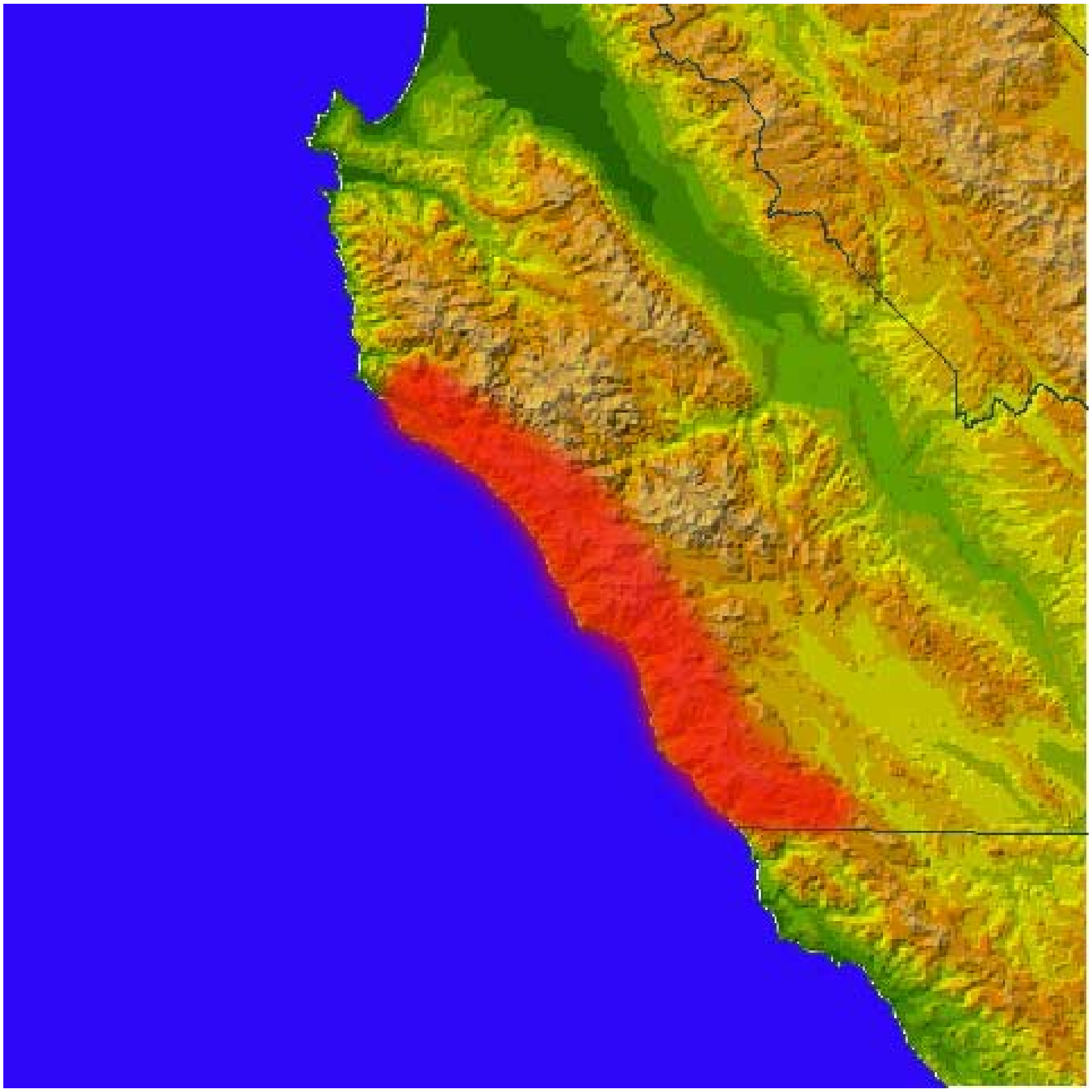
The Use of Geographic Information Systems in Understanding Invasive Species in The Big Sur Weed Management Area



A Capstone Project
By
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Abstract

Invasive species can rapidly and seriously degrade the quality of native vegetation communities by altering natural processes and reducing biodiversity. At the same time, control methods that land managers use can also affect the habitat. Land managers must determine which control method is most effective against the invasive species, while being the least damaging to the ecosystem.

It is estimated that some 3,500 to 4,000 invasive species are currently infesting the United States (USFS, 1996). In hopes of preventing the spread of invasive species in the Los Padres National Forest as well as in the surrounding California State Parks of Monterey County, there has been a concerted effort to address the growing problem of invasive plant species. For this reason the formation of the Big Sur Weed Management Committee (BSWMC) was created. The BSWMA is a multi-agency task force committed to the control of invasive species within the Big Sur Weed Management Area (BSWMA).

The Big Sur WMA is concerned with 8 specific species (See Appendix 1). Their origins are quite diverse and have growth forms ranging from perennial grasses to annual herbs to shrubs. To investigate the various factors associated with these invasive species, I have created a Geographic Information System (GIS) database. The database was created to map, interpret, and examine the areas of infestation within Monterey County and the Big Sur WMA.

Database analysis revealed that there were high occurrences of infestation within 200m of Highway 1 as well as surrounding county and private roadsides. Primarily, infestations were discovered to be in soil type: Rock Outcrop / Xerothent. The majority of infestations were found on Southerly and Westerly facing aspects with slopes ≥31%. Areas of infestations occurred largely in areas classified as coastal mixed shrub much of which had experienced fairly recent fire activity.

A weed hazard map was created based on a ranking system of these most significant commonalties found in current infestations. The weed hazard map created for the Big Sur Weed Management Area can be utilized as a tool for weed treatment, eradication, or prevention by indicating which areas are most at risk. In this same manner, the weed hazard map can also serve as a basis for strategic planning as a result of soil disturbances such as: landslide, wildfire, or road maintenance. It is hoped that the weed hazard map can serve as an additional tool in the on going war on invasive weeds in the Big Sur Weed Management Area.

Introduction

The Los Padres National Forest, encompassing almost 2 million acres, is the third largest National Forest in California. It occupies a major portion of the coastal mountain ranges and extends for about 220 miles from the west boundary of Los Angeles County to mid-Monterey County on the north (USFS, 1999). The forest spans some of the most ruggedly beautiful landscapes to be found anywhere in California. This environment provides a wide diversity of plant communities and wildlife habitat. However, this national treasure is quietly under attack.

Invasive plants have been called nonnatives, exotics, aliens, nonindigenous species, weeds, as well as a host of other names. All of these definitions incorporate a basic concept: invasive plants are plants that have been introduced into an environment in which they did not evolve and thus usually have no natural enemies to limit their reproduction and spread. Whether plants are transported across an ocean to a new country or across a mountain range into a new valley, the result is often the same; their fast growth characteristics and high reproductive rates allow them to “invade” the new habitats.

"The invasion of noxious weeds has created a level of destruction to America's environment and economy that is matched only by the damage caused by floods, earthquakes, wildfire, hurricanes and mudslides," Secretary of the Interior Bruce Babbitt said. "This is truly an explosion in slow motion by opportunistic alien species with few if any natural enemies" (USDA, 1998).

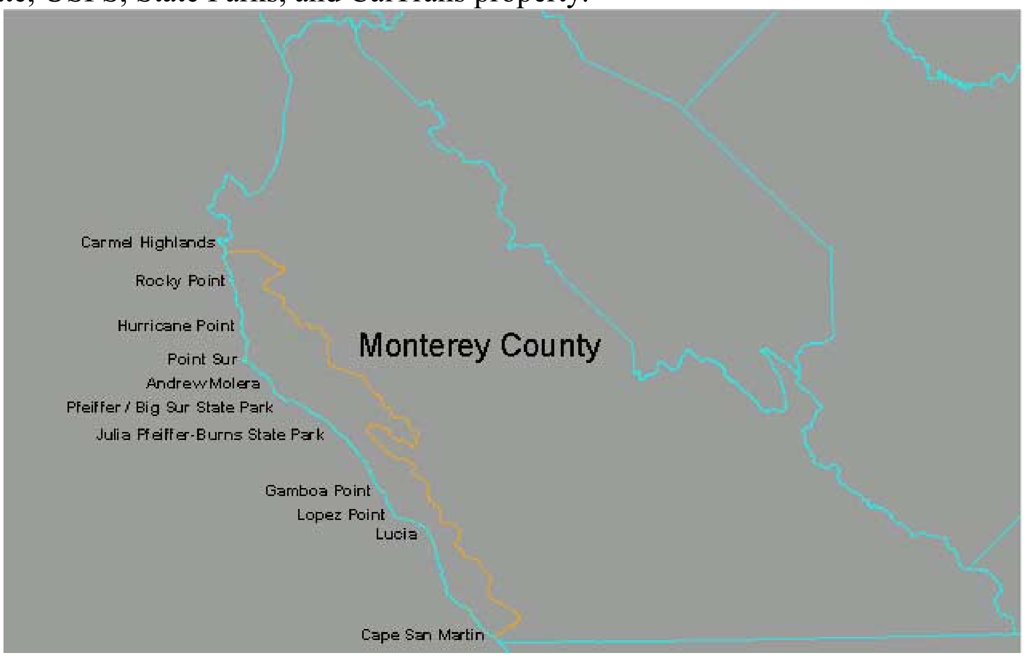
Invasive species are now considered by some experts to be the second most important threat to biodiversity, after habitat destruction (Randall 1996; Pimm and Gilpin 1989). Over the past several decades there has been a heightened concern at the national and international levels concerning the impacts of invasive species on habitat destruction and on biodiversity. In recent years, the impact of invasive species on biodiversity has become a major concern nation wide. These silent invaders are constantly encroaching on parks, preserves, wildlife refuges, and urban spaces.

Besides the devastating effects on biodiversity, invasive plant species can alter various properties of plant communities including: primary productivity, nutrient cycling, ecosystem stability, as well as community dynamics (Ramakrishnan and Vitousek 1989). Furthermore, nonnative species threaten 2/3 of all endangered species (Pimm and Gilpin 1989). Over the past decade, devastating impacts have been reported on every continent except Antarctica.

In hopes of preventing the spread of invasive species in the Los Padres National Forest as well as in the surrounding California State Parks of Monterey County, there has been a concerted effort to address the growing problem of invasive plant species. The Big Sur Weed Committee (BSWMC) is a multi-agency committee created to act on the invasive species problems along the Monterey County coast. The BSWMC is comprised of the United States Forest Service, California State Parks, Caltrans, and the Monterey County Planning and Building Inspection Department.

Once established, the primary objective of the (BSWMC) is to prevent the reproduction and spread of non-native invasive weeds into and within the weed management area (WMA). The formation of the Big Sur WMA has replaced jurisdictional boundaries that are barriers to comprehensive weed management programs in favor of a coordinated approach that facilitates weed management and control. Given the WMA geography it is easy to see that one agency/landowner's weed management success will be largely determined by the cooperative efforts of other agencies or landowners in the area.

Figure 1 Ownership boundaries within the Big Sur Weed Management Area include Private, USFS, State Parks, and CalTrans property.



It is estimated that some 3,500 to 4,000 invasive species are currently infesting the United States (USFS, 1996). The Big Sur WMA is concerned with 8 specific species (See Appendix 1). Their origins are quite diverse and have growth forms ranging from perennial grasses to annual herbs to shrubs. The species being targeted are Giant Reed (*Arundo* donax), Cape Ivy (*Delairea odorata*), Yellow Starthistle (*Centaurea solstitialis*) Eupatory (*Ageratina adenophora*), Italian Thistle (*Carduus pycnocephalus*), Pampus grass (*Cortaderia jubata*), French broom (*Genista monspessulana*), and Ice Plant (*Mesembryanthemum crystallinum*).

In an attempt to assist the United States Forest Service, which is the lead agency in the Big Sur Weed Committee, I have created a Geographic Information System (GIS) database. The database was created to map, interpret, and examine the areas of infestation within Monterey County and the Big Sur WMA. The land managers involved with this committee are responsible for a large portion of land and the use of GIS technology allows a more comprehensive examination with a limited amount of footwork.

Methods

The development of this invasive weed database serves a dual purpose. Primarily, the database will allow the Forest Service to archive invasive species and invasion locations around the Monterey County. GIS layers in the database will be observed for correlations and trends that may anticipate areas vulnerable to invasion. Secondly, the database will provide a record of several test treatment sites. After all, monitoring the progression of treatment sites is as important as the treatment itself.

The susceptibility of a plant community to invasion is thought to be related to three factors; successional status, species density and diversity, and the extent of disturbed ground within a community (Crawly, 1987; Rejmanek, 1989). Often the most influential of these three factors is the severity of disturbed ground within an invaded plant community. Since these disturbances can come by means of natural occurrences, as well as anthropogenic disturbances it was necessary to examine various data sources.

The impact of invasive plant species on native ecosystems can be most pervasive following natural disturbance such as erosion or wildfire (USDA, 1999). Fires and landslides are common occurrences in the Big Sur WMA. GIS layers of fire history in and around the Los Padres National Forest have been created to study this correlation. To observe the effects that erosion may have on ecosystem susceptibility slope and soil analysis was performed for the areas of infestation.

It is asserted that communities subject to anthropogenic disturbances are more vulnerable to invasion (Huenneke et al., 1990; Ramakrishnan and Vitousek, 1989). To examine the probable effects that anthropogenic disturbances have on local ecosystems, the following GIS vector layers have been created: Highway 1, roads, off road trails, hiking trails, and campsites. Proximity to these influential features will be evaluated to determine their significance.

To effectively manage project resources, land managers must be able to access quantitative data to describe the current land conditions. The field data I have obtained will provide the Big Sur Weed Management Area with an invaluable weapon in their ongoing war on weeds in the Monterey County. The ability to archive these GIS data layers provides the BSWMA with a means to distribute the data for collaborative inter-agency efforts.

After the data is compiled and analyzed my objective is to provide the United States Forest Service with a GIS/GPS database that can be used to produce maps of current infestation sites and to monitor the success of site-specific treatments. In addition, based on a correlative analysis of the database, I will provide the USFS with a map that illustrates areas of potential infestation. This analysis will be preformed for general invasive species trends as well as several highly representative species

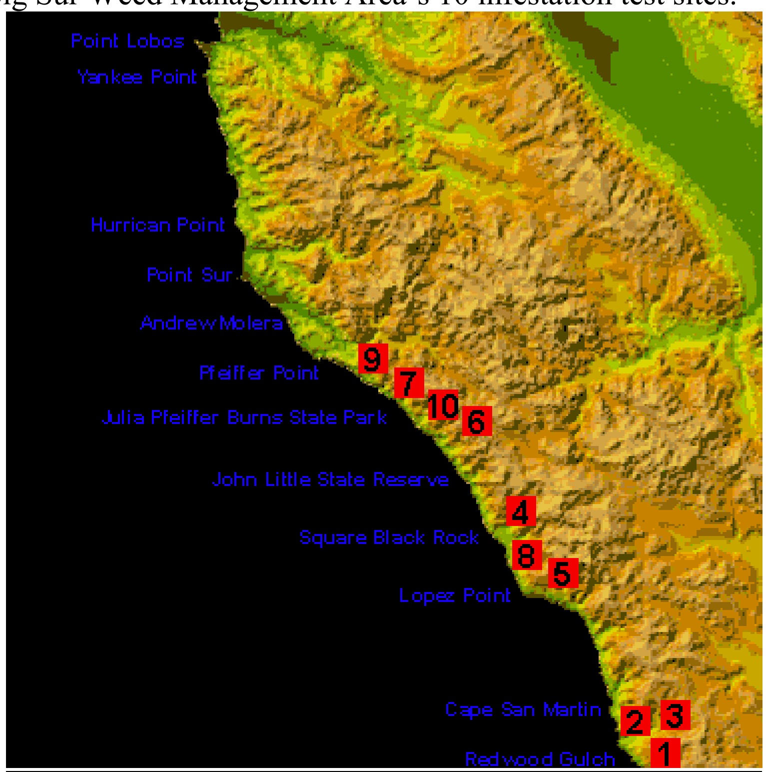
The Big Sur Weed Management Area encompasses the coastal slope of the Santa Lucia Mountains, including (but not limited to) the watersheds that flow into the Pacific Ocean between Malpaso Creek and the Monterey-San Luis Obispo county line. The WMA enhances the ability to address invasive species by uniting individual ownership or jurisdictions that form this extensive land unit for mapping, planning, monitoring, and conducting weed programs. Cooperators in the Big Sur WMA jointly prioritize weed management efforts based on species, geographical area or other selection criteria.

Invasive species are problematic throughout the Big Sur WMA. Implementation of an integrated weed management system is somewhat of a new land management strategy for the Big Sur WMA. This being the case, it is necessary to monitor the success or lack there of in dealing with invasive species locations. There were 10 infestation test sites that were selected for just this reason.

The site locations were: **1)** Redwood Gulch, **2)** Highway 1 (Kirk Creek), **3)** San Martin Top, **4)** Diggs Homestead, **5)** Kirk Creek, **6)** Sycamore Draw, **7)** Boronda Ridge, **8)** North Coast Ridge Road, **9)** Anderson Peak, and **10)** Sycamore Canyon.

The sites were selected using the Big Sur Weed Management Area prioritization and selection criteria. Site feasibility evaluations were conducted working in a manner consistent with Federal, State, and Monterey County policy, laws, and regulations. Other feasibility factors such as cost, site access, and the extent of infestation were considered. Sites were 10 geographically centralized locations, containing several invasive species at diverse infestation severities. Frequently traveled vectors of spread were of particular interest, as well as areas that impaired aesthetics or terms of visual contrast with surrounding natural landscape (in accordance with the Monterey Co. General Plan; Big Sur Resource Maps).

Figure 2 The Big Sur Weed Management Area's 10 infestation test sites.



Field data collection

The United States Forest Service (USFS) was responsible for the initial data collection. Areas that were determined by the Big Sur WMA were surveyed by the USFS. The results of these surveys were illustrated by means of hand-drawn maps. The base layer for these maps were United States Geological Service (USGS) 7.5-minute quadrangle maps. For greater detail the maps were photocopied at a 1:12,000 scale from its original 1:24,000 scale.

Infestation areas were first categorized by size. Three size quantifications were applied to describe the extent of weed infestation. Infested areas less than 1 acre in size were denoted by a square symbol on subsequent maps. Infested areas 1-5 acres were represented by a triangle symbol. A true proportion polygon sketch represented infested areas that were greater than 5 acres in area.

In addition to the categorization of infestation size, a system to describe the magnitude of infestation was devised to further demonstrate weed infiltration. There were four levels of infestation under this system: Trace (T) less than 1% canopy cover, Light (L) 1-5% canopy cover, Moderate (M) 5-25% canopy cover, and Severe (S) 25-100% canopy cover.

GIS Database Creation

After the initial classifications were assigned, all mapped weed infestation sites were compiled and consolidated into one set of printed quad maps. These maps were digitized at CSU Monterey Bay's SIVA center, and then imported into TNTmips, a GIS software manufactured by Microimages Inc. To ensure an accurate correspondence of transferred data, geographic map coordinates via GPS were used to georeference the imported maps. As requested by the U.S. Forest Service the Latitude/Longitude coordinate system, along with the 1984 World Geodetic System (WGS 84) datum was used.

In order to interpret the field data collected by the USFS it was necessary to utilize the Spatial Data Editor function in TNT mips. Since the field data came in the form of hand-drawn maps it was necessary to digitize the information. By doing so each infestation site became an independent GIS vector layer. These digitized polygon vectors layers then acquire the map coordinates associated with the base layer map it was created from.

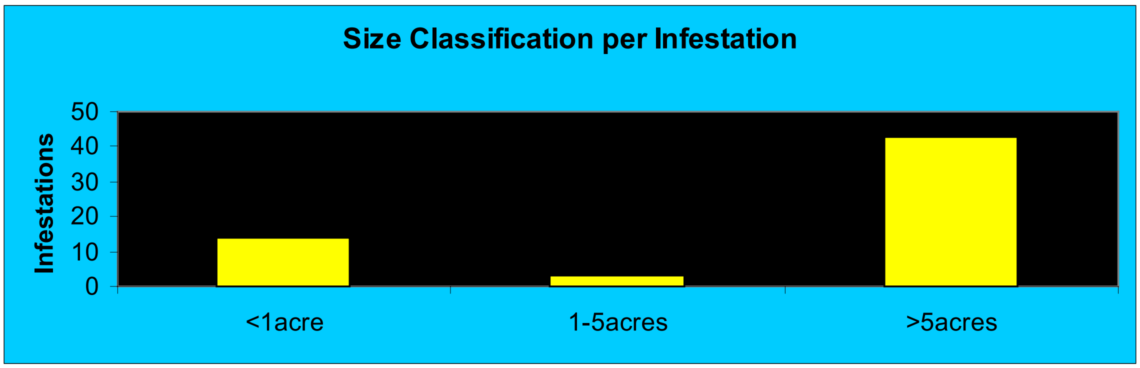
Creation of the Weed Atlas Database was derived from these digitized GIS layers. For each infestation, information included geographical data layers such as; map location, GPS position, infestation area, elevation, aspect, slope, and proximity to roads/trails. Regional land altering processes such as fire history was documented as well as areas with highly erodable soils. Also, specific site information such as site vegetation classification, infestation size classification, and infestation severity.

Results

There were a total of 58 invasive species sites mapped in the Big Sur WMA. On subsequent maps there were 3 size classifications used to classify and represent BSWMA infestations; Infested areas less than 1 acre in size were denoted by a square symbol. Infested areas 1-5 acres were represented by a triangle symbol. A true proportion polygon represented infested areas that were greater than 5 acres in area.

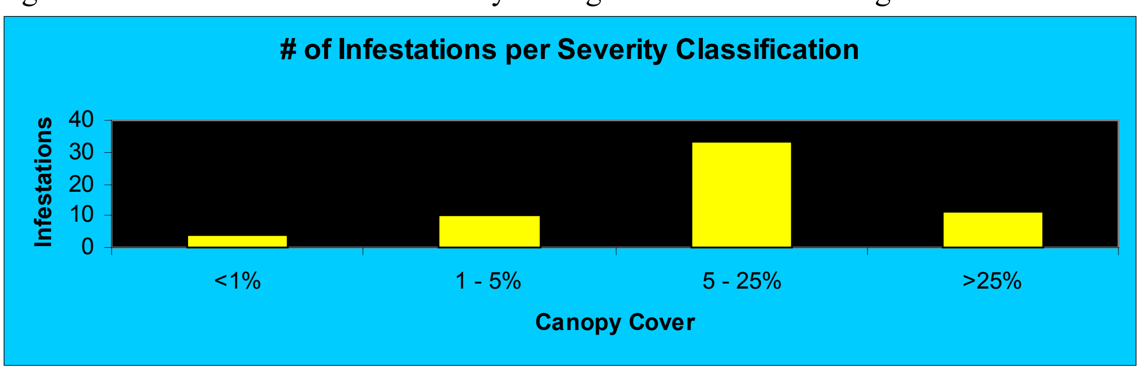
It was found that the typical infestation within the BSWMA was classified as greater than 5 acres. The area of an individual infestation ranged from 0.3 ha to 74 ha. There was an average infestation size of 6.3 ha.

Figure 3 Distribution of size classifications among infestations in the Big Sur WMA.



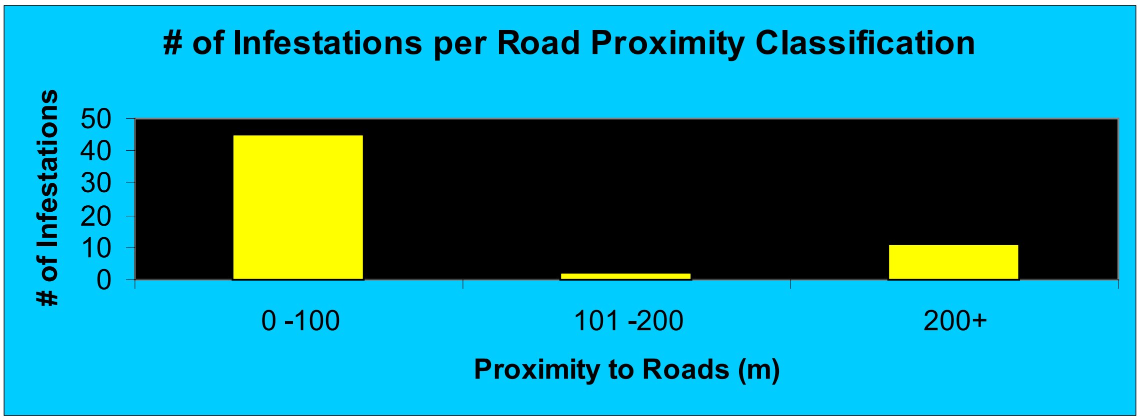
Only (24%) of all infestations were classified as Trace or Light infestations within the infestation severity classification. The majority of infestations (57%) were classified as moderate in severity, only (19%) of all infestations were classified as severe.

Figure 4 Division of infestation severity among infestations in the Big Sur WMA.



Proximity to roads and trails were classified using three road and trail buffer zones: 1) 0 – 100m 2) 101 – 200m and 3) 200+m. Database analysis found that (76%) of all infestation sites exist along the 0 – 100m road buffer zone (See Figure 5). Furthermore, (81%) of all infestation sites occur in the 0 – 200m buffer zone. In regards to trail proximity, the database indicated that (36%) of infestation sites occurred in the 0 – 100m trail buffer zone, (49%) of infestations exist in the 0 – 200m trail buffer zone.

Figure 5 Proximity of infestations to roads in the Big Sur weed Management Area



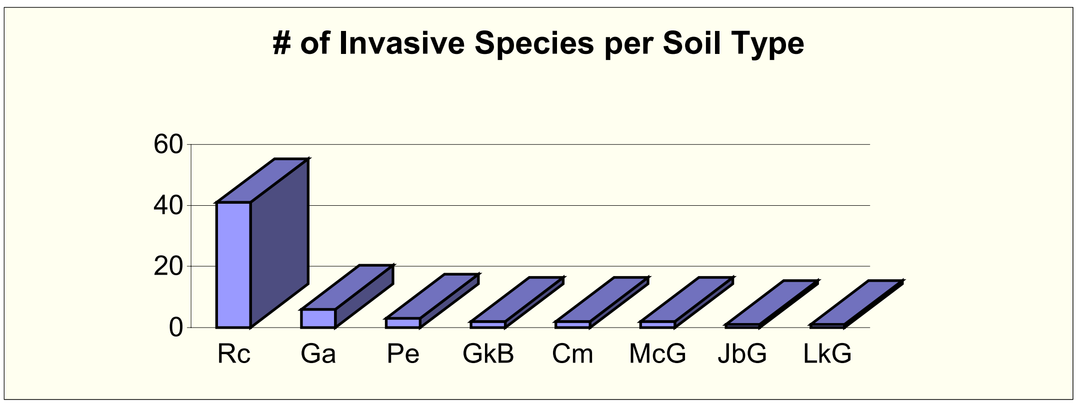
There are a wide variety of soil types that make up the California coastal zones and the BSWMA is no exception. A soil analysis of infestation sites was conducted to uncover any correlations between soil type and areas of infestation.

Figure 6 Chart shows the various soil type found in areas of infestation in the BSWMA

Soil Type	Soil Name	Infestations	Percentage
Rc	Rock Outcrop / Xerothent	41	72%
Ga	Gamboa / Sur / Junipero	6	10%
Pe	Pfeiffer / Rock Outcrop	3	5%
GkB	Gorgonio	2	3%
Cm	Coastal Beaches	2	3%
McG	McCoy Variant	2	3%
JbG	Junipero	1	2%
LkG	Los Gatos	1	2%

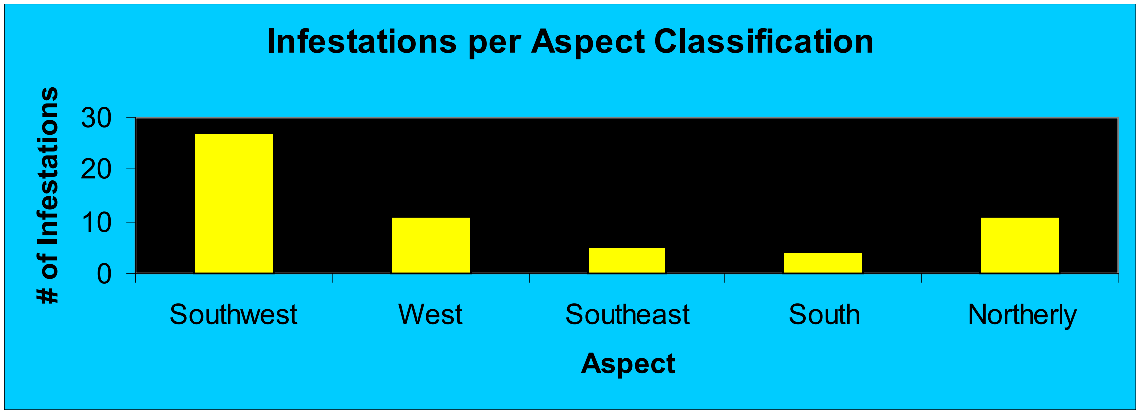
It was found that 72% of the mapped infestations occurred in a single soil type, Rock Outcrop Xerothents (Rc in the USGS soil classification guide). Rock Outcrop Xerothents is loosely consolidated soil consisting of fractured granite, which makes it highly erodable. Gamboa/Sur/Junipero (Ga in the USGS soil classification guide) represented the second highest soil type (10%) that exists among infestations sites in the BSWMA.

Figure 7 The distribution among soil types in areas of infestation.



The weed sites that were mapped within the BSWMA were largely coastal sites. As a result, the elevation range was from 4 to 987 meters, with an average elevation of 234 meters. The occurrences of invasive weed infestations were most prevalent (62%) on Southward facing slopes. South Southwest slopes had the most infestation sites (27) and Western-facing slopes showed the second highest total with (11) infestation sites.

Figure 8 The percentage of total infestations per aspect category.



Slope analysis for the invasive site locations throughout the Big Sur WMA indicated a high occurrence of invasion at step slopes, 85% of the data was found at a slope of ≥31%. The slope analysis of the invasive weed sites within the BSWMA showed the majority of the infestations (52%) occurred within the >50% degree range. The next largest portion (33%) of the infestations occurred in the 31% - 50% range.

Figure 9 The majority of infestations occur on slopes of 31% or greater.

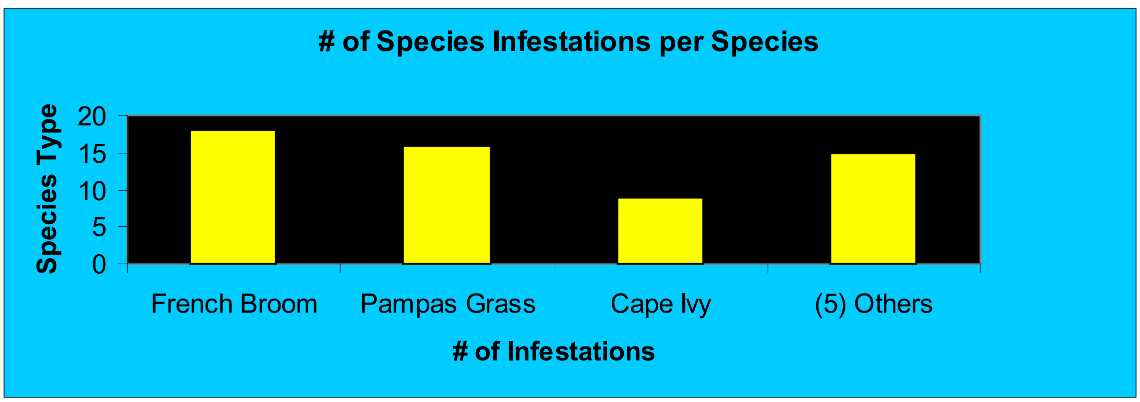
Slope	Infestations per Slope	%
>51%	30	52
31% - 51%	19	33
16% - 30%	6	12
6% - 10%	2	4
0 - 5%	1	1

The majority of infestations (72%) occur in the Coastal Mixed Shrub community. The second highest occurrence (18%) of invasive species was found among the California Sagebrush vegetation classification. The database showed a majority of the most recent fire activity associated with infestation locations in the Big Sur WMA to be

1996. There were a small percentage of sites that had not seen significant fire activity since 1912 however; the majority of infestation sites (66%) were last burned in 1996.

Three of the most pervasive species present in the Big Sur Weed Management Area are Cape Ivy (*Delairea odorata*), Pampus grass (*Cortaderia jubata*), and French broom (*Genista monspessulana*). The most numerous species encountered was French Broom. A total of 18 French Broom infestation sites were discovered, of which 89% were classified as 5 acres or greater in size classification. Furthermore, the average area of a French Broom infestation within the Big Sur WMA is 9.9 ha.

Figure 10 Distribution of species discovered in the Big Sur WMA.



In most cases (72%), French Broom infestations were categorized as moderate in severity, only 17% of documented infestations were classified as severe in nature. It was interesting to note that 13 of 18 of infestations were situated on South-facing slopes, of which 10 were on South-southwest slopes. The trend for road proximity was also note worthy, as 89% of all infestations were classified as (0 – 100m) in proximity.

Pampus grass (*Cortaderia jubata*), was the second most abundant invasive species mapped by the Big Sur WMA. The Pampus grass severity classification was categorized as severe in (100%) of all cases. Pampus grass infestations also represented the overall largest average area (12.7 ha) of all species. The majority of Pampus grass infestations (56%) were classified as moderate in severity, (25%) of infestations were classified as severe.

There was an apparent trend in Pampus grass infestations in regards to aspect. The highest occurrence (69%) of infestation took place on South-facing slopes. Of these sites, 7 or (44%) were situated on South-southwest facing slopes. There was also a very high correlation between Pampus grass and road proximity. In 15 out of 16 cases (94%), infestations were classified as 0 – 100 meters in proximity to a road.

The third most abundant species (9) recorded in the Big Sur WMA was Cape Ivy (*Delairea odorata*). Cape Ivy infestations did not show any general trends in size classification. Behind Pampus grass and French Broom, Cape Ivy showed the third largest average area (8.3 ha). The majority of Cape Ivy infestations (69%) within the WMA were classified as light to trace in severity.

Cape Ivy was primarily found on South-southwest slopes (55%), there was a (45%) occurrence of Cape Ivy on Western-facing slopes. There was also a very evident trend of road proximity. In (100%) of all cases, Cape Ivy infestations were found within 100 meters of roads.

Weed Hazard Map

The most persuasive factor in the database analysis was the proximity to roads. There was a 76% occurrence of invasion in locations within 100 meters of a road. Furthermore, 81% of all infestations occurred within 0 – 200 meters of a road. Infestations along U.S. Highway 1 represent 72% of that figure. For this reason a 200-meter buffer zone along Highway 1 was classified as an area of severe susceptibility or Extreme Hazard.

The next most influential factor was discovered by means of the soil analysis. It was determined that 72% of all infestation sites occurred within soil type Rock Outcrop Xerothents (Rc). The second most abundant soil type was Gamboa / Sur / Junipero (Ga) which was found at 10% of infestation locations. To find areas within the BSWMA that have these particular soil types, a GIS database query was run on the region of interest.

The slope analysis of the Big Sur Weed Management Area revealed slope to be a very substantial factor in locations where current invasions have occurred. While conducting the slope analysis it was found that 52% of infestations occur at slopes >51%. Furthermore, 33% of infestations occur at slopes between 31 – 50%. Map database queries were run on the BSWMA region of interest to identify areas with slopes greater than 51% and a separate data layer of areas with a slope between 31-50%.

Aspect also played a comparatively significant role in determining infestation locations within the BSWMA. Southerly aspects dominated statistically and accounted for 62% of invasive species locations. However, overall the database analysis demonstrated that Southwest aspects (47%) and Western aspects (19%) contain the highest occurrence of infestation. GIS database queries were run to locate all southwest and western aspect that exist within the BSWMA.

GIS database queries produced 4 very prominent factors that were the basis for the weed hazard map criterion. The first and most influential factor was Highway 1, which is within 200m of 72% of all invasion locations. The significance of soil type, slope, and aspect were ranked and classified by their statistical significance.

Figure 11 The basis for the BSWMA Weed Hazard Map.

Most Influential Factor	2nd Most Influential Factor	3rd Most Influential Factor
Soil	Slopes	Aspect
Rc	**>51%**	**Southwest**
Ga	**30-50%**	**West**

The results of the GIS database queries produced mapped polygons that represented all areas within the BSWMA that were in Rock Outcrop Xerothents and Gamboa / Sur / Junipero. Likewise, I created GIS layers that represented all areas with slopes at >51+% and all areas that had slopes of 30-50%, as well as layers that represented all Southwest and Western facing slopes.

Significant factors were ranked to create a weed hazard map classification to illustrate areas susceptible to invasion within the BSWMA. Through a series of GIS processes the soil, slope, and aspect layers were clipped and merged. The subsequent GIS layers revealed areas within the BSWMA that experience combinations of the weed hazard ranking commonalities.

Figure 12 The ranking classification for the BSWMA Weed Hazard Map

Hazard Rank	Soil	Slope	Aspect
1	Rc	51+%	SW
2	Rc	30-50%	SW
3	Rc	51+%	W
4	Rc	30-50%	W

As weed hazard maps were produced it became apparent that many areas along U.S. Highway 1 experiences characteristics of extreme hazard ranking. There were also several isolated inland areas that also experience similar soil, slope, and aspect. The most significant area of weed hazard was found along a 15-mile stretch of land along Highway 1. The land area extends from the southern portion of Pfeiffer / Big Sur State Park and runs southward through the town of Lucia. Areas classified as extreme hazard dominate this 15-mile land area. This stretch of land includes coastal landmarks such as; Slate Rock, Dolan Rock, Square Black Rock, Gamboa Point, Lopez Point, and Rockland Landing.

In the northern portion of the BSWMA Weed Hazard Map a potentially problematic area was located at the base of Sierra Hill. The potential hazard area lies on the coastal side of Sierra Hill. The area is borders Hurricane Point in the north and extends southward to the mouth of the Little Sur River. The fact this area also borders the northern park boundary of Andrew Molera State Park may also be of interest to the BSWMA. An additional potentially problematic area to the Andrew Molera State Park occurs on Dam Peak. Dam Peak is near Pico Blanco and borders Andrew Molera State Park to the northeast. This area is largely classified as an area of extreme hazard.

There is also significant invasion risk from invasive species in the Julia Pfeiffer – Burns State Park. The area is situated from the coastal side landmark of McWay Rocks and proceeds approximately 0.75 miles within the park boundary. According to the BSWMA Weed Hazard Map, approximately 40% of Julia Pfeiffer – Burns State Park is classified as an area of extreme hazard.

There is also significant infestation potential in and around Partington Point as well as in and around the Partington Ridge area. These areas may be of particular interest to the BSWMA due to the northern proximity to Julia Pfeiffer – Burns State Park. Likewise Anderson Landing, which lies to the south of Julia Pfeiffer – Burns State Park is also an area of extreme hazard.

Discussion

These findings of this study will serve as a basis for decision-making processes concerning invasive species in the Big Sur Weed Management Area (BSWMA). If eradication efforts are to be made then the GIS database can provide many useful products, such as maps and reports that can assist the BSWMA in planning and or eradication efforts. The database will also assist the BSWMA in determining limiting treatment factors such as proximity to endangered species and site accessibility.

As a result of this study there were many interesting trends found regarding the invasive species in the Big Sur Weed Management Area. The most prevalent factors were proximity to roads, soil type, slope, and aspect. These are the factors that largely determine the classification of Weed Hazard Map vector layers. However, there are several other factors that deserve mention, as well as further investigation.

To begin with, fires are common occurrences in the Big Sur WMA. GIS layers of fire history in and around the Los Padres National Forest were analyzed. GIS vector layers of fire history from The California Department of Forestry and Fire Protection (CDF) were obtained courtesy of Captain Mark Edria. The U.S. Forest Service (USFS) contributed access to paper maps that I interpreted and digitized. The results showed a high occurrence of recent fire activity in a majority of infestation. But in the final analysis, it seemed that fire data was somewhat contradictory and therefore was omitted as weed hazard criterion from this particular study.

Also, time constraints and logistical strains prevented me from obtaining and including landslide data in this study. Caltrans was said to have had data on recent slide activity along Highway 1. The Big Sur coastline is prone to frequent landslide activity. It is quite possible that since soil and slope played such a significant role, landslide activity might coincide within these areas.

As well as serving as a tool for planning eradication efforts, the BSWMA can use the database to gain a better understanding of how invasive plant species are introduced throughout the BSWMA. As the Big Sur Weed Management Committee begun to pre-plan for this project there were several significant vectors of introduction that were of particular interest; Highway 1, Palo Colorado Rd., North Coast Ridge Rd., Nacimiento-Fergusson Rd., and Plasskett Ridge Rd.

This assumption proved to be well founded, since a large portion (81%) of infestations occur in areas within 200 meters of roads, buffer zones were created to illustrate the susceptibility of these areas. Many of the roads that exist in the BSWMA are also in close proximity to Highway 1. As a result, many of the sites of infestation occur in areas that are in close proximity not only to Highway 1, but also to many of the county and private roads in the BSWMA.

The soil analysis provided results that are consistent with the nature of invasive species. Invasive weeds are opportunistic species that thrive in disturbed soils. Rock Outcrop Xerothents is loosely consolidated soil consisting of fractured granite, which makes it highly erodable. This provides a perfect medium in which invasive species are able to infiltrate. This factor is further magnified coupled with the fact that many infestations existed at slopes, which were greater than 31%. I believe this combination of steep slope and erodable soil provides an ideal setting for invasive species to invade.

The aspect analysis also produced results that suggest a tendency for invasive species in the BSWMA to establish themselves on hillsides with a particular aspect. The majority of invasive species were found on Southwest and Western facing aspects respectively. However, overall southerly aspects dominated the invasion sites within the BSWMA.

This could be caused by the amount of sunlight and water stress that these aspects experience and the relative Mediterranean Climate that the BSWMA experiences. Many of the invasive species are Mediterranean in origin including; Giant Reed (*Arundo* donax), Cape Ivy (*Delairea odorata*), Yellow Starthistle (*Centaurea solstitialis*), Eupatory, *Ageratina adenophora*), Italian Thistle (*Carduus pycnocephalus*), Pampus grass (*Cortaderia jubata*), French broom (*Genista monspessulana*), and Ice Plant **(***Mesembryanthemum crystallinum*).

Additionally, southerly aspects generally represent the least vegetated aspect. As a result there is less ground cover on theses aspects and thus less competition. For this reason, I believe that this may have resulted in a more opportunistic situation for invasive species to establish a foothold on Southerly facing aspects in the BSWMA.

Each weed infestation within the Weed Management Area was evaluated to determine the priority for control and control objective (i.e., prevention, eradication, and suppression). Each site was evaluated separately to determine the priority level as well site-specific control objectives. I believe that the weed hazard map can serve as an additional tool for management.

Since it is unlikely that only one option will be successful at eradicating intended invasive species, a combination of control options is necessary. The Integrated Weed Management system is based on five general categories of management option actions (No Action, Legal, Biological, Cultural, and Chemical). However, I propose that a Weed Hazard Map can be utilized as an additional management option for the BSWMA.

The results of this study suggest that the BSWMA invest time in further defining of potential infestation within the WMA. There is a possibility of pre-emptive action on areas that are prone to invasion before they become a significant problem. There was overwhelming evidence that suggests an ability to predict likely conditions that invasive species may take advantage of. Mapping these susceptible areas provides an illustration of where these hazards occur in the BSWMA.

I suggest that this Weed Hazard Map be utilized by BSWMA for future planning and treatment. For instance, this map could be referenced after wildfire, construction, or landslides. Habitat restoration has become quite important to the BSWMA given the number of wildfires and landslides that occur yearly in this region of interest. The weed hazard map could be used when planning these rehabilitative efforts.

This project for the Big Sur Weed Management Committee has provided an interesting lesson in the economic and political side of range management as it relates to government agencies such as the U.S. Forest Service. Also, investigating the overall ecology of these invasive species involved with the project provided a good opportunity to used the skills I have received in an integrated science program like that of the Earth System Science and Policy major at CSU, Monterey Bay. Using this ecological knowledge and integrating it into a GIS database allowed me to use the knowledge gained at CSUMB to integrate science and technology towards environmental issues in the real world. I hope this type of project can foster partnerships with other agencies to benefit future CSUMB students.

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Appendix 1

The Big Sur Weed Management Area Species List

Species: Giant Reed, *Arundo donax*
Growth form: Perennial grass
Indigenous range: Mediterranean region
Invaded range: AL AR AZ CA FL GA HI IL KS
KY LA MD MO MS NC NM NV OK SC TN TX UT VA WV
Introduction data: California-Introduced before 1820 (Hoshovsky (1993a).

Species: Cape Ivy, *Delairea odorata*
Growth form: Perennial liana
Indigenous range: South Africa
Invaded range: AL AR AZ CA FL HI IL KS
KY LA MD MO MS NC NM NV SC TN TX UT
Introduction data: Introduced to California before 1888 (Hickman 1993).

Species: Yellow Starthistle, *Centaurea solstitialis*
Growth form: Annual herb
Indigenous range: Mediterranean region
Invaded range: AZ CA CO CT DE FL
IA ID IL IN KS KY MA MD MI MN MO MT NM NV OR UT WA
Introduction data: Introduced to the United States before 1814 (Pursh 1814)

Species: Eupatory, *Ageratina adenophora*
Growth form: Annual herb
Indigenous range: Mediterranean region
Invaded range: AZ CA CO CT DE FL
IA ID IL IN KS KY MA MD MI MN MO MT NM NV OR UT WA
Introduction data: Introduced to the United States before 1814 (Pursh 1814)

Species: Italian Thistle, *Carduus pycnocephalus*
Growth form: Annual herb
Indigenous range: Mediterranean region
Invaded range: AZ CA CO CT DE FL
IA ID MA MO MT NM NV OR UT WA

Introduction data: Introduced to the United States before 1814 (Pursh 1814)

Species: **Pampus grass,** *Cortaderia jubata*
Growth form: Perennial grass
Indigenous range: South America
Invaded range: CA
Introduction data:

Species: **French broom**, Genista monspessulana
Growth form: Shrub
Indigenous range: Mediterranean region
Invaded range: CA OR WA
Introduction data:

Species: **Ice Plant,** Mesembryanthemum crystallinum
Growth form: Annual herb
Indigenous range: Mediterranean region
Invaded range: AZ CA PA
Introduction data: Seeds available in U.S. trade by 1807.

Species: **Kikuyu grass**, Pennisetum clandestinum
Growth form: Perennial grass
Indigenous range: Northern Africa and Middle East
Invaded range: CA HI
Introduction data: Hawaii-First collected 1938

Species: **Fountain grass**, Pennisetum setaceum
Growth form: Perennial grass
Indigenous range: Africa
Invaded range: AZ CA CO FL HI LA TN
Introduction data: Mainland United States- Seeds available for trade by 1883.