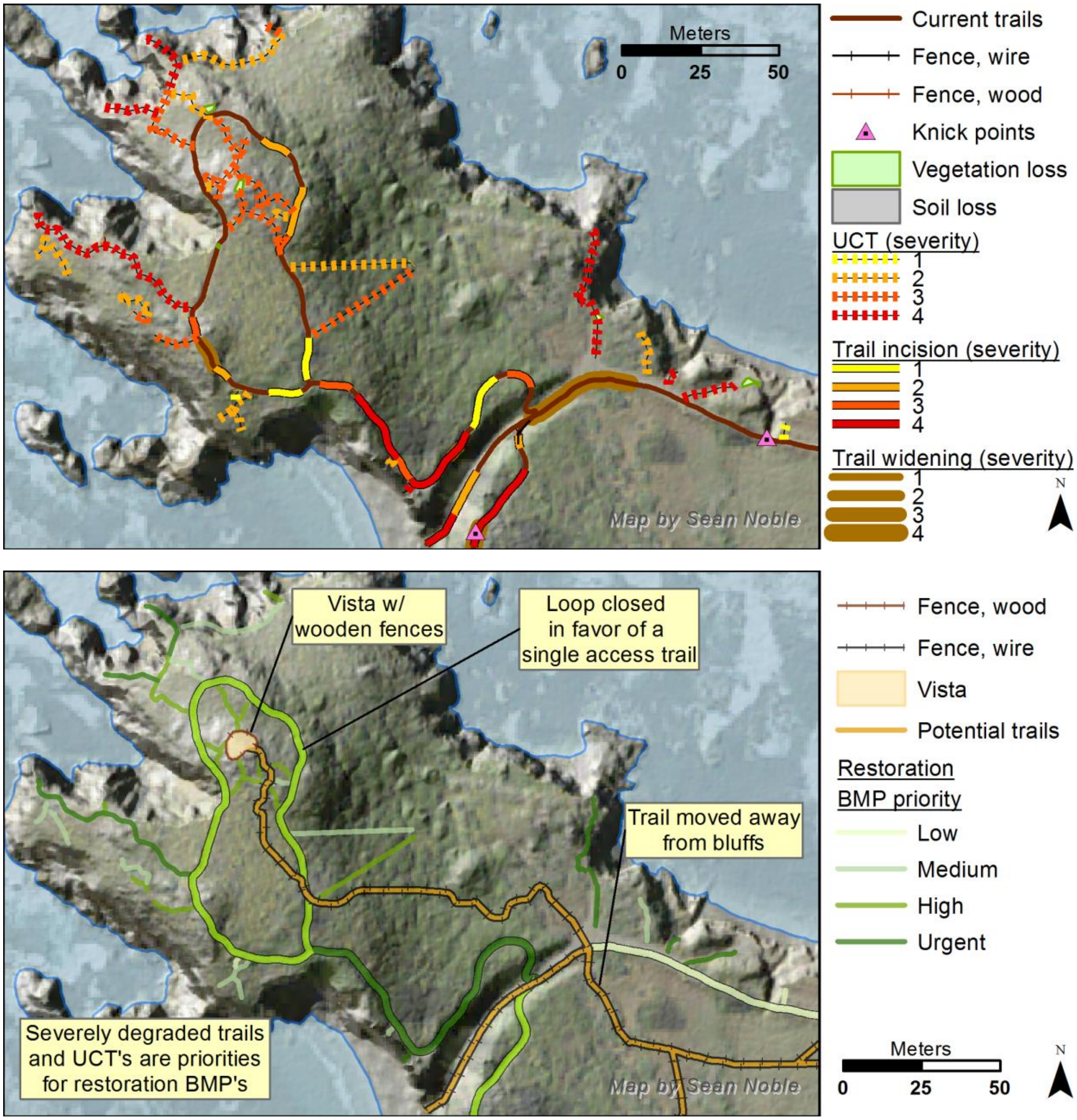


Figure 18: Suggested alternate trail paths around Granite Point. The vista point is location around a large rock at the peak on the point, which is the destination of most of the UCT's in the area.

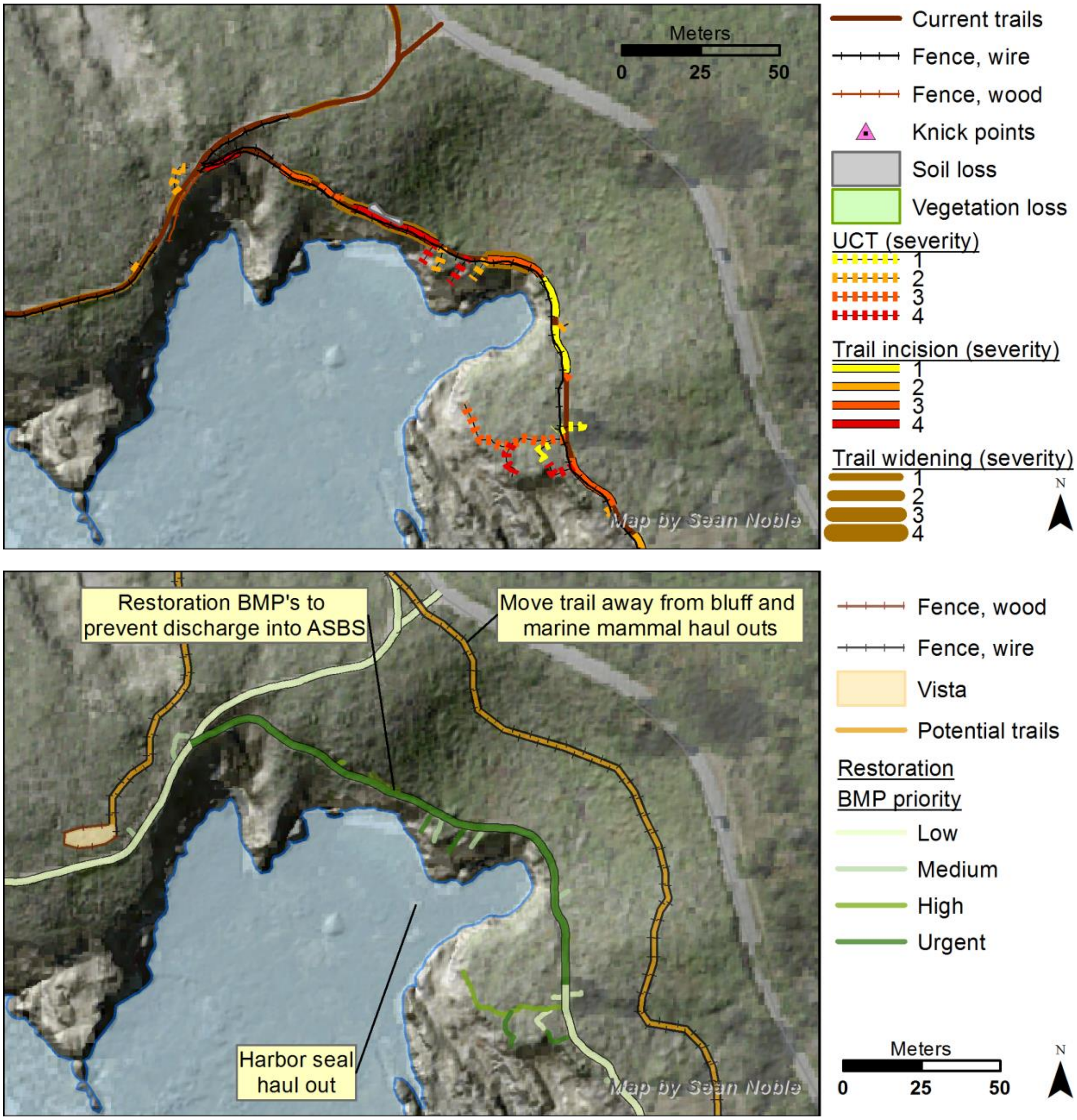
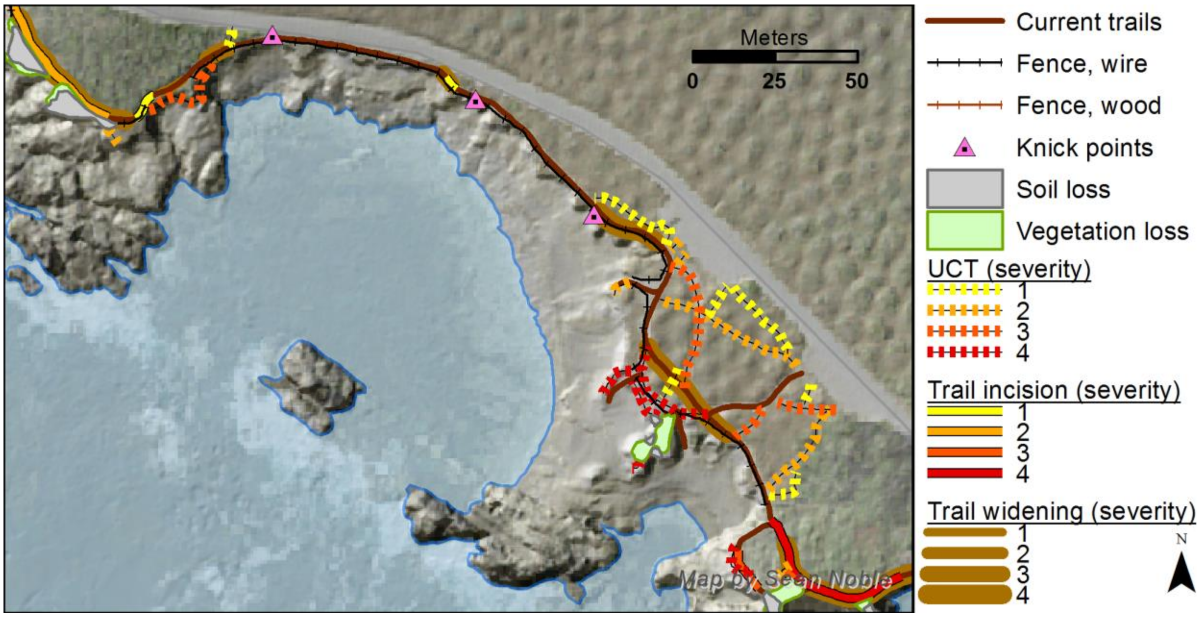


Figure 19: Suggested alternate trail paths around Sand Hill Cove. The vistas were chosen from the existing vista location and a point that has views of the Sand Hill Cove and the southern coast. The suggested trail does not account for orientation against slope and may be better positioned closer to the road.



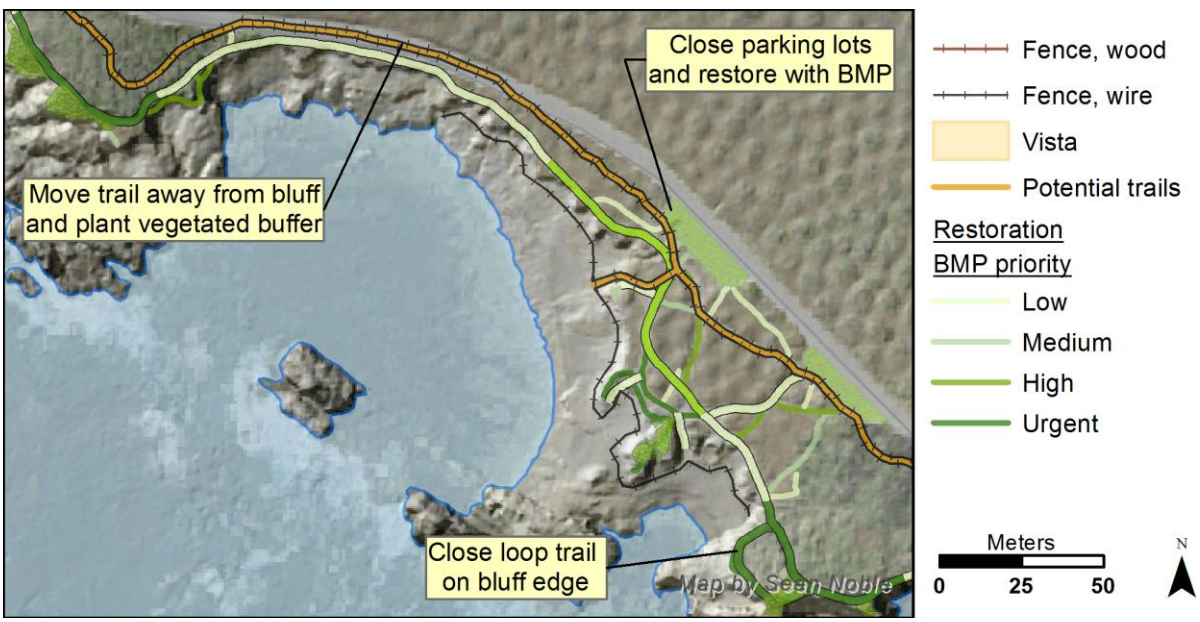


Figure 21: Suggested alternate trail paths around Weston Beach. It may be advisable to add an additional beach access on the North end of the beach, have official access is preferable to visitors accessing beaches by creating UCT's.

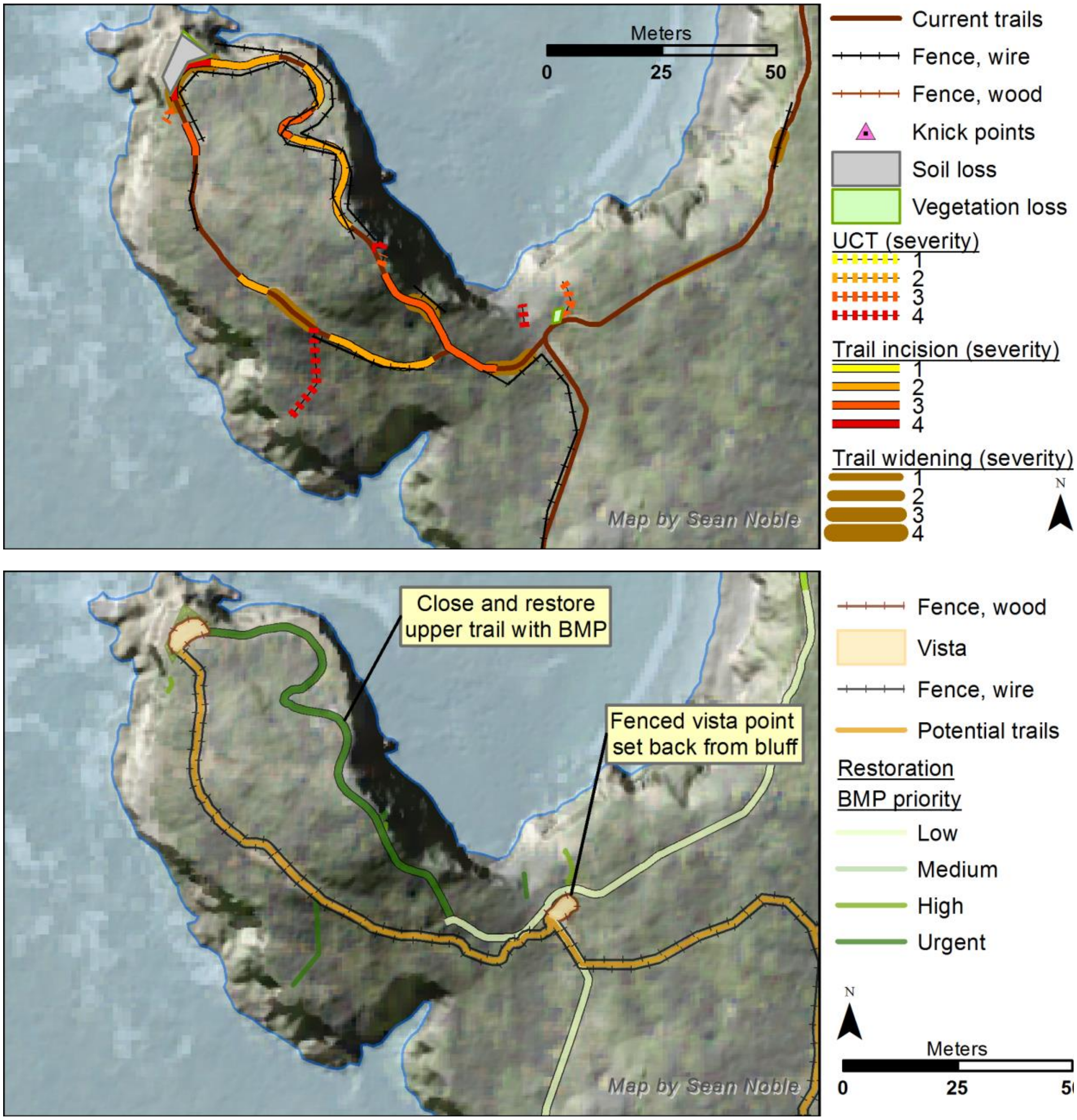


Figure 23: Suggested alternate trail paths on Coal Shoot Point. Closing the Northern section of trail would avoid most of the steeper section of the point. By fencing in a vista, a vegetated buffer can be implemented around the edge of the bluff.

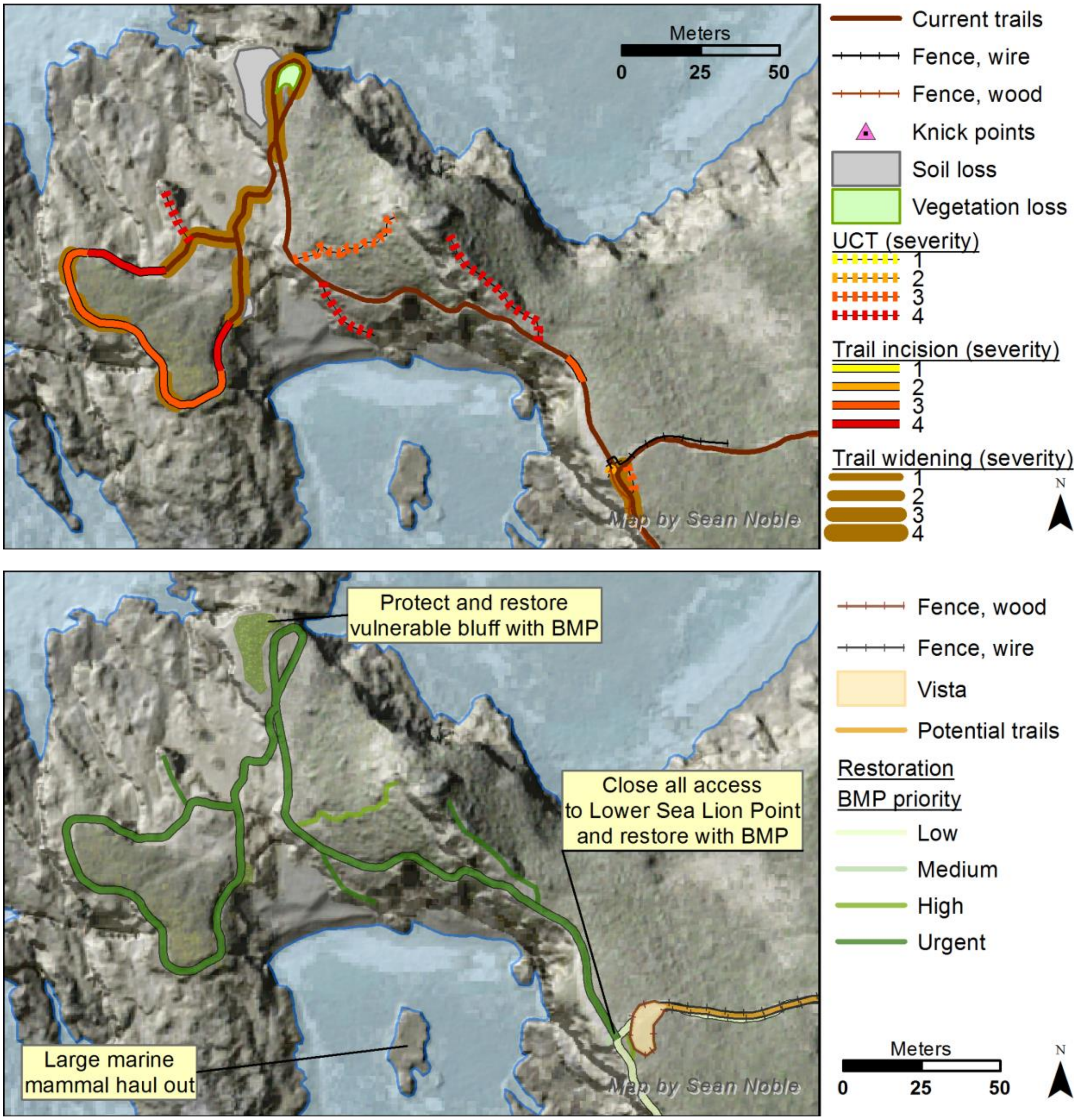


Figure 24: Suggested that Lower Seal Lion Point be closed to visitors and the vista be upgraded to include comprehensive wood fencing.

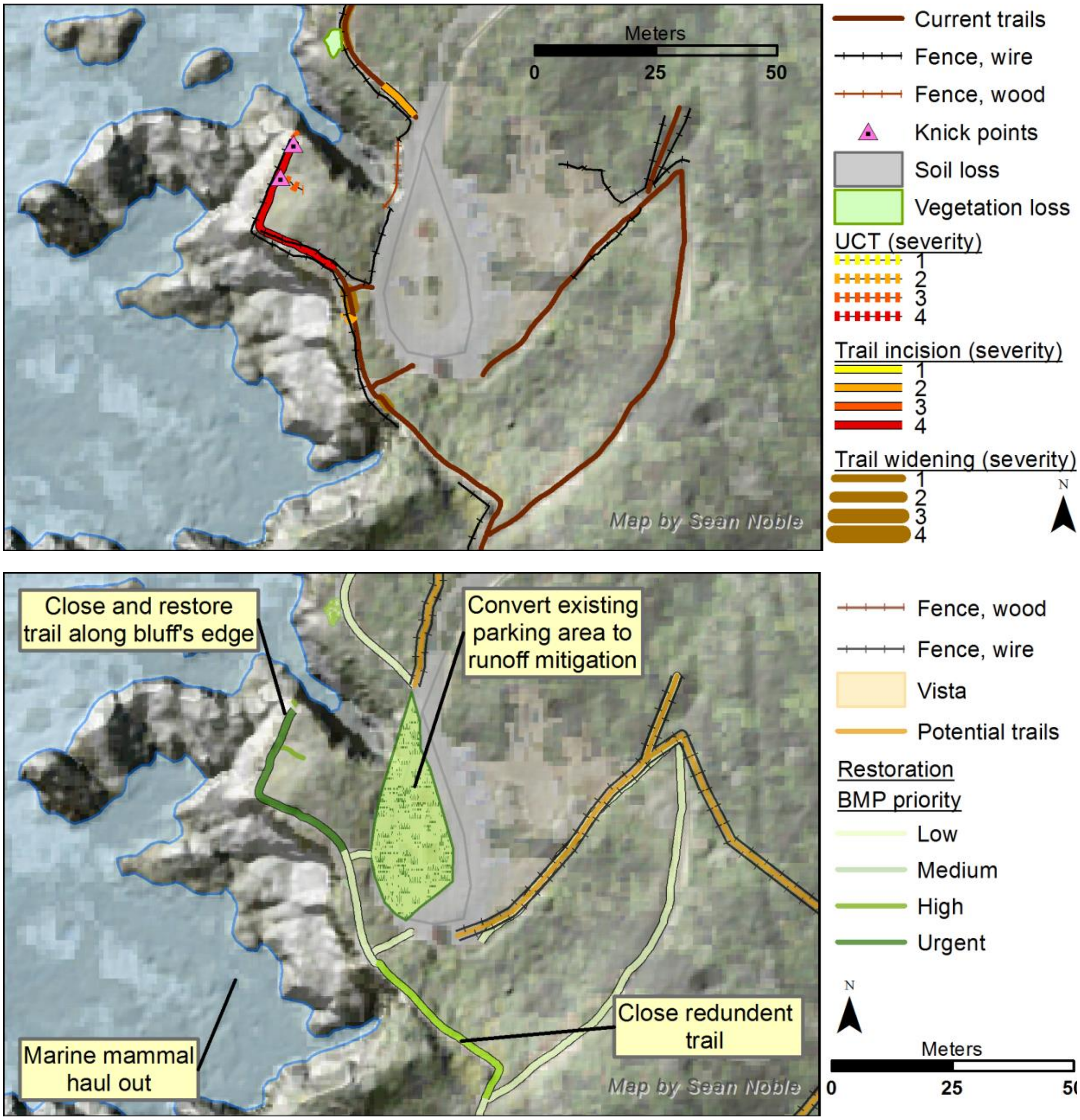


Figure 25: Suggested alternate design for the Bird Island parking area to avoid runoff into the ASBS. This would significantly reduce the amount of available parking in the area, but may be preferable to completely closing the parking lot. Significant research would have to be conducted to ensure that appropriate runoff mitigation could be implemented in the given space. Contrary to what the figure suggests using the existing ADA trail is preferable.

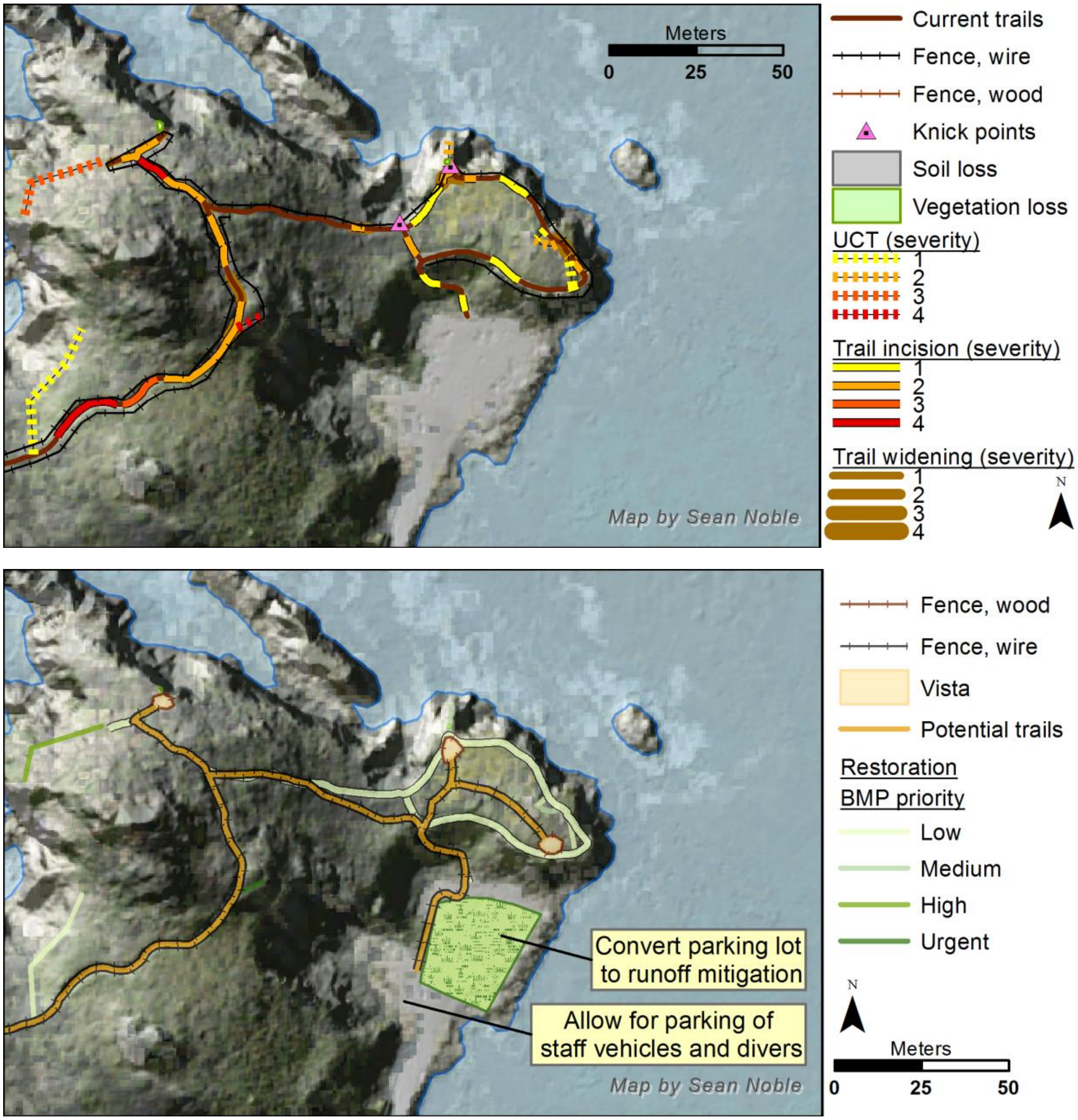
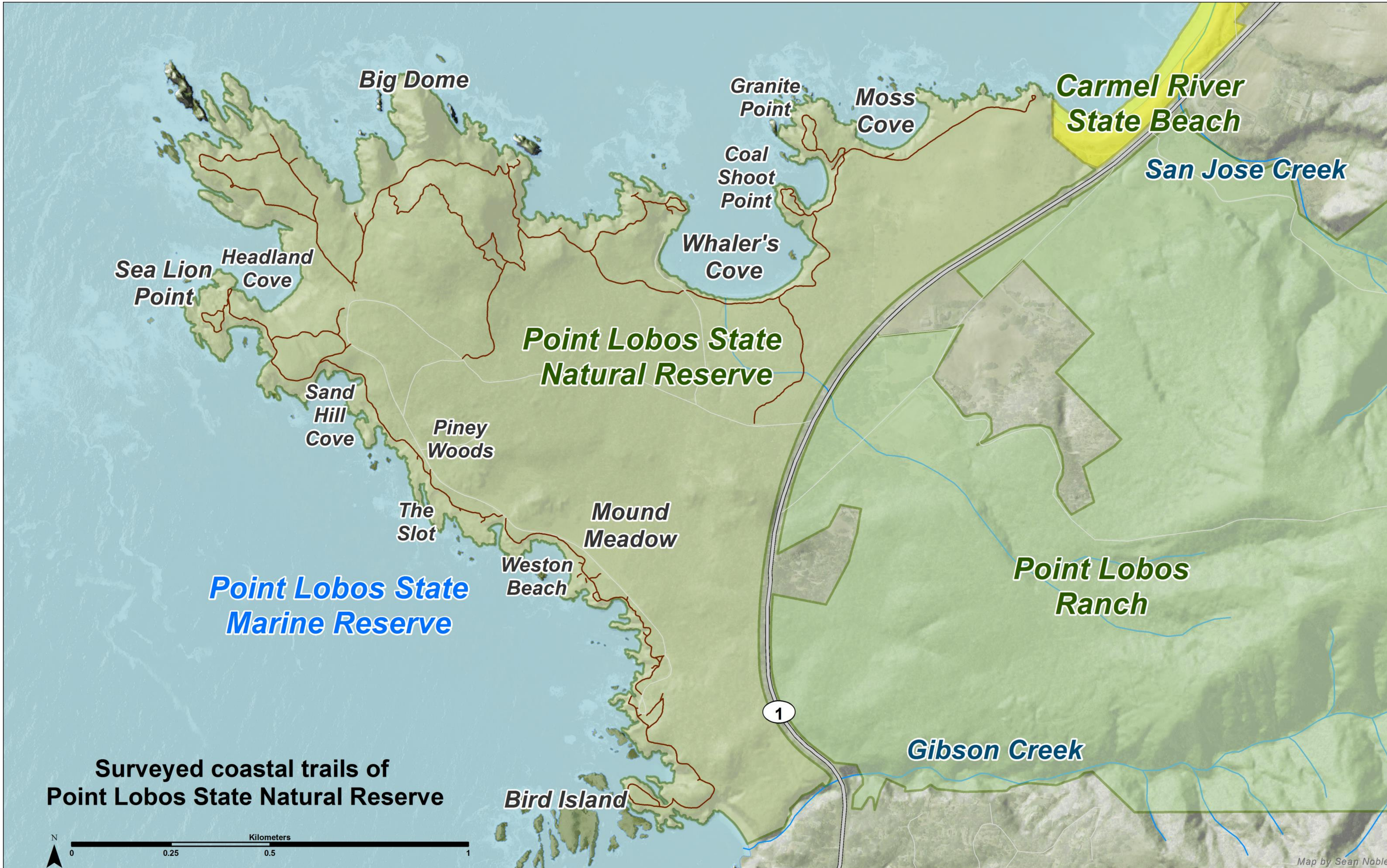
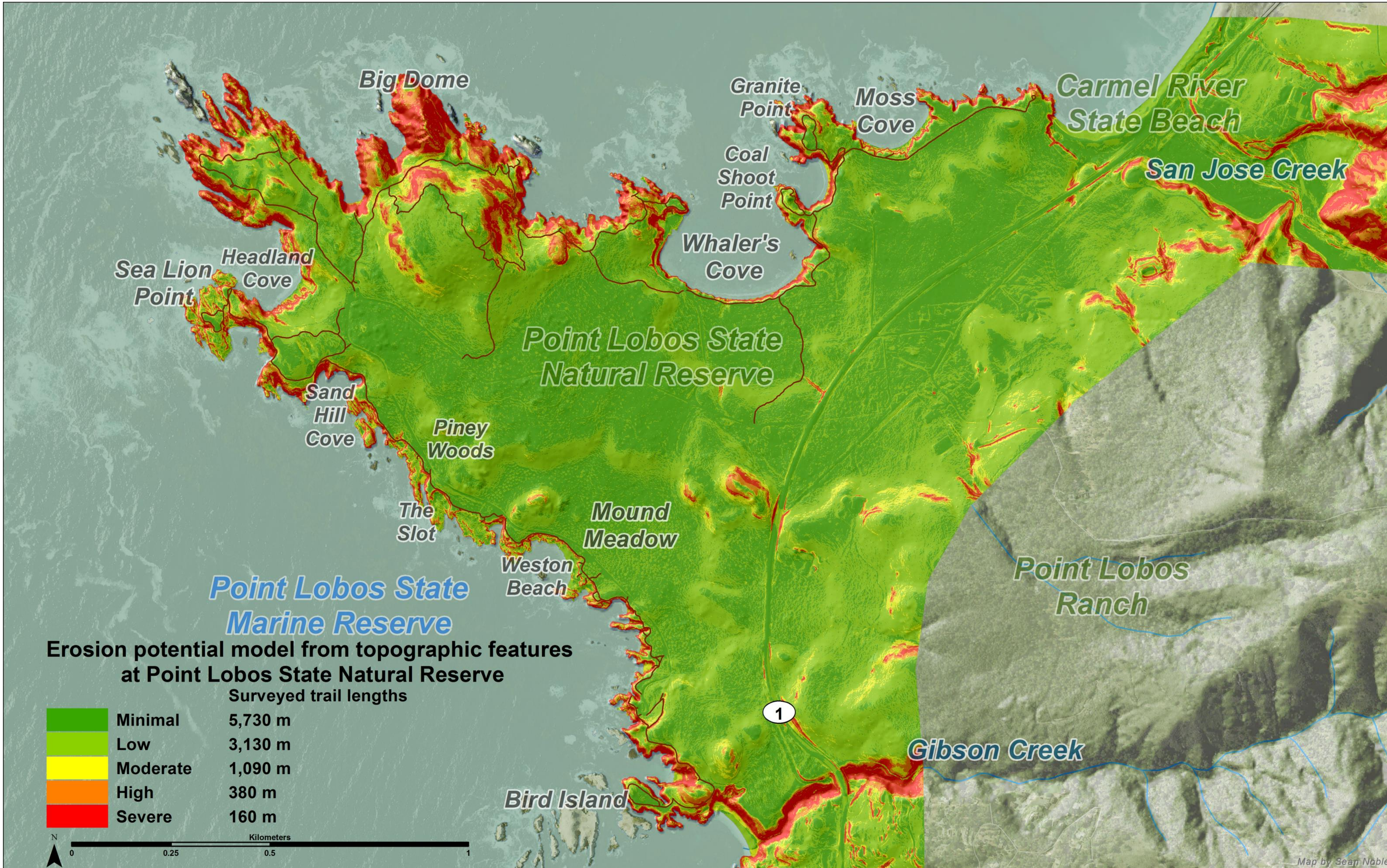


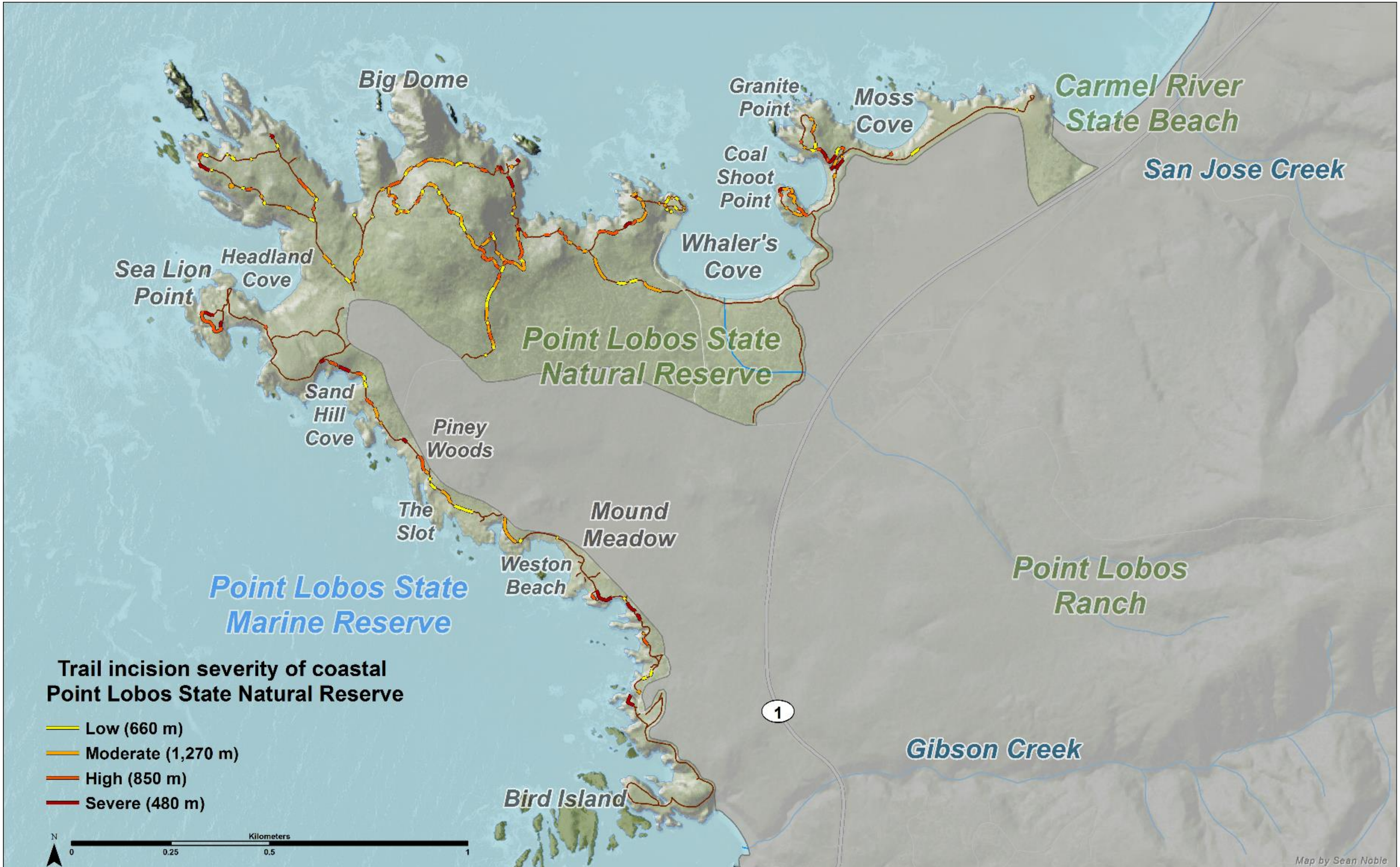
Figure 26: Suggested alternate design for the Whalers Point parking area to avoid runoff into the ASBS. Runoff down the road would have to be diverted towards the runoff mitigation. Similar to the Bird Island area, significant research would have to be done to determine what runoff mitigation could be implemented and how effective it may be.

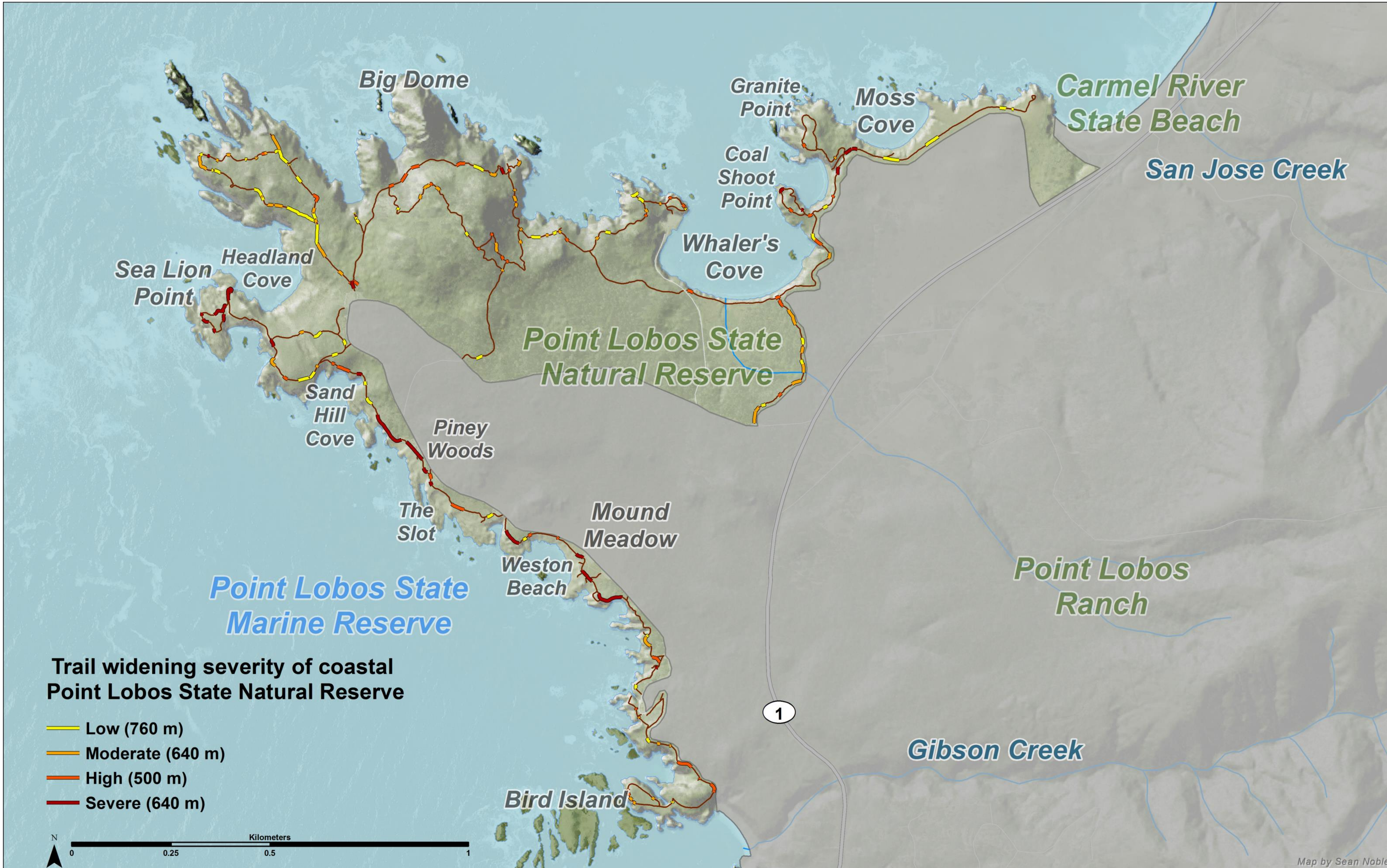
Appendix B: Full Size Maps



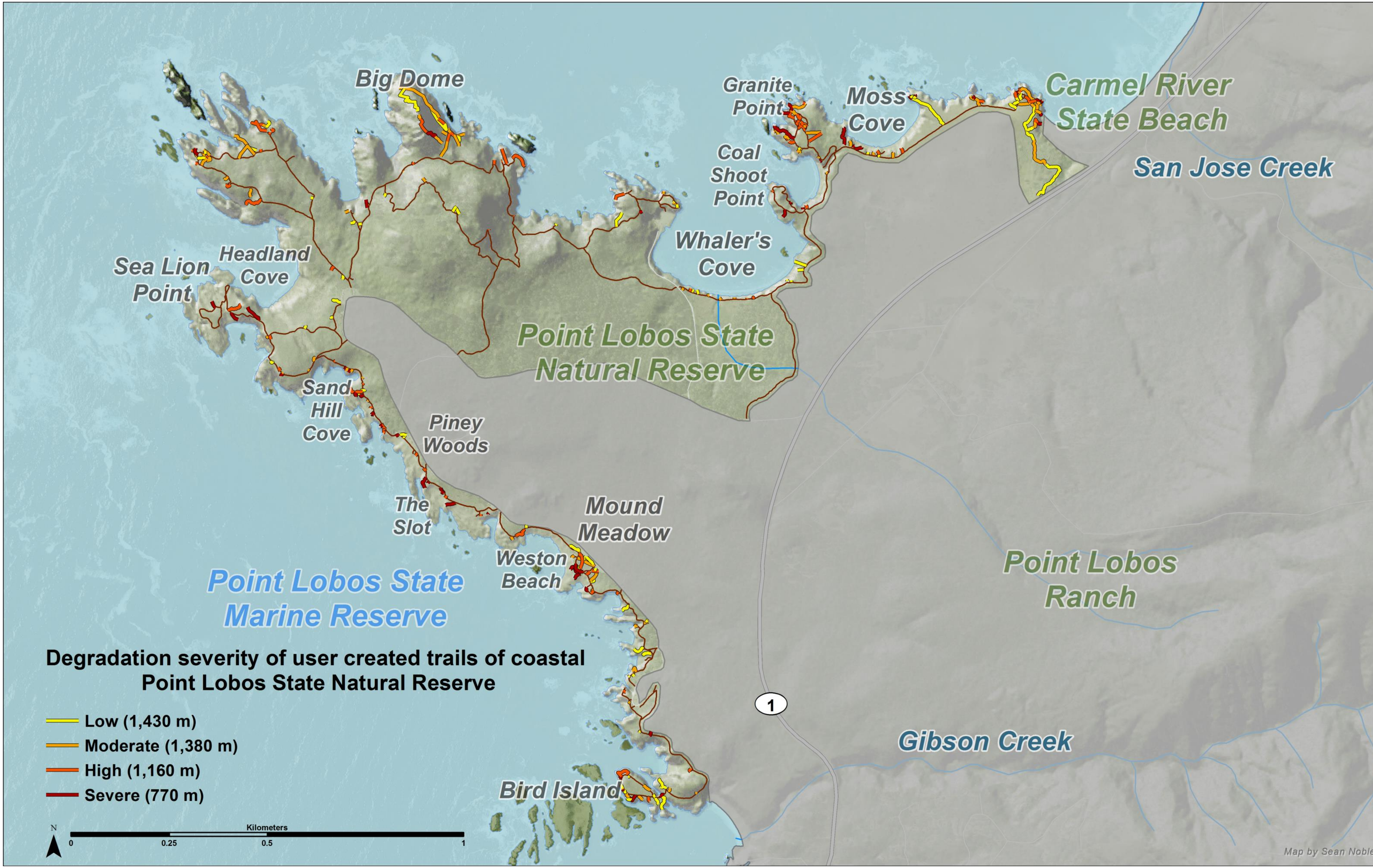
Surveyed coastal trails of
Point Lobos State Natural Reserve


Big Dome
Granite Point
Moss Cove
Carmel River State Beach
San Jose Creek
Coal Shoot Point
Whaler's Cove
Sea Lion Point
Headland Cove
Point Lobos State Natural Reserve
Sand Hill Cove
Piney Woods
The Slot
Mound Meadow
Weston Beach
Point Lobos Ranch
Point Lobos State Marine Reserve
1
Gibson Creek
Bird Island
Erosion potential model from topographic features at Point Lobos State Natural Reserve
Surveyed trail lengths
Minimal 5,730 m
Low 3,130 m
Moderate 1,090 m
High 380 m
Severe 160 m
N
Kilometers
0
0.25
0.5
1
Map by Sean Noble


Big Dome
Granite Point
Moss Cove
Carmel River State Beach
San Jose Creek
Coal Shoot Point
Whaler's Cove
Headland Cove
Sea Lion Point
Point Lobos State Natural Reserve
Sand Hill Cove
Piney Woods
The Slot
Mound Meadow
Weston Beach
Point Lobos State Marine Reserve
Point Lobos Ranch
Gibson Creek
Bird Island
1
Trail incision severity of coastal Point Lobos State Natural Reserve
Low (660 m)
Moderate (1,270 m)
High (850 m)
Severe (480 m)
N
Kilometers
0
0.25
0.5
1
Map by Sean Noble



Big Dome
Granite Point
Moss Cove
Carmel River State Beach
San Jose Creek
Coal Shoot Point
Whaler's Cove
Sea Lion Point
Headland Cove
Point Lobos State Natural Reserve
Sand Hill Cove
Piney Woods
The Slot
Mound Meadow
Weston Beach
Point Lobos State Marine Reserve
Point Lobos Ranch
Gibson Creek
Bird Island
1
Trail widening severity of coastal Point Lobos State Natural Reserve
Low (760 m)
Moderate (640 m)
High (500 m)
Severe (640 m)
N
Kilometers
0
0.25
0.5
1
Map by Sean Noble


Big Dome
Granite Point
Moss Cove
Carmel River State Beach
San Jose Creek
Coal Shoot Point
Whaler's Cove
Sea Lion Point
Headland Cove
Point Lobos State Natural Reserve
Sand Hill Cove
Piney Woods
The Slot
Mound Meadow
Weston Beach
Point Lobos Ranch
Point Lobos State Marine Reserve
Degradation severity of user created trails of coastal Point Lobos State Natural Reserve
Low (1,430 m)
Moderate (1,380 m)
High (1,160 m)
Severe (770 m)
1
Gibson Creek
Bird Island
N
Kilometers
0
0.25
0.5
1
Map by Sean Noble

Appendix C: Field Methods

Trail degradation

Walk the official trails, tracking there location on the GPS. Also marking the location of any fences boarding the trails and the type of fence (wooden, wire, or chain).

Track and note where the official trails show signs of incising and widening and rank into 1 of four severity categories. Each noticeable feature increases the severity level by one level of severity e.g. a 2.5 m trail with trampled vegetation on the sides would be a severity level 3. Some of the features are subjective and depend on the best judgement of the researcher.

Widening

- Trampled vegetation on the side of trail.
- Trail is wider than 1.5 m.
- Trail is wider than 2 m.
- Bare ground outside of clear trail boundary infrastructure.
- Trail splits into multiple paths around vegetation or obstructions.
- Signs of cutting corners at trail mergers.

Incising

- Trail is noticeably lower than surrounding soil height (~0.0 – 0.2 m).
- Trail is significantly lower than surrounding soil height.
- Trail is difficult to navigate due to sudden drops of exposed rocks.
- Signs of erosion on side of trail (trail boundary eroding down a slope, no clear trail boundary on downslope side).
- Trail is significantly lower than trail infrastructure.
- Rill channels are present.
- Exposed roots in trail boundary.
- Undercutting or eroding around trail steps.

User created trails

Walk user created trails (UCT) while tracking with the GPS and the UCT should be ranked into one of the following categories.

1. Trail is lightly used, and still has vegetation
2. Trail is moderately used, and has significant bare ground
3. Trail is heavily used, predominantly bare ground and can show signs of incising or widening
4. Trail is heavily used and has significant incising or widening.

- If a UCT shows evidence of causing bluff erosion it should be moved up one severity rank.
- If walking a user created would do any of the following then the trail should be marked with a point, photos should be taken, and the length of the trail should be digitally created using heads up digitizing.

- Walking the trail poses significant to the field tech.
- Walking the trail has significant risk of damaging plants of the bluff.
- Walking the trail would harass protected wildlife.
- Walking the trail risks inspiring user to also walk the trail.

Areas of disturbance

Create polygons of area of degradation. These are areas where there is no clear trail and is best represented as a polygon. These are split into two categories areas of vegetation degradation, and areas of significant soil loss.

Vegetation loss

- Significant area of trample vegetation.
- Significant area of bare ground with evidence of vegetation in nearby similar location.

Soil loss

- Exposed bare rock in an area of vegetation loss.
- Significant depression in soil in an area of vegetation loss.

Any one factor can overlap with another.

Examples:

- If there is an area of vegetation loss with a well-defined UCT running through it then the entire vegetation loss polygon are would be mapped as well as the UCT line cutting through the middle.
- If the main trail passes through a large vegetation/soil loss area and is not clearly defined, then the best guess should be made as to the path of the main trail and recorded, as well as the vegetation loss and soil loss polygons. The main trail in this instance would probably be marked as widening.

Appendix D: Field picture form rain event

These pictures were taken after a significant rain event on 1/6/2016.

Figure 27: Ponding and running water on Sand Hill Cove Trial. Lack of water control features leads to sediment transport and trail degradation.

Figure 28: UCT off of trail by Sand Hill Cove allowing for sediment to discharge directly into ASBS.

Figure 29: Water running down the road into the Piney Woods beach parking area. This increases the rate of bluff erosion by directing runoff onto the devegetated parking lot and bluff.

Figure 30: Sheet and rill flow across Piney Woods beach parking area to the adjacent devegetated bluff. The substrate form the parking area is being transported to the bluff and ocean.


Figure 31: Unimpeded flow of water across the bluffs at the Piney Woods beach parking area to the ocean.

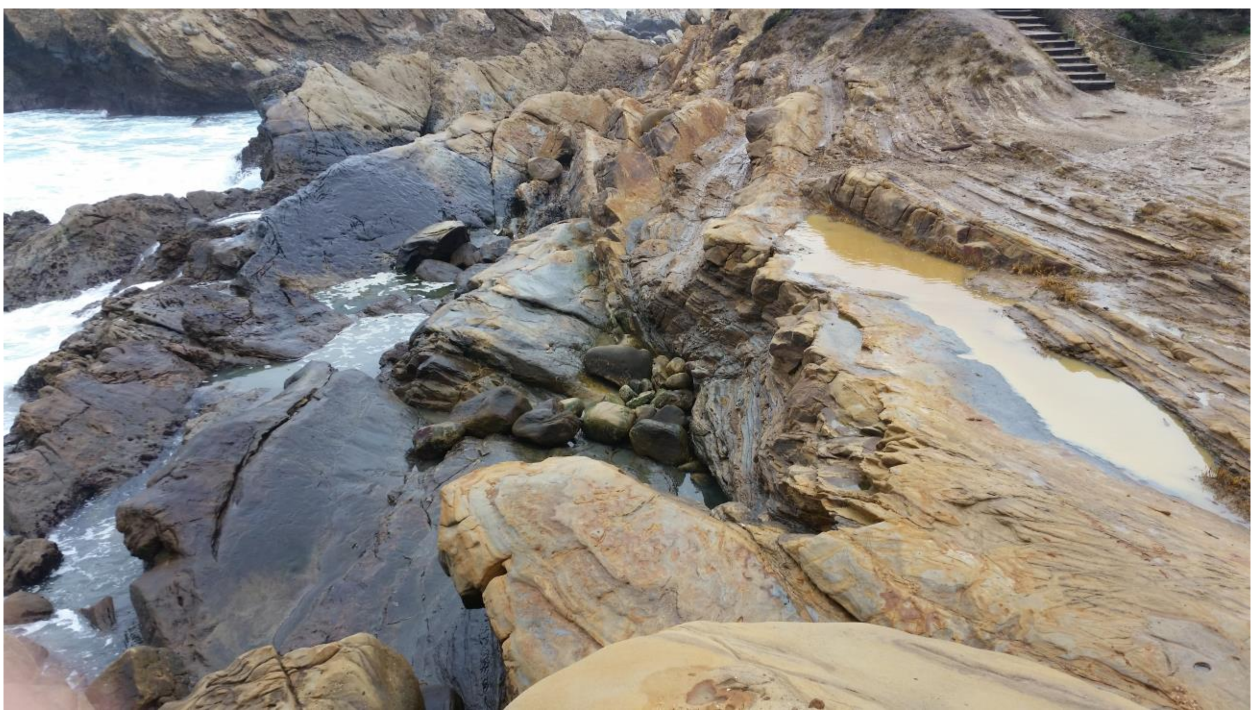


Figure 32: Sediment filled pools draining into ASBS.

Figure 33: Sediment coloration to the foam in the surf adjacent to Piney Woods beach parking area.

Figure 34: Erosion of the Whalers Point parking area into the ASBS.