The Dunes of Venice: A Prototype for the Environmental Atlas of the Lagoon

This *Interactive Qualifying Project* Proposal, submitted to the faculty of Worcester Polytechnic Institute, in partial fulfillment of the requirements of the Degree of Bachelor of Science was completed by the team members listed below:

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Abstract

The Dunes of Venice: A Prototype for the Environmental Atlas of the Lagoon project examined three dune sites on the outer islands of the Venetian lagoon. We collected data on the vegetation and geomorphology of each site, and proposed site specific preservations plans based on condition assessments we took. The database of our field data, in conjunction with published research was used to create the prototype of the *Environmental Atlas of the Venetian Lagoon*. This *Atlas* will be used by the Environment Department of the City of Venice to conduct impact assessments of future development plans, and assist in maintaining data for environmental monitoring and preservation.

Acknowledgements

Dott. Lorenzo Bonometto- our project sponsor. Mr. Bonometto was very receptive to our ideas and was extremely resourceful. He gave us a lot of information regarding plant species and band recognition and accompanied us on the dunes the first day of data collection. Mr. Bonometto also provided direction for us when we needed it.

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Authorship

The word authorship refers to the actual writing of the document, but does not encompass the effort of data collection, database creation, and creative input that drives the completion of the IQP. While Sergio and Keith concentrated on data collection and producing the physical results, Caroline created the database and Environmental Atlas interface, and Jennifer wrote… a lot. We all participated equally in the revision process and assembling the presentation.

Executive Summary

Venice is being threatened by increasingly high tides every year. Preventing the total inundation of the city are the outer islands, the *Lidi.* The *Lidi* are a pair of barrier islands, Lido and Pellestrina, which shelter the lagoon from strong tides and destructive waves from storms. Historically, these islands served as the outer defenses for the city, and today, they house Venetian homes and businesses. Sand dunes have formed on the seaward shores of these islands, near the jetties that have been built. Sand dunes protect the inland areas and play a role in maintaining the dynamic and delicate equilibrium of the coastal environment. Due to human use, these dune areas have been compromised, causing them to develop irregular vegetation patterns and sizes, thereby endangering several important ecotopes. The dunes are also threatened by development projects near or on the coastline, like the MOSE project. The MOSE project is the building of enormous floodgates at the entrances to the lagoon, between the jetties, and thus adjacent to, and at times on top of, the sand dunes. Preserved and protected, these dunes could grow properly again and provide recreational and educational uses while also fulfilling the role of protecting the barrier islands that in turn protect the city of Venice.

The Italian central government has recently given control of coastline to the local government organizations of major coastal cities. The City of Venice Environment Department is now responsible for these coastal dune areas, and is obligated to create a coastal management plan by the summer of 2003. This plan will be followed up with a large environmental impact analysis study, on all of the aspects of the lagoon that have been determined to be sites of ecological importance to the European Union. The Environment Department is looking to establish a system for maintaining all of the environmental information collected for use in future impact analysis. To accomplish this, they want to create an *Environmental Atlas of the Venetian Lagoon.* The *Atlas* will be an electronic integration of the history of the Venetian lagoon coupled with detailed environmental information about ecotopes, tides, geomorphology and dynamics, for educational purposes and to conduct environmental impact analysis for future commercial or residential development.

Our team was given the task of creating the prototype for this *Atlas,* using research and data collection on the sand dunes as its foundation. We used the sand dunes as the base for the prototype because it will also assist the Environment Department in their creation of the coastal management plan. This preliminary database will be expanded as more information on other areas of the lagoon is gathered in the future. The goal of this project was not only to create this prototype, but also to promote the preservation of these endangered areas by establishing restricted areas for public use and setting aside other regions for educational and recreational purposes. We developed preservation plans for the dune areas of Alberoni, San Nicolò, and Ca' Roman, located on the outer islands of the Venetian Lagoon. This project integrates all of this environmental information to provide the Environment Department with an accurate, interactive and adaptable prototype for the *Environmental Atlas*.

Our methodology consisted of two main components. The first involved collecting previous information pertaining to the history and current state of the dune areas. We interviewed members of the Environment Department about the history of the barrier islands and about the different ecological aspects we needed to be aware of before conducting our fieldwork. This information served as the foundation for our data collection process.

The second component involved the collection of data on the dunes themselves, originally on the dune site of Alberoni and then expanded to San Nicolò and Ca' Roman. This included plant species locations, evolution of dune size and structure, photographs and locations of structural interventions in the dune areas. The locations of the plant species, dunes and structures were recorded with a Global Positioning System and were then overlaid onto aerial photographs to provide a better visual representation of the areas. These characteristics were then entered into a database that served as the data repository for the *Environmental Atlas*.

The next phase of the project involved refining our research methods on the different dune sites and making them adaptable to other areas of the lagoon. We tested our methodology by using the same methods we developed on the Alberoni and applying them to the two other dune sites. Each site has its own distinctive set of characteristics; so our methodology had to be sufficiently broad to encompass these differences, yet still maintain its integrity. The method of mapping bands of vegetation and creating dune elevation profiles for use in condition assessment and monitoring was determined to be robust for our project.

Our methodology yielded results of environmental data, photograph documentation and structure data. This data included GPS Band Data, Forest Clearing Data, Structures Data, and Vegetation Records. The GPS band data described the progression of vegetation and dune structure from the shore to the pine forest. We found that each band was successively more vegetated, and contained different plant species, although a number of species did exist in more than one band. We discovered that many different plants migrate from band to band, making many of them their home. The two most notable plants on the Alberoni are the *Ammophila litoralis* and the *Oenothera biennis*. Although they are the dominant plants in bands 3 and 4 respectively, they have spread throughout the dune field.

The Forest Clearing Data includes information on present vegetation and landscape characteristics of the clearings. We encountered two types of clearings during our study. The sandy, less vegetated clearings always had moss and usually had some dune plants from the 4th or 5th bands. Plants like the *Juncus litoralis* and the *Eranthius ravennae* dominated the largely vegetated clearings. We also recorded the location and shape of the man-made structures present on the dunes. The impact of these structures was determined by comparing cross-sections of the dunes, to study the differences in geomorphology and band sequence.

We analyzed each of the dune sites to determine the condition of the individual sites, and to compare them across all the dune sites. Because the Ca'Roman dune field was the least affected by human impact, it served as the basis of comparison for the other dune sites. To make comparisons between the dune sites, and also to make recommendations for usage, we calculated several indices, including the Natural Index and Aesthetic Index, and defined the characteristics of Natural Tendency and Natural Importance. Each of these indices and characteristics were determined by area, not by dune site, since different areas within the dune field can have very different values. The Natural Index is a measure of how natural an area is; similarly, the Aesthetic Index is a value for how beautiful an area is. The Natural Trend the determination of whether an area is in the process of reverting to a more natural state, or is progressing to a more developed state. Naturalistic Importance is the characteristic that weights the importance of natural areas. The entire dune field of Ca' Roman was determined to have high importance since it is a bird sanctuary and since it is the most unscathed by human interference. The Alberoni and San Nicolò dune sites each had different values of importance, naturalness, and aesthetics for each section. The Ca'Roman dune site was homogeneous in its characteristics; therefore all sections had the same values for the indices. The overall natural index was high due to limited human impact, so that the dune structure, band sequence, and vegetation remained mostly in their natural state. The aesthetic index was high, and the trend is toward its natural state. We entered all of our field data into a database that served as the prototype for the Environmental Atlas of the Lagoon. The data was organized at its broadest level by Site of Critical Importance, and then by dune site. Within each dune site, the data was further separated into eight sections: soil, air, climate, biotopes, water, land use, traffic/noise, and energy. The only categories that were related to our project were biotopes, land use and soil. The biotopes section involved most importantly a vegetation catalog, which shows pictures of vegetation, sorted by band. The land use section included damaged areas and paths, and the soil section contained a dune elevation profile.

Due to human interference on the dunes, the areas of indigenous vegetation and structural characteristics are non-continuous, and in some cases are isolated. For the dunes to return to their natural state, these isolated populations need to be connected. Biological corridors are a way of connecting these vegetation populations, and the method that we recommended was an adaptation of that used for establishing these corridors for animals. Our analysis allowed us to propose preservation plans for each dune site individually, as well as make some overall recommendations for all three sites. Suggested areas of usage for each dune site, delimited by fences, were designated to prevent widespread damage. We determined that wooden walkways should be built at each dune site to give people beach access without traversing the dunes and trampling vegetation. We also made recommendations for the establishment and location of biological corridors for use in environmental monitoring and education. The data that we collected will be used by several city departments for environmental monitoring, design of the coastline management plan for the Lido and the environmental management plan for the maintenance of sites of European Ecological Importance, as mandated by the European Union. Eventually our database will be linked to databases of information on other areas of the Lagoon to make up the Environmental Atlas. While the data incorporated in the Atlas is likely to come from many different sources and provided by different agencies, the Atlas will be the centralized location for all environmental information about the Lagoon. This will allow the effects of development on dynamic ecotopes to be more accurately forecasted, thereby preventing the need for restoration in the future.

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Introduction

The mission of the Environment Department of the City of Venice is to monitor and prevent activities that pose environmental risk to the lagoon ecosystem, in which Venice sits. Its duties include the protection of the waters, animals and grounds, energy saving, in addition to developing performance strategies of environmental reorganization and development of green lands. For the Environment Department to effectively monitor and protect the lagoon and its component parts, it must assess the impact that proposed development projects will have on the environment.

The Italian central government has recently given control of coastline to the local government organizations of major coastal cities. The City of Venice Environment Department is now responsible for these coastal dune areas, and is obligated to create a coastal management plan by the summer of 2003. This plan will be followed up with a large environmental impact analysis study, on all of the aspects of the lagoon that have been determined to be sites of ecological importance to the European Union. The Environment Department is looking to establish a centralized system for maintaining all of the environmental information collected for use in future impact analysis. To accomplish this, the city wants to create an *Environmental Atlas of the Venetian Lagoon.* The *Atlas* will be an electronic integration of the history of the Venetian lagoon coupled with detailed environmental information about ecotopes, tides, geomorphology and dynamics, for educational purposes and to conduct environmental impact analysis for future commercial or residential development.

One area of critical ecological importance in the Venetian lagoon is the sand dunes situated on the outer islands of Venice, known as the *Lidi,* that separate the lagoon from the Adriatic Sea. Coastal dunes protect the inland from waves and tides. They also serve as repositories for sand, which replenish the beaches during and after storms. Protection of the sand dunes is thus of critical importance to the future stability of the coastal region and to the survival of the City of Venice, which has been threatened by unusually high tides during the last century.

The coast is an extremely diverse and dynamic environment, and dunes play a key role in maintaining its stability. Human activities can have a serious effect on the delicate dune ecosystems, causing their erosion or complete demolition. A shift in the equilibrium of the littoral process of the area can cause serious erosion in some areas, and a buildup of sediment in others. The impact of human development within the coastal region must be assessed prior to the commencement of the project, to limit the potential damage and negative affects of development.

Our project was twofold in its mission: to help to preserve and protect the sand dunes and coastal environment of the *Lidi,* and to create a prototype of the *Atlas of the Lagoon.* We accomplished these goals by creating a database of information about the sand dunes, which can be expanded to encompass the ecotopes of the entire lagoon. The database contains published research in addition to our collected field data, and has been organized according to dune site. The database, in combination with GIS data and photographs, compose the prototype of the atlas. The methodology we used in collecting our field data and organizing the database is adaptable, and thus can be adjusted to be useful for other lagoon ecotopes. Our database, and eventually the full *Atlas*, will be used for impact assessment of future development in the lagoon, as well as for environmental monitoring and management.

The chapters that follow provide background on sand dunes and topics related to the project, our methodology used to collect data and design the database, in addition to our results and analysis, and resulting conclusions and recommendations.

- Chapter 2 includes the background necessary for our studies. It contains information about the structure and formation of sand dunes, erosion, wildlife, laws and regulations, and examples information management systems.

- Chapter 3 describes the methodology we used to collect field data and create the prototype for the *Atlas of the Lagoon*.

- Chapter 4 explains the results and analysis of our collected field data.

- Chapter 5 describes our conclusions based on the analysis of the data.

- Chapter 6 details our recommendations, including preservation plans for each dune site and suggestions for the structure of the *Atlas*.

- Chapter 7 contains the bibliography of the sources we consulted in the process of our project.

Background

To prepare ourselves for field research and data collection on the coastal dunes of the Venetian *Lidi* and the creation of an Information Management System, we conducted extensive research on certain aspects of dunes including:

- Coastal Ecology
- Dune Ecology
- Coastal preservation methods and terminology
- Coastal Laws and Regulations
- Geographic Information Systems
- Environmental Information Management Systems

This information provided us with a better understanding of our project's subject area and enabled us to make a more accurate analysis of the recorded data.

2.1 Coastal Ecology

The coast is the zone where the land meets the sea. It is a region of indeterminate width that extends inland from the sea to the first major change in landscape, such as a ridge, dune or barrier. The sediment from the land is transient along the coasts, existing only temporarily to form beaches, dunes and islands, before ending up on the ocean floor. The coast is therefore dynamic and constantly evolving. The geography and environment of coastal areas is extremely diverse around the world.[1]

A beach is an accumulation of sand or gravel that occupies a portion of the coast. Shore materials include muds, silts, sands, shells, gravels and cobbles. The area of loose sediment that is transported by wind and waves is known as the active beach. The active beach is bounded by the coastal upland, which can be a sand dune.[2]

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[1] U.S. Army Corps of Engineers. 2001. *Coastal Engineering Manuel.* Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).
[2] Beach Management Plan for Maui. Available: online 3/17/02 http://www.soest.hawaii.edu/SEAGRANT/bmpm.

2.1.1 Dune Morphology

Coastal sand dunes are accumulations of wind-blown sand. Dunes can be barren; however, most are vegetated with coastal plants that help stabilize them.[4] The effects of wind, waves, vegetation and sediment supply determine the occurrence and characteristics of coastal dunes.[5] Dunes can be found in a wide range of environments, with different types occurring in areas of different wind patterns.[6]

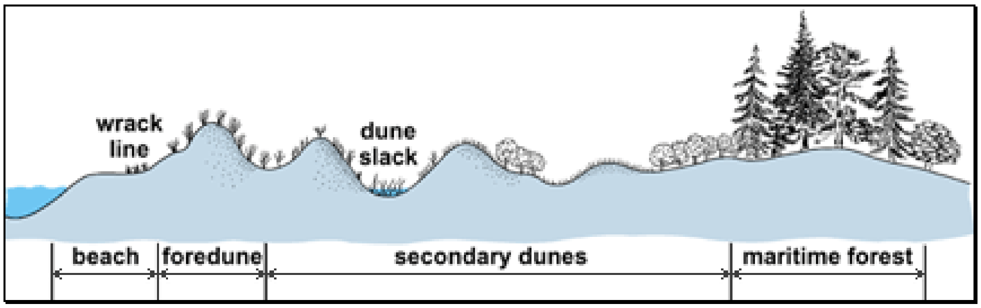

Figure 1: Typical Dune Profile[3]

The coastal dune profile, shown in Figure 1, is separated into four different sections, generally defined by vegetation. The primary dunes, or foredunes, are located closest to the water, behind what is called the wrack line. The wrack line is a stretch of debris along the shore typically found in the beach area that defines the highest tide. Located behind these foredunes are secondary dunes, sometimes referred to as the dune field. Flood-resistant plants are usually found in the dune slacks, damp, low areas between dunes, where the sand has been blown away by strong winds. In some of the larger dune sites, a maritime forest may appear behind the secondary dunes. In addition, salt marshes may reside behind the maritime forest in barrier beaches or islands.[7] The dune areas undergo continuous cycles of formation, stabilization and erosion. Newer dunes can be distinguished from older dunes by the color of the sand; older dunes have sand that has faded from yellow to gray.[8]

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[3] Seliskar, Denise. *Dune Vegetation*. Printed from AccessScience @ McGraw-Hill (www.AccessScience.com)
[4] Ibid.
[5] Seliskar, Denise M. Dune Vegetation. Printed from AccessScience @ McGraw-Hill (www.AccessScience.com)
[6] Trenhaile, A.S. Coastal Dynamics and Landforms. Clarendon Press. Oxford: 1997.
[7] Ibid.
[8] Trenhaile, A.S. *Coastal Dynamics and Landforms.* Clarendon Press. Oxford: 1997.

2.1.2 Dune Sediment Composition and Transport[9]

The base component of dune sediment is generally quartz, with calcium carbonate. This is seen particularly in warm tropical and Mediterranean regions, such as Venice. Sediment usually found on coastal dunes is known as calcite sand. The sand that makes up the dunes is generally medium to fine-grained.

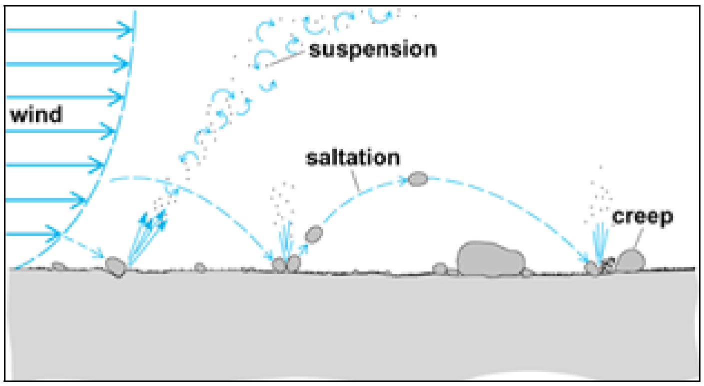

Figure 2: Sediment Transport[10]

Sand particles are constantly moved around by the wind. The wind can move sand particles through the process of saltation, movement by leaps or hops, or by rolling or creeping along the surface. Very fine-grained particles of sand or silt can also be lifted into suspension clouds in the air. Empirical research has been done to determine exactly how the wind affects sand particle movement, and to determine transport rates and distances.

The sand or sediment that makes up the active beach and the dune is moved by the wind in different ways, depending on the size of the particles. These transport processes are shown in Figure 2. The three main transport processes are saltation, suspension and creeping. Sand-sized particles often move by saltation. Finer materials, like silt, travel in suspension, or dust clouds, and coarser, heavier particles creep, or may remain immobile.[11]

In the Alberoni dune region, the sand is of the finest grain classification because the movement of the current is very slow, so it can only carry the smallest particles. Thus, the sediment moves only by suspension or saltation.

Mode of Transport	Size of Sand Grain (mm)
Suspension	< 0.1
Saltation	0.1 to 1
Roll, Creep	1 to 6

Table 1: Transport Method According to Sand Grain Diameter[12]

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[9] Ibid.
[10] Loope, D.B. Dune. Printed from AccessScience @ McGraw-Hill www.AccessScience.com
[11] Idem.
[12] Trenhaile, A.S. *Coastal Dynamics and Landforms*. Clarendon Press. Oxford: 1997. p.146.

2.1.2 Dune Formation[13]

Dunes form when obstacles existing just above the spring high-tidal line deflect wind, carrying sand particles. Such obstacles include vegetation, rocks, and other objects. Vegetation is the most common wind barrier; because it grows and spreads, it facilitates the further deposition of sand, which allows the dunes to grow in size as sand accumulates around them. The vegetation can grow as high as eighteen centimeters, causing grains of sand in saltation clouds to be caught and deposited. Vegetation also prevents the energy of the falling particles to dislodge other particles that were previously wedged into place, thereby allowing for continued growth of the dune. Vegetation also reduces the ability of the wind to erode and transport sand from the dune area.

Foredunes develop in the supratidal zone, the region of the shore that is just above the highest water level and is also know as the supralittoral zone.[14] Sand is trapped within the growing vegetation and piles up to form a dune. Generally, these mounds of sand are approximately one to two meters in height, and represent the initial stage of dune formation. The initial and subsequent development and morphology of coastal dunes is dependent upon the characteristics of the pioneer plants.

2.1.3 Dune Vegetation

Important vegetation characteristics for dune creation include: mode of colonization, growth and survival rates, and response to environmental factors like rate of sand burial, surface erosion, nutrient availability, temperature, and salt spray. Most pioneer species tend to have a high tolerance to salt, extensive root systems, and rhizomes that grow parallel to the dune surface. They also tend to flourish when burial rates are between 0.3 and 0.5 meters per year, and perish when burial rates are low.[15]

[13] Ibid 154-156.
[14] Academic Press Dictionary of Science and Technology. Available online. www.harcourt.com/dictionary, 2002.
[15] Ibid.

Figure 3: Ammophila litoralis[16]

Dune vegetation is highly adaptable and resistant to sea spray, high winds and sand accumulation. For the plants to survive being potentially buried by sand, an underground system of stems, called rhizomes, helps the plants spread throughout the dunes with new buds appearing from the ground. In addition, the roots of the plants and rhizomes are instrumental in preventing wind erosion and stabilizing the dunes. Wrack-line plants, such as the *Cakile maritima* shown in Figure 4, initiate the formation of the dune by trapping sand and debris. It stores water in its stems and leaves to dilute the large amounts of salt it intakes from its roots, and has skin that is resistant to wind damage. Foredune plants are responsible for the formation and retention of the dune because they provide a wind barrier. Grass-like plants such as *Ammophila litoralis* (*arenaria*), shown in Figure 3, are essential to dune survival. It is primarily found in the foredune region, and serves as a wind barrier to help prevent erosion.

Figure 4: Cakile maritima

Within the dune field, two kinds of vegetation exist: plants that can withstand flooding, and plants that are adapted to dry land, as this area provides more protection from water. Also found in the secondary dunes are shrubs, often found as large patches of vegetation. Plants usually found in wetland regions also reside here. A large variety of larger plants live in the maritime forest such as pine trees.

2.1.4 Ecological Bands

The dune regions can be divided into ecotopes, a region uniform in environmental conditions and in its population of flora and fauna[17], which run parallel to the coastline.

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[16] DUNE Escursioni naturalistiche agli Alberoni . Available Online: http://digilander.iol.it/vpisani/dune/index.html, 2002.
[17] *Merriam Webster Colligate Dictionary.* Available Online: http://www.m-w.com/cgi/bin/dictionary. June 2002.

These ecotopes are distinguished by their characteristic vegetation and dune structure and are termed ecological bands. In the Alberoni dune region, there are five such bands. The first exists from the wrackline to the presence of *Ammophila litoralis*, and includes up to three species, the most prevalent of which is the *Cakile maritima*, or the Sea Rocket. The second band is in the primary dune region, and encompasses three species of vegetation: *Ammophila litoralis, Xanthium italicum,* and *Agropyron junceum*. These first two bands compose the embryonic dunes, which are those dunes just beginning to form, and are highly individualized.

The third band, situated on top of the primary dunes, is distinguished by an increase in dune height, as well as the fact that the individual dunes and vegetation have begun to grow together. *Calystegia soldanella*, a plant that serves for consolidating the dunes, is the plant most characteristic for this band. *Ammophila litoralis* is also commonly found in this band. The fourth band can be identified by the presence of such plants as the *Euphorbia paralias*, *Oenothera biennis*, *Echinophora spinosa*, *Vulpia membraonacea*, *Eryngium maritime,* and the *Medicago maritima* that can be found in a valley between the primary dune and the secondary dune. The fifth and final band is home to the *Populus alba*, *Scabiosa gramuntia*, and *Apocynum venetum*, which live on top and behind the secondary dunes.

2.2 History of Venetian Coast

The Venetian Lagoon was created about six thousand years ago, after the last Ice Age. The barrier islands, Lido and Pellestrina, were created by sand that was carried by the rivers north of the lagoon. Sand accumulated, forming the large barrier islands that still protect the lagoon today. In the 14th century, Venetians became concerned that the sediment being carried into the lagoon from these rivers would end up obstructing the three *bocche di porto*, or openings to the sea. During that time, construction began to divert the major rivers' course to the sea.[18] The diversion of these rivers created marshes and mud flats called "barene" which have populated the lagoon over time and have become the home for many different species of flora and fauna. This section focuses on

[18] Knopf Guides: Venice, Italy. New York 1996 p.16-17.

the history and the changes that have taken place in the Venetian Lagoon since its creation.

2.2.1 Jetty Construction

A jetty is defined as a structure made of a solid material that is

> built at the entrance to a river or tidal inlet to stabilize the entrance as well as to protect vessels navigating the entrance channel. Stabilization is achieved by eliminating or reducing the deposition of sediment coming from adjacent shores and by confining the river or tidal flow to develop a more uniform and hydraulically efficient channel.[19]

Jetties are useful in preventing crosscurrents and making navigation through a specific area much safer by maintaining deeper channels.[20]

According to the US Army Corps of Engineers, two basic jetty designs exist: single jetties, and twin jetties. Twin jetties are two jetties built at once. Single jetties can be oriented in different directions with respect to the shore to ensure a secure entrance to a channel. For example, a curved or straight jetty can be placed "perpendicular to the shoreline or [may be placed] at an angle with the shoreline, depending on the predominant wave direction, the channel alignment of the natural inlet and the desired alignment of the improved inlet."[21]

Between 1890 and 1910, the City of Venice built jetties at its three openings to the Adriatic Sea: Bocca di Porto di Lido, Bocca di Porto di Malamocco, and Bocca di Porto di Chioggia, to create larger and more defined entrances to the city's port. Since the construction of the jetty near the Alberoni dune region, the beach has grown over a kilometer, vastly changing the landscape of the Lido.

2.2.2 History of Alberoni Dune Region[22]

Our liaison Lorenzo Bonometto described the history of Alberoni during our first site visit with him. The pine forest located on the dunes is non-indigenous, and was first

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[19] Sorensen, Robert M. Coastal Engineering. Printed from AccessScience @ McGraw-Hill (www.AccessScience.com)
[20] Silvester, Richard and John Hsu. *Coastal Stabilization.* World Scientific: Singapore. p.489.
[21] Kieslich, James M. *Tidal Inlet Response to Jetty Construction.* Department of the Army: Coastal Engineering Research Center. Fort Belvoir, Virginia. 1981. p.12..

planted following *World War II.* In the tradition started by the ancient Romans, pine trees were planted along the coastline, rather than the broadleaf plants that are indigenous to the area. The trees were planted very densely, thirty times denser per hectare than they would naturally grow. This has caused the trees to burn up underneath, leaving the only live needles at the tops of the pines, and a very acidic soil underneath. However, the Forestry Service maintains this area, and replaces the dead trees. In some areas within the forest, clearings have allowed indigenous vegetation to take root, a promising sign of the area coming back to life. It is the goal of the Environment Department to further this re-growth of indigenous vegetation, in hopes of returning the area to a more natural state.

In the first years of the twentieth century, jetties were built at the three entrances of the lagoon, effectively changing the coastline of the outer islands. The coast of the Lido has grown by over one kilometer since the building of the original sea wall in the 1700's. Most of this growth has occurred within the last century, due to the disruption of the tides and the littoral drift of particles by the jetty. This has allowed the sand dunes of the Alberoni, provided that they were not subject to human interference, to grow very large, and are among the largest in the Adriatic region.

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[22] Lorenzo Bonometto, interview with authors, June 10, 2002.

2.2.3 The MOSE Project

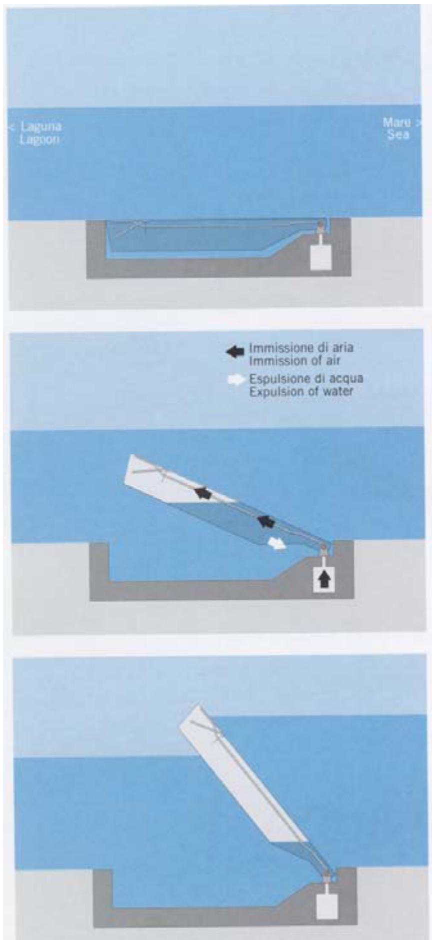

Figure 5: Floodgates in Action

Between the months of October and April every year, the city of Venice is flooded by exceptionally high tides referred to as the *acqua alta*. Rising global sea levels, normal tide levels for that time of year, increasing winds, and changes in atmospheric pressure are believed to cause these unusually high tides. A severe flood on November 14, 1966 caused Venice to be inundated, as the water rose 1.92m above sea level. Since the occurrences of *acqua alta* have been increasing over time, the City of Venice has developed a plan to protect the city from these high tides, and preserve the masterpiece it has become.[23]

The MOSE project began as research aimed at preventing Venice from becoming another Atlantis, after the most recent flood of November 1966. Researchers decided that the best way to protect Venice from these tides was to build large floodgates at the three entrances to the Venetian Lagoon: Bocca di Porto di Lido, Bocca di Porto di Malamocco, and Bocca di Porto di Chioggia. Each bocche di porto will have its own floodgate configuration. When open, the floodgates sit hinged on the sea bottom in a foundation of concrete, with its hollow steel arms moving with the flow of the sea. In the event of a possible flood, the gates will take only 30 minutes to rise by replacing the water in the steel arms by air, allowing them to float up on their own. When completely opened, the floodgates will turn away an extra 8.3 feet of water.[24] These three phases are shown in Figure 5.

As part of the research involved, the Consorio Venezia Nuova, the company in charge of the project, conducted a study on the possible environmental impact the

[23] Knopf Guides: Venice, Italy. New York 1996
[24] Dybas, Cheryl Lyn. "Can High Tech Keep Venice Above History's Tides?" *Washington Post.* 4 Mar. 2002. A09.

floodgates might have on the lagoon. Rafael Bras, a civil and environmental engineer at the Massachusetts Institute of Technology who has studied Venice's rising sea-level problems stated to the Washington Post, "The study concluded that the gates can be operated in a way that benefits the ecosystem." The project is said to cost $2.6 billion and will take 8 years to complete the construction of over 40 floodgates.[25]

2.2.3.1 Bocca di Porto di Malamocco

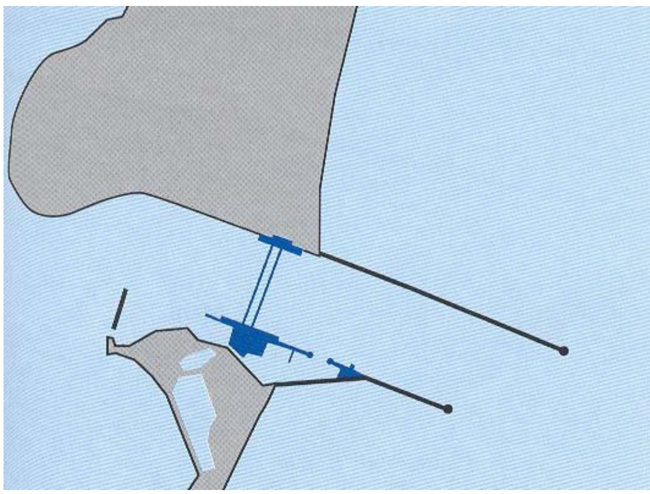

Figure 6: Malamocco Floodgate Design[26]

[25] Idem.

[26] Opere mobili alle bocche di porto: il progetto MOSE. Available Online: http://www.salve.it/it/attivita/OPERE/ACQUA/FRAMES/FMOBI.html, 2002.

2.2.3.2 *Bocca di Porto di Lido*

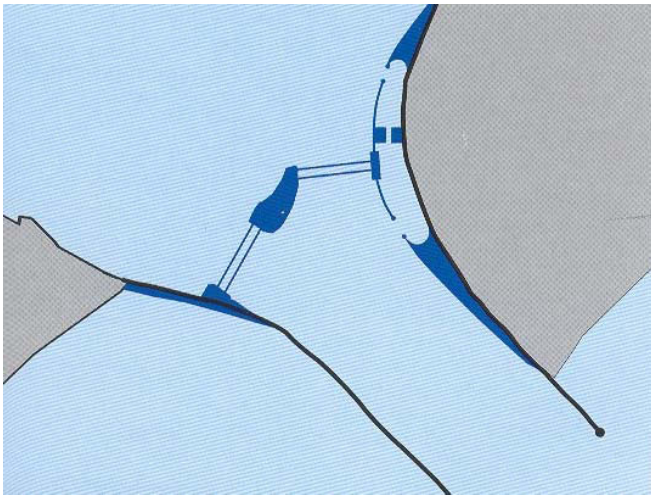

Figure 7: Lido Floodgate Design[27]

2.2.3.3 *Bocca di Porto di Chioggia*

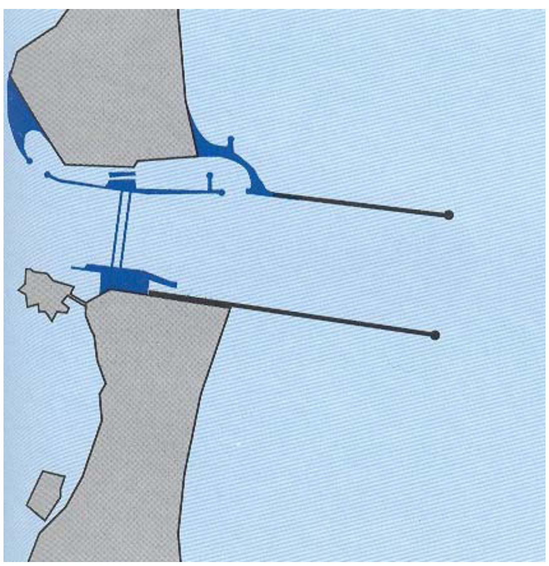

Figure 8: Chioggia Floodgate Design[28]

[27] Idem.
[28] Idem.

2.3 Coastal Erosion

The changing amount of sediment in a beach is termed the littoral budget.[29] Instability and erosion of coastal areas occurs because the shores are not in equilibrium with the littoral processes that are present. A beach is healthy when it is in a state of dynamic equilibrium, or when the net inflow of sediment equals the net loss of sediment.[30] Shores can be classified as having significant erosion (constant), short-term cyclical or episodic event-driven cyclic erosion and accumulation patterns or long term stability. Long-term stability occurs when there is a balanced sediment supply and little relative sea level rise influence. Shores that have been significantly modified by man's activities and development generally require a continuous commitment to maintain stability. These modifications often entail the changing of sediment sources or sinks, often contributing to erosion.

2.3.1 Dune Erosion and Natural Impact

Dunes are a dynamic coastal feature, in a constant cycle of erosion and accretion. They erode during periods of high waves and wind, and accrete during normal wave conditions. A process called scarping is what is responsible for wave erosion of dunes. Sand is released that was stored in the dune, and it returns to the active beach and can be transported off shore to create sand bars. When the high waves subside, normal wave actions dismantle the offshore bars and will rebuild the beach.[31]

Dunes become eroded by pressure continuously exerted on them by winds and waves. Typically this pressure is not significant, provided that the sand supply remains the same, the beach, dunes, and offshore areas will continue to rotate the sand among them. However, loss of vegetation causes the dune to become eroded much quicker by the wind and waves. This is especially bad during storms, when the winds increase, and the wave power becomes much more substantial.

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[29] Beach Management Plan for Maui. Available: online 3/17/02 http://www.soest.hawaii.edu/SEAGRANT/bmpm.
[30] Ibid.
[31] Beach Management Plan for Maui. Available: online 3/17/02 http://www.soest.hawaii.edu/SEAGRANT/bmpm.

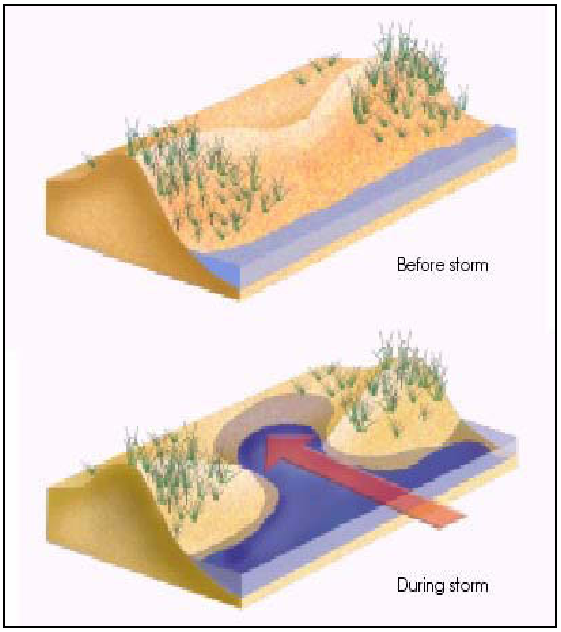

Figure 9: Storm Wash-over Damage[32]

During a storm a wash-over may occur, as shown in Figure 9, the water overflows the low points in the dunes and spills onto the inland side. This cuts a valley between the two higher points on either side, allowing for more water to spill over. The water will move the eroded sand into areas behind the dunes or out into the ocean where they collect to form a sand bar. This damage can be quite extensive and replenishment requires a long time.

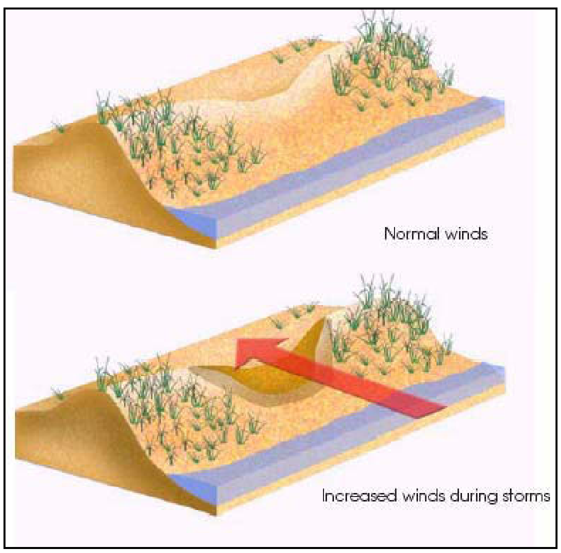

Figure 10: Wind Damage[33]

Another problem during storms is the increased wind velocity and strength. Unlike water, which will only get the low points of the dunes, the wind will ravage any area of the dunes that is not protected by vegetation. This can wear away at the dunes, making a sort of valley that could be used by the increased waves of the next storm. This means that the main problem is the loss of vegetation, which makes the dunes more susceptible to the power of the winds and waves.

2.3.2 Human Impact

The presence of human beings on the dunes presents potential problems. The actions of one person may hardly be enough to affect dune erosion, but when many

[32] Texas Land Office. Available online. http://www.glo.state.tx.us/coastal/pdf/DuneManual-03.pdf. 2002.

individuals have unrestricted access to traverse the dunes, there exists a problem, such as on the dune fields of the barrier islands. Various actions of individuals on dunes include walking, driving or riding vehicles, and construction of structures. The creation of paths for walking and driving creates large open areas susceptible to erosion. These actions, therefore, remove sediment and even more crucially damage vegetation that acts as a dune stabilizer. Large structures disrupt the carrying of sediment by wind, halting the regeneration process. When dunes are weakened, they become more vulnerable to wash-overs and high winds that can permanently damage it, as shown in Figure 11.

Figure 11: Dune Erosion

Human impact also includes the introduction of new plants and animals to a natural environment. Currently, most of the vegetation visible in the dune region of the Alberoni is non-indigenous plants that have been brought to the area, either by planting, like the pine trees, or have appeared by some other means, like various plants from the lagoon. The effect of human impact coupled with natural impact creates more erosion and slows regeneration.

2.4 Coastal Preservation

Dunes become destabilized by wind and wave action or destruction of the vegetation. Human activities such as building, sand extraction, forestation and deforestation all have a negative effect on sand dunes. Stabilization methods like the construction of sand fences and the planting of sand binding vegetation must be undertaken in order to preserve these coastal defense structures.

[33] Idem.

2.4.1 The European Union

The European Union (EU) is an international organization launched on May 9, 1950, dedicated to establishing European Citizenship, to ensure freedom, security and justice in Europe, to promote economic and social progress, and assert Europe's role in the world. "The EU has 15 Member States and is preparing for the accession of 13 eastern and southern European countries."[34]

The European Union is also very involved in Environmental Conservation. The European Environment Agency works in coordination with the 15 member states of the EU to determine endangered areas and species of Europe. This research will aid us in determining whether certain flora or fauna we encounter on the dunes are threatened. By knowing the number of endangered species per dune site, we will determine the dune's overall need for preservation or restoration. Endangered species that we may encounter on the dunes in Venice include:

- Shifting dunes along the shoreline with Ammophila arenaria (white dunes)
- Decalcified fixed dunes with Empetrum nigrum
- Dunes with Hyppophae rhamnoides
- Crucianellion maritimae fixed beach dunes
- Dunes with Euphorbia Terracina
- Malcolmietalia dune grasslands
- Brachypodietalia dune grasslands with annuals
- Dune juniper thickets (Juniperus spp.)
- Dune scleorophyllous scrubs (Cisto-Lavenduletalia)
- Wooded dunes with Pinus Pinea and/or Pinus Pinaster

2.4.2 Criteria for Dune Preservation

Typically, standardized criteria are consulted to determine which environmental areas need the most attention and preservation. In Massachusetts, the Areas of Critical Environmental Concern (ACECs) is a state run operation that outlines the standards for designation and reviews areas that are of environmental concern. The criteria that are used include the nomination by qualified individuals, the consultation of a specific list of areas that are deemed important, and the consultation of specific criteria of designation[35]. Other communities governing coastal areas use similar criteria designation with decision

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[34] The European Union at-a-glance. Available online: http://europa.eu.int/abc-en.htm, 2002.
[35] 301 CMR 12.00 Areas of Critical Environmental Concern. http://www.state.ma.us/dem/programs/acec/acecregs.pdf. 1987

making power given to a proper governing agency, whether it is city, state, federal, independent, or a combination of any of these.

The ACEC is an excellent model for critical designation of Venetian dunes. The dunes are an integral component to the barrier islands and the lagoon of Venice. Venice is considered a very unique city because it was built on a lagoon and is home to so many cultural and historical artifacts. The barrier islands are also a unique geographic landscape. A critical "area is unique or unusual from a regional, state, or national perspective.[36]" The barrier islands of Venice are recognized as an area of environmental importance by municipal, regional, and national government levels, as well as the European Union.

The dunes of Venice, just like dunes in any coastal area, are extremely difficult to replace once damaged or destroyed, due to the natural processes incorporated in their creation. Dunes take years to create, stabilized by growing vegetation. Some vegetation simply cannot be replaced because of a deep network of roots it creates in the dune. A critical "area has resources or characteristics which are potentially exhaustible or so fragile that alterations may have irreversible consequences.[37]" Methods for replenishing dunes, such as creating structures to catch sand and build dunes, and beach nourishment are unnatural forms of dune construction that may have adverse affects on the ecology of the area. The destruction of dunes, therefore, has an irreversible impact and preservation is needed.

The Venetian dunes may be deemed of critical importance because of the current threat facing them. The MOSE project, section 2.2.3, is the proposal for floodgates to be placed at the entrances of the lagoon between the outer islands. The dunes are situated at the ends of the islands where the floodgates are to be built. A critical "area is subject to imminent threat such as: current proposals for major private development projects; plans for major new public infrastructure developments…[38]" The transportation and erection of the gates may potentially damage or wipe out dune areas if precautions are not taken.

[36] Article 4, ACEC Criteria for Designation, http://www.state.ma.us/dem/programs/acec/acecregs.pdf. 1987
[37] Article 5, ACEC Criteria for Designation, http://www.state.ma.us/dem/programs/acec/acecregs.pdf. 1987
[38] Article 6, ACEC Criteria for Designation, http://www.state.ma.us/dem/programs/acec/acecregs.pdf. 1987

The floodgates may be implemented in the next few years, thus they are an imminent threat to the dunes.

The use of criteria such as those described above allows an elected official or committee to make an educated decision on whether or not an area should be preserved. These criteria were used by the European Union and the Venice Environment Department, determining that the dunes possess many qualities that mandate preservation.

2.4.3 Preservation Techniques

Due to the diversity of coastal environments, no single set of rules exists for the management and preservation of coastal areas; however, various generalized techniques have been developed. These techniques include the use of "hard" structures built of rock, steel or concrete, materials that are erosion-resistant. Other techniques involve the addition of littoral material or the modification of vegetation.

Implementing man-made structures to stabilize dunes has been proven to cause many different problems. Structures, known as groins, are built to increase littoral deposits on an area of the coast. Groins are built perpendicular to the coast and tend to interrupt the littoral drift of sediment. Subsequently, sediment usually piles up on the updrift side of these structures, and usually is eroded on the down drift side (jetties also cause this to occur). This causes deformations in the coastline and alters the ecosystem. There is also the potential of undermining foundations of buildings on the down-drift side of groins due to erosion In order to prevent deformations from occurring on a large scale, many US locations have adopted sediment-bypassing systems that transfer the sand from the up-drift to the down-drift side of these structures. Unfortunately, bypassing systems are very expensive to put into place and tend to have many mechanical failures[39].

Since these "hard" structures damage the environment, soft structure construction, usually in the form of beach nourishment has become a popular means of protecting and replenishing dune areas. Beach nourishment consists of taking sand from usually an offshore location and adding it to the endangered dune in a specifically designed

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[39] Davis Jr., Robert A. Barrier Islands. Printed from AccessScience @ McGraw-Hill (www.AccessScience.com).

configuration. Unfortunately, this is also a very costly task and usually needs to be repeated every 5 to 10 years.[40] Typically, the planting of vegetation is coupled with beach nourishment, but can be carried out on its own. Planted vegetation potentially may be an effective dune stabilizer, but one must be aware that natural vegetation has grown with the dune and usually has parts that extend deep into the dune, which offers the stability. This is difficult to achieve when planting vegetation superficially on the surface.

2.4.3.1 Biological Corridors[41]

Human impact causes environmental degradation, threatens biological diversity, and causes habitat loss and fragmentation. These losses lead to the isolation of small populations of flora and fauna, making them more susceptible to extinction. Interaction between small populations is necessary to promote biodiversity and prevent inbreeding depression. Ecologists have developed strategies to promote the interchange between local populations. The creation of biological corridors is the strategy that has been most advocated recently, because it is the least intrusive and yields the best results. Biological corridors are continuous, narrow strips of vegetation that facilitate movement among habitat patches, thereby decreasing isolation and promoting breeding among different groups. Corridors can include linear patches such as streamside areas, shelter belts, forest remnants, and fence rows.[42]

For the most part, biological corridors are used to help the fauna recover, not the vegetation. Experts disagree on how effective biological corridors are in promoting the interchange of individuals among populations, however, in the case of the Alberoni region, this strategy would likely be very effective, since we are trying to promote the growth of indigenous vegetation, rather than increasing the populations of the local fauna.[43]

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[40] Idem. Davis Jr., Robert A. Barrier Islands. Printed from AccessScience @ McGraw-Hill (www.AccessScience.com).
[41] Rosenberg, Daniel K. et al. "Biological Corridors: Forms, Function, and Efficacy." *Bioscience.* Vol. 47 No. 10. Nov. 1997. p. 677-87.
[42] Idem
[43] Idem

2.5 Dune Laws and Regulations

Coastal areas are extremely valuable to human beings and the environment. People benefit from recreational use of beaches and local residents benefit from the tourism coupled with the stimulation of the local economy. Coastal areas are also important to vegetation and other wildlife that are dependent on this habitat for survival. Dunes serve as a barrier between beach areas and inland areas, remaining very important in times of storms or hurricanes, absorbing impact of storm surges and high waves, preventing loss of life and property, and inhibiting water from moving inland. Dunes slow shoreline erosion by storing sand and replenishing beaches that have been eroded by storms. Dunes serve unique biological and ecological functions and provide a habitat to a number of flora and fauna, including threatened and endangered species[44].

2.5.1 Dune Preservation Laws

Laws pertaining to environmental areas in the U.S. are typically composed by state or local legislatures. Although coastal environments around the world have many similarities, each possesses specific differences that set them apart from each other. Each dune area has a different geographical landscape, variances in species, and is affected by differing weather and tidal patterns. Dune environmental concerns tend not to fall under federal legislature, but remain a state, town and county concern in the U.S.

The federal agencies involved in environmental matters include the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the U.S. Environmental Protection Agency, and the U.S. Department of Agriculture Natural Resources Conservation Service. In 1987, these agencies drafted the *Federal Manual for Identifying and Delineating Jurisdictional Wetlands*. This document incorporated the use of federal permits issued by the Army Corps of Engineers for any activities in wetland areas. Typically, this jurisdiction did not pertain to coastal dunes, unless the wetlands encroached on the dune areas[45].

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[44] Texas General Land Office. Dune Protection and Improvement Manual for the Texas Gulf Coast Second Edition. "Beach Access and Dune Protection Laws" (http://www.glo.state.tx.us/coastal/pdf/DuneManual-07.pdf) January 2002.
[45] Texas General Land Office. Dune Protection and Improvement Manual for the Texas Gulf Coast Second Edition. "Beach Access and Dune Protection Laws" (http://www.glo.state.tx.us/coastal/pdf/DuneManual-07.pdf) January 2002.

The Federal Emergency Management System classifies areas of dunes, but only in the context of flooding. Foredunes are considered V-zones, which are areas that absorb impact of high velocity wind and/or water. "FEMA requires more rigorous construction standards within V-zones and also prohibits 'any human-caused alterations of sand dunes which could increase potential flood damage'."[46] The FEMA is more concerned with dunes as functioning to block the flooding of inland areas, rather than the concern and preservation of the actual dunes.

There are a number of state legislatures that highlight dune protection. Typically, laws are passed that allow the general public free access to beaches. Coastal areas represent land owned by state, county, and/or town and so should be opened with free access to all of the citizens living in the area. Texas passed the "Open Beaches Act" in 1959, which gave unrestricted access to public beaches. In this case, a public beach was defined as the area from the line of mean low tide to the vegetation on the shoreline. Texas has also enacted a "Dune Protection Act" that was passed in 1973 and was amended in 1991. This act basically emphasizes the need of a "dune protection line" restricting access to the dunes.[47]

2.5.2 Dune Preservation Regulations[48]

Dune regulations are a set of rules that are created based on federal and/or state laws pertaining to access to dune areas and activity and development on dunes. Although regulations may vary depending on the governing agency of a particular coastal area, each set of regulations follows a general format to ensure the protection of dunes and surrounding areas.

The U.S. Fish and Wildlife service provides a set of general regulations pertaining to beach areas. These regulations include rules such as prohibiting:

- access to closed areas
- the collection, disturbance, or feeding of wildlife
- the collection or disturbance of vegetation; and
- the collection or the removing of sand and other inorganic materials

[46] Idem Texas General Land Office.
[47] Idem Texas General Land Office
[48] Friends of the Parker River National Wildlife Refuge, "Regulations" (http://www.parkerriver.org/pages/refuge2.htm) 2000)

In general, access to the dune areas is completely prohibited. The beach is an adequate and appropriate area that people use for recreational purposes. Permits are issued to individuals that need to be on or around the dunes for specific reasons. These reasons include the study of dunes for educational pursuits or photography of the coastal area. If given access to the dunes, there are specific paths that limit the damage to one area so people do not trample and devastate the entire dune. Human presence must be limited to an absolute minimum to ensure the survival of the dunes.

2.5.3 Local Coastal Areas: Specific Case

There exist many coastal areas in the United States that are geographically and ecologically comparable to the *Lidi* in Venice. This section outlines one specific area that is found in the United States whose coastal areas is in need of preservation and is comparable to the *Lidi*. This area has striking similarities and may offer some valuable regulation and preservation attempts.

2.5.3.1 Case Study: Plum Island, Massachusetts

An area known as Plum Island, shown in Figure 12 is a barrier beach found on the northeast coast of the U.S. in the state of Massachusetts, and is similar in many ways to the *Lidi*. The refuge occupying the area is 4,662 acres in size (3/4 of the island) and includes 6.5 miles of sandy beach including dune-beach complexes. The entire island is about 8.4 miles long, and between 1/2 to almost a mile wide in places.[49]

This area is of great importance for preservation for several reasons. The dunes and surrounding marsh areas are the breeding grounds for over 60 species of birds. Over three hundred species of birds in the area, seventy-five of which are extremely rare, have been found. More than four hundred ninety species of flora have been catalogued over various studies. The area is also an important site for fishing, shell fishing, tourism and recreation. The Plum Island refuge implements the regulations put forth by the U.S. Fish and Wildlife Service. The beach area is open to the public, yet the dunes are completely

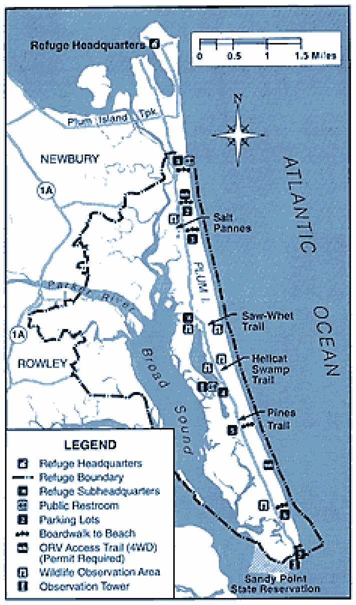

Figure 12: Plum Island, MA[51]

closed to the general public, with some exceptions. Permits are issued to those individuals whose activity on the dune pertains to wildlife observation, study and photography. There are designated paths through the dunes that allow these activities to take place. Photography permits range from $25/day for personal use, and up to $100/hr for commercial operations.[50]

Another similarity between Plum Island and the islands of the *Lidi* is the construction of jetties. Plum Island has jetties placed at the mouth of a river forming the Merrimack River Bar, while the jetties in Venice are placed between gaps of the barrier islands. The jetties have caused unnatural erosion and littoral deposits in different areas of Plum Island due to local ocean currents. This too has occurred in Venice because of jetty construction. The current existence and future construction of jetties is an important aspect of coastal engineering in association with coastal regulations. Although they are beneficial for navigational purposes, they are also a threat from an environmental perspective.[52]

2.6 The Geographical Information System (GIS)

A Geographical Information System is a computerized database management system designed for the capture, storage, analysis, and display of spatial data. Our project relied heavily on the use of such a system in order to portray accurate scale mappings of objects found within the dune area. Objects are defined by cartographic data consisting of points (one geographic location), lines or arcs (a series of connected points), and polygons or areas (an area enclosed by lines and arcs). Each object has a unique set of

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[49] Friends of the Parker River National Wildlife Refuge. "About the Refuge" Available online: http://www.parkerriver.org/pages/refuge2.htm 2000.
[50] Friends of the Parker River National Wildlife Refuge. "Photography Permit Information" Available online: http://www.parkerriver.org/pages/refuge2.htm 2000.
[51] Ibid, http://www.parkerriver.org/pages/directions.htm.
[52] Spinney, Edward. The Lower Merrimack River Valley: A Surficial Geology Field Trip Guide. Available online: http://www.necc.mass.edu/MRVIS/MR1_10/start.htm#p16 1998.

coordinates that places it at specific location. The coordinate system is site specific depending on the country or local area in which the GIS map is created. The GIS program used for this project is called MapInfo. It allows the user to create “layers” of spatial data in order to geographically represent different objects. Each object also has non-graphic data, known as fields, which may contain multiple descriptions of the objects characteristics.

2.6.1 GPS Data Collection for GIS

The Global Positioning System (GPS) is a satellite-based positioning system created and operated by the U.S. Department of Defense (DoD). It serves both civilian and military use for navigational and positioning purposes throughout the world. GPS is made possible through a combination of satellites orbiting the earth and ground receivers. Each of the twenty-four satellites has an atomic clock accurate up to a nanosecond. A satellite sends a signal that is picked up by a ground receiver. The receiver then calculates the distance to the satellite based on the travel time of the signal; however, this only creates one distance, narrowing down the position to an infinite number of points on the surface of a sphere.[53]

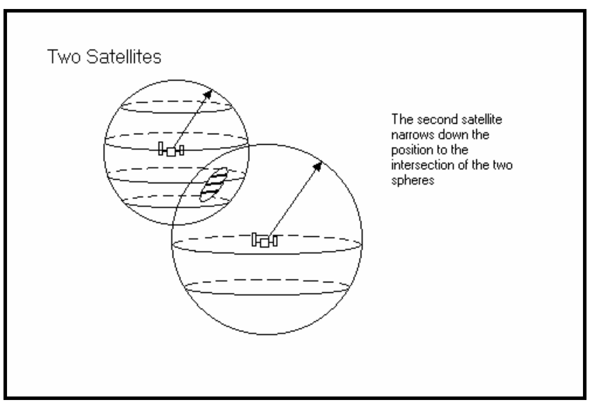

Figure 13: Two Satellites

A second satellite creates another sphere of points at a fixed radius from the satellite. The intersection of the two spheres creates a circular plane of possible points, shown in Figure 13. A third satellite creates yet another sphere of points that narrows the field down to two possible points, shown in Figure 14. A fourth satellite confirms the exact point,

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[53] *Mapping Systems: General Reference.* Trimble Navigation Limited. Sunnyvale, CA. Jan. 2000.

but often is not needed because one of the two points typically is not any where near the earth's surface.[54] The more satellites that are actively sending signals allows for more accurate and frequent readings.

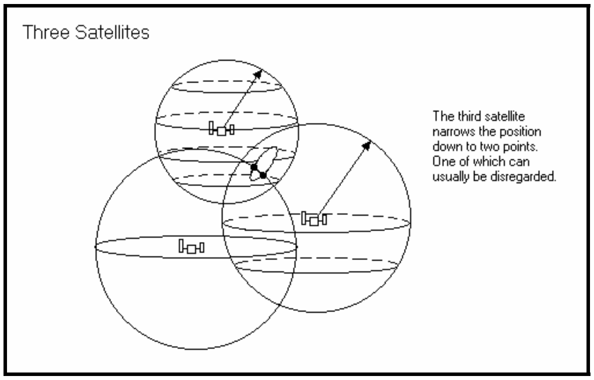

Figure 14: Measuring Distance with Three Satellites

Unfortunately, the GPS is not perfectly accurate, especially for mapping systems. There are many different factors that lead to miscalculations of the exact location of a point. These errors may include a slight error in the timing or the exact path of the satellites' orbit. Radio signals also do not behave exactly as one might suspect, nor do they always travel at a constant velocity, while calculations assume that they do. The largest source of error, ironically, is intentional error, implemented by the DoD, which falls under the policy of "Selective Availability". This is used to ensure that the GPS cannot be used against the US and its allies.[55]

These miscalculations can be overcome by using differential GPS, reducing the error to only a few meters. To do this one needs to have a known point occupied by a second ground receiver. The second ground receiver acts as a reference station, knowing where the satellites are supposed to be and knowing its own location. From this it can compute a theoretical distance and a time the signal should have taken. Comparing this signal to the actual signal allows the reference station to define the error.[56] Although a differential GPS was not available to our group, we did have access to a website that allowed us to make corrections to our collected data points. This correction is based on the same principle of differential GPS.

The use of GPS was extremely important in defining ecological bands, vegetated areas, and the presence of clearings. When comparing our collected data positions to the aerial photograph, we found that the GPS was accurate enough for our needs without the

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[54] Idem.
[55] Hurn, Jeff. *Differential GPS Explained*. Trimble Navigation Limited. Sunnyvale, CA. 1993.
[56] Idem

use of differential GPS. In the future, it may be important to achieve even more accurate positions by using differential GPS methods, depending on the application.

2.7 Aerial and Satellite Photography

Aerial and satellite photography is the technology and science of taking still or moving-picture photographs from a camera mounted on a balloon, airplane, satellite, rocket, or spacecraft. Aerial and satellite photography have many uses including surveillance, cartography, and environmental condition and land-use assessment. When taking aerial photographs, a course and speed are set before entering the area to be photographed, to ensure uniformity of speed and altitude. The photograph must be taken directly vertical over the site of interest in order to achieve a precise two-dimensional representation. A series of photographs are taken that later are overlapped with neighboring photographs in order to create a picture of a broad area. Another method may be applied that includes taking multiple photographs of one area at different angles. These are then scaled, joined and viewed under a stereoscope that renders a three dimensional topographic map.[57]

Our GIS mappings relied on both aerial photographs (provided by the Environment Department) and the Global Position System. Photogrammetry is the science of making measurements and maps from photographs. It is important to note that aerial photographs are not maps. Maps are geometrically and directionally correct representations of an area. Aerial photographs are pictures that offer a technique for creating maps. They include a degree of radial distortion, which is distortion in the topography. Some GIS programs have the ability to correct these errors. Map layers can be created by overlaying and tracing noticeable objects and positions; however, Aerial photography is limited to those objects and areas that are visible on the photograph. Despite the fact that GPS and aerial photography have some inaccuracies, using them in conjunction with each other will limit the inaccuracy as much as possible.[58]

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[57] Aerial Photography. Available online. http://www.encyclopedia.com/html/a1/aerialn1s.asp. Tucows Inc. Copyright © 2002.
[58] Crum, Shannon. "Aerial Photography and Remote Sensing." Available online. http://www.colorado.edu/geography/gcraft/notes/remote/remote_f.html. 2000.

2.8 Environmental Information Management Systems

Information Systems are used to store large amounts of information, and to make that information accessible and able to be manipulated. This allows for data to be stored easily and in an efficient manner, also, it allows results to be displayed in a meaningful way. The system itself must be easy to maintain and updateable, as the user's needs may change over time. It is necessary that the system is easy to operate; otherwise there is no benefit to using one.[59]

Most information systems work basically the same way. Data is input into the system, which then processes that data and stores it or updates existing files. Following input, the stored data is entered into a process that produces the desired output. Data must be stored in an organized manner; particularly the aspect of each record (or set of data) that is used to identify it. In this way the stored data can be ordered and searching for a particular record requires a short amount of time. Provided that the information is stored in an efficient manner, based on the objective the system is to fulfill, the output would simply be a manipulation of the information stored, and display it in the manner asked for, such as a map, table, or some other type.

The Atlas of Cape Cod uses a geographic information system lab at Woods Hole Oceanographic Institute to generate all of its maps and tables. The Atlas of Cape cod currently only has information in three areas, current land uses and land cover of the Cape, critical habitats of Cape Cod, and the protected lands of Cape Cod. These three areas were those of immediate concern, and were researched first, over time more areas are to be added. The areas of the Atlas that currently in working order can be shed some light as to how an Atlas of Venetian Lagoon should be created. [60]

In the current land uses section, the Atlas uses many tables to show the changes in the land over the past 50 years. They illustrate the continued growth of the population of the cape, which has one of the highest growth rates in the nation. Using the same input, there were also many maps made showing the distribution of the land coverage.

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[59] Connor, Denis. "Information System specifications and Design Road Map"
[60] The Woods Hole Research Center: An Electronic Atlas of the Cape Cod Environment. Available Online: http://www.whrc.org/ccatlas/ccatlas.htm. 2002.

In depicting the critical areas of the Cape, the Atlas contains pictures of critical areas and information about that type of habitat. The critical areas are divided up into categories, Fresh water systems, Coastal/Marine systems, and Upland systems. Such a method of documenting the critical areas of the Lagoon would prove to be extremely useful.

The Venetian Lagoon does not deal with exactly the same problem of a rapidly increasing population; however, the reason behind, and potential use of, the Cape Cod Atlas and the creation of the *Atlas of the Lagoon* in Venice are similar. Each is to be used for managing land use. Both areas are relatively fragile ecosystems that could be easily disrupted by misuse of the land that is available.

Methodology

This project focused on the preservation of the sand dunes situated on the outer islands of Venice, known as the *Lidi*, that separate the lagoon from the Adriatic Sea. We developed a database, in collaboration with the City of Venice Environment Department, which laid the foundation for the Environmental *Atlas of the Lagoon*. The database presents environmental information pertaining to the dunes on the *Lidi,* such as records of flora, fauna, geomorphology and damage assessment so that the City's Environment Department may monitor and protect these endangered ecotopes as well as evaluating the impact of proposed plans for development and utilization of the areas. We used the Geographical Information Systems to create precise and detailed maps that will serve as part of the interface for the *Atlas* as well as for environmental monitoring. To successfully complete this project, the group set forth the following objectives:

- Accumulating published research on the dunes, identifying specific areas of indigenous vegetation, and collecting fieldwork measurements relating to the geomorphology and topography of the dune sites.
- Design a database using published research and field work data that is restricted to the dune study area.
- Use the database, in conjunction with GIS data and photographs, to create a prototype for the *Environmental Atlas of the Venetian Lagoon*, the foundation of a more comprehensive, centralized information database for use in monitoring and future analysis of environmental impact of future development and utilization of the area.
- Provide the Environment Department of the City of Venice with a documented methodology for conducting fieldwork for the expansion of the Atlas to include all areas of the Lagoon.

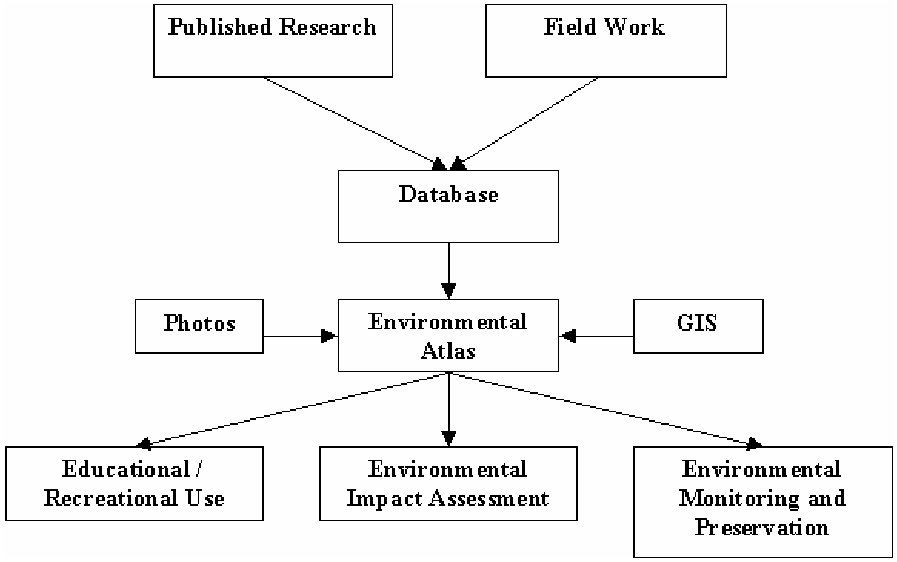

Figure 15: Methodology Flowchart

Figure 15 shows an outline of how we plan to implement our research methods to help the Environment Department complete its tasks easily and efficiently. Both types of data, accumulated published research and our fieldwork, were integrated to form the database. We then used the database to start the Environmental Atlas, for use in future monitoring and preservation efforts, in conjunction with impact analysis and educational uses. We used the database in order to establish some specific preservation suggestions for the Environment Department, including the proposal of areas that serve as biological corridors.

The rest of the methodology chapter is divided into the following sections that provide further details about the objectives of our project:

- Section 3.1: Specifies the subject matter of our research and defines terms of importance to the study. (Domain of Inquiry and Definitions)
- Section 3.2: Describes the geographical area in which field research will be conducted. (Study Area)
- Section 3.3: Describes the season, months and time of day in which the study was conducted. (Temporal Coverage)
- Section 3.4: Information requirements for the completion of the project

- Section 3.5: Overview of data collection, including parameters, locations, procedures, and data archival

- Section 3.6: Data integration and analysis, including describing the achievement of objectives 1-4

3.1 Domain of Inquiry and Definitions

Our project focused on the mapping of data on sand dunes, including vegetation, geomorphology, and other ecological aspects. Our project does not deal with local fauna and migratory patterns. To complete the previously established project objectives in terms of this subject matter, we used geographical information systems, aerial photography, and researched the history, evolution, and current utilization of the dune areas. The following terms will be useful to understand our subject area of dune ecosystems:[61]

- **Beach** extends from the mean low tide line to the line of natural vegetation along the shoreline.

- **Beach/Dune system** includes all of the land from the line of mean low tide to the landward limit of dune formation.

- **Biological Corridors**[62] are continuous, narrow strips of vegetation that facilitate movement [of flora or fauna] among habitat patches to prevent isolation of populations.

- **Ecotope** is a region uniform in environmental conditions and in its population of flora and fauna

- **Foredunes** are the first clearly distinguishable, vegetated dune formations landward of the water. They are also the first to dissipate storm-generated wave and current energy. Although foredunes may be large and continuous, they typically are separate rounded knolls.

- **Habitat**[63] is a patch or collection of patches that provides resources for survival, reproduction, and movement.

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[61] Texas General Land Office, Dune Protection Guide. (http://www.glo.state.tx.us/coastal/duneguide.html) January 2002

[62] Rosenburg, Daniel K. et al. “Biological Corridors: Form, Function, and Efficacy.” *Bioscience.* Vol. 47, No. 10. Nov. 1997. p.677-87.

- **Wrack line** a stretch of debris along the shore typically found in the beach area that defines the highest tide

3.2 Study Area

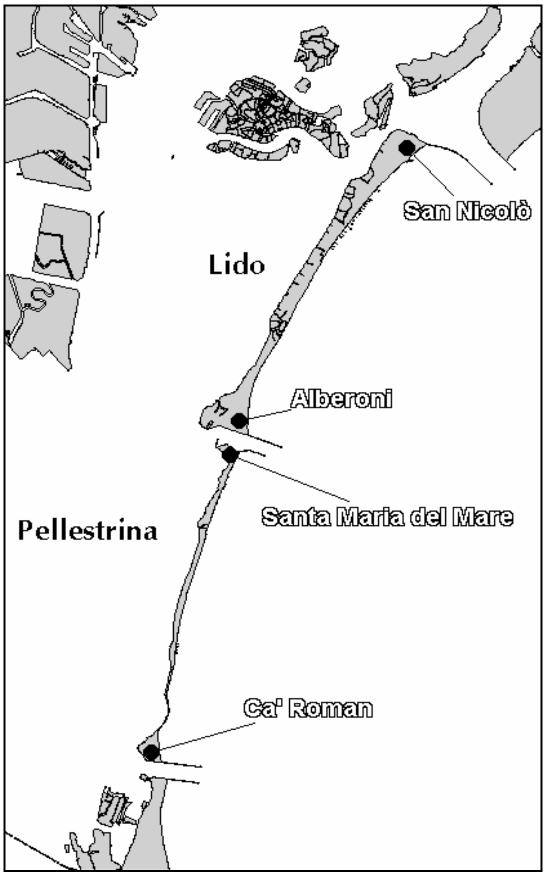

Figure 16: Dune Sites

Our project involved studying four specific dune sites on the Lidi, the barrier islands that protect the City of Venice from the Adriatic Sea. The data collection was conducted on Alberoni, San Nicolò, and Ca' Roman, as shown in Figure 16. Our primary focus for environmental analysis was the dunes and pine forest on the Alberoni.

3.3 Temporal Coverage

We traveled to the dunes most weekdays from about June 14 to July 10th to collect the data, collecting data from approximately 8AM to 6PM, dependent upon satellite coverage. As our efficiency improved, only part of our team traveled to the dunes to collect data, the other team members remained in the city and worked on data entry, database design and writing up the report. The GPS requires 4 satellites to operate properly, assuming the satellites are in "good" geometry. As more satellites are recognized by the GPS (potentially up to 8), accuracy increases and the GPS is actively reading positions more often. This allows for quicker and more precise data collection. We found the best times to collect data were early in the morning and later in the afternoon. We collected data in pairs, one pair in the morning and the other in the late afternoon in order to take best advantage of the satellite coverage.

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[63] Idem.

Since some of the species of vegetation are annual, and die each year, the issue of seasonality plays a large role in how our maps will be interpreted by the Environment Department, at a later date. To best reproduce our methods, data collection should be conducted at the same time of year in the future. If data is conducted during other times of the year, seasonality should be taken into account during collection and later analysis.

3.4 Objective 1: Accumulating Published Research and Field Data

The first step in creating a centralized data system is to gather all the data and research that has been previously published, relating to the dunes and their surrounding environment. This objective encompasses the collection of both types of data to be included in the database: existing data, with the addition of our own collected data. The collection of published research and information occurred soon after we arrived in Venice, and was performed prior to and concurrently with collecting our field data. We first interviewed key people at the Environment Department to determine what information they already possessed on the dunes, as well as to learn about the vegetation and geographic areas within which we worked. Once we had a working knowledge of the dune environment, we used the GPS to collect data on the location of vegetation and other natural characteristics. This was then integrated with the information that was collected previously to create a comprehensive database.

3.4.1 Prior Research

We gathered research from what the Environment Department already possessed. They provided us with information about the current state of the dune ecosystems we studied, including vegetation, clean-up efforts, and history. They also provided us with publications on the ecology of the dune regions:

- Wildlife and vegetation living on the dunes
- Current use of the dunes
- Previous human influences and building in nearby areas
- Preservation efforts
- Jetty effects
- Changing coastal geography patterns

- Environmental impact studies

Data was first gathered through interviews with key persons at the Environment Department, principally Lorenzo Bonometto, a biologist responsible for environmental planning and education. He provided us with information on the types of plants that we encountered on the dunes, what their presence indicated, whether or not they were indigenous to the area, and how they contribute to dune survival. We also interviewed Daniele Mion, a biologist who works for the Environment Department on a limited basis. He helped us to refine our data collection methods, provided further information about the dune ecosystem, and supplied us with related publications.

3.4.2 Field Data

To make our field data collection methods appropriate for areas throughout the lagoon, we had to look at the lagoon's different environments. Besides dune regions, the lagoon also includes "barene" or marshes, which can be either fresh or salt water, depending on the source of water, rivers or ocean, respectively. Although both ecosystems are dynamic, dunes continuously evolve over time, and take longer to mature, while marshes mature quickly and maintain equilibrium. Encompassing both types of environments with the same data collection methods is very difficult due to resulting differences in impact analysis, monitoring, and preservation; therefore, designing a methodology that generalizes to the entire lagoon is not feasible. Our data collection was hence geared towards the dune areas. The underlying concept of mapping out sub-ecotopes within the larger ecosystem can be applied to all areas of the lagoon; however the specific collection methods will have to be adjusted with each new area.

The fieldwork was first conducted on the dune site of Alberoni, shown in Figure 17. The figure shows part of our complete study area, which is later discussed in more detail in our results On the Alberoni, we focused on the maritime forest, outlined in green, and dune field, outlined in red. The maritime forest is distinguished by the golf course to the west and a fence before the dune field to the east. The dune field south of the road, seen in Figure 17, spans from the fence to the active beach. Dune fields to the north of the road span from the beach to houses built behind the dune field.

Figure 17: Map of Study Area

The individual dune sites were further disaggregated into sections that were more manageable, given the size of the dune fields and the amount of data to collect. These sections were defined by breaks in the bands due to human structural intervention, distinguishable landmarks, or other natural occurrences differentiating the landscape. We collected band data section by section, using the man-made or natural breaks as reference points.

Our team conducted qualitative and quantitative assessments of the dunes. Collecting data on the dunes significantly added to our database, and the data was used to determine orientation and size of each band. Our data collection was broken down into three main parts: geomorphology, vegetation, and current use. To study geomorphology and current use, we documented human impact on the dunes and recorded the elevation and the coordinates of the dune peaks to better illustrate their current state and orientation. We recorded coordinates of paths, damaged, and developed areas for current use. Developed areas were larger areas, typically cleared of dunes and vegetation for permanent structures and the creation of a recreational beach. Damaged areas were smaller, typically caused by pedestrian traffic. We also recorded the coordinates of bands that are determined by dune structure and vegetation. The density of each plant species in each particular band was also calculated. The field experience helped us better understand dune morphology and allowed us to better evaluate the dunes' current condition. Data will be collected in the future based on our techniques to continuously monitor the condition of the dunes. Our data will then serve as a basis for comparison.

3.4.2.1 Weather Conditions Data

Each day, we collected data on the current environmental conditions. This data is not crucial to the measurement of the dune structures, but may account for error in measurements. For example, large cloud cover or the time of data collection can negatively affect our measurements because of the selected availability of the satellites and disturbance of satellite signals from which the GPS receives data. The following are the environmental conditions that we will be documenting on the days fieldwork is conducted:

- Weather description
- Date and time interval of data collection
- Dune site

3.4.2.2 Geomorphology

In order to track how the dunes change over time, we recorded information about the general topography of the dunes and their general makeup: dune height and ecological bands. We added a qualitative description to the following quantitative data collected for each section.

3.4.2.2.1 Permanent Structures

We also mapped permanent structures found in the dunes using the GPS because they are responsible for altering and negatively impacting the dunes and their environment. The permanent structures will be used as both reference points when mapping the dune areas and as possible explanations for the damage done to the dunes.

In our measurements, we considered permanent structures as a "non-indigenous" species that we took note of.

3.4.2.2.2 Transects

A dune transect is a graphical representation of a sample section of the dune site that runs perpendicular to the coastline. Each band within the dune transect is shown as a different section. As part of the transect data, a dune profile (also running perpendicular to the coastline) was produced that showed the topography of the dune field within the representative transect area. Two different types of areas were considered when producing each transect. The first type was an area representative of the entire dune site, to show the natural progression of the band sequence. The second type was an area that had been adversely affected by human impact, which included the presence of structures or areas of pedestrian use.

Figure 18: Equipment Used for Transect Measurement

For assessing the dune profile, we used simple surveying methods to find the relative height of the dune peaks and valleys for the dune profile. We recorded the height of a series of points along the transect, taking measurement approximately every 10 meters. We also made sure to take measurements at the extremities of dune peaks and valleys. We established a point of reference prior to taking elevation measurements, giving it an elevation of zero. All other heights were taken with respect to this reference. Reference points were established at distinguishable, immovable points, such as the jetty, which would be undisturbed in the future. We established reference points because we did not have access to points of known elevation at each dune site. When the actual elevation of the reference point is discovered, all other points along the profile can be calculated. This will be important in the future in order to compare geomorphology and the change in elevation of the dune site from year to year.

Finding the relative heights of each point in the dune field was sufficient for our analysis. After establishing the elevation of the points with respect to our reference point in the field, we added the same elevation to all the points (since many had a negative elevation with respect to our reference point) in order to create a graphical representation of the profile on a graph, with the lowest point at a zero.

The instruments used to create the dune profile were a measuring rod, a tripod, and a laser level. The laser was shot in the direction of interest, leveled, and a measurement was recorded by reading where the beam showed up on the measuring rod. Typically, to do such a survey as ours, and auto-level and graduated rod would have been used. An auto-level is an instrument that incorporates an automatic leveling mechanism with a telescope that allows one to read heights on a graduated rod. Although this tool was not available to us, the laser level had adequate accuracy. The laser level is also a more time consuming way of measuring elevation, and in the future an auto-level or other surveying instrumentation could be utilized to make the process more precise and less timely.

We used typical land surveying methods, measuring back sites and fore sites with the laser level and measuring rod. The back site allows one to find the height of the instrument (laser) above the point of known elevation. The fore site is the measurement of a point of interest of unknown elevation. In order to calculate its elevation, the back site is added to the previous known elevation and the fore site is subtracted. This renders the elevation of the new point (Elevation + BS – FS = New elevation). The steps are repeated, until the instrument is moved and a new back site needs to be found. The instrument needed to be moved at some points because of a drastic increase in elevation, in which the laser could not shoot over, or deep valleys, in which the rod could not reach the height of the laser. Table 2 is a sample of our actual results for the San Nicolò dune site dune profile, which demonstrate our calculations.

Dune Site	Section	Point	S (m)	S (m)	Reference elevation	Positive Ref. Elevation	Description
SNICO	2	REF	0.78	X	0	0.52	Mark on flag pole at end beach
SNICO	2	1	1.86	1.3	-0.52	0	Profile point, and TP
SNICO	2	2		1.88	-0.54	-0.02	Profile point
SNICO	2	3		1.19	0.13	0.65	Profile point
SNICO	2	4		1.24	0.75	1.27	Profile point
SNICO	2	5		1.84	0.77	1.29	Profile point
SNICO	2	6	1.35	1.97	0.66	1.18	Profile point, and TP
SNICO	2	7		1.34	0.67	1.19	Profile point
SNICO	2	8		1.33	0.69	1.21	Profile point
SNICO	2	9		0.98	1.06	1.58	Profile point
SNICO	2	10		1.34	1.07	1.59	Profile point

Table 2: Sample Elevation Measurement Results

The reference elevation is the elevation assuming the elevation of the first reference point it correct. In our case, we simply used zero, which is obviously incorrect, but can be later found and updated. The reference elevations were then made positive by adding the same number to every elevation, simply for graphing purposes. The profile was very accurate because all the point heights were relative to each other; the actual elevations were not correct. As shown in Table 2, the same back site was used for a series of fore sites, until the instrument needed to be moved.

Each point was also recorded and mapped with GPS. The accurate distance between each point was calculated so the dune profile was more accurate with respect to the position of each point. Once imported into the GIS program, we indicated where the transect was taken and found which part of the dune structure occupied which bands by overlaying the layers. The dune profile was created using a simple chart, and the band coverage was indicated at the bottom with the appropriate color.

3.4.2.3 Dune Vegetation

Aside from measurements about the dunes themselves, we also gathered data about the environment on and surrounding the dunes. These environmental factors that we included were primarily vegetation. We paid particular attention to those species that are considered endangered, so that our recommendations for dune preservation also included the preservation of the habitats of these scarce creatures.

For each plant species we collected the following information:

- Photo of plant
- Whole plant
- Close-up of flower/stem/fruit if available
- Name of plant species
- Latin
- Italian
- English
- Location
- Coordinates
- Band
- Density of vegetation
- Related publications

3.4.2.3.1 Determination of Ecological Bands

To best represent the diversity of the dune area, we chose to use ecological bands, areas that run parallel to the coastline and are representative of certain ecological environments. The dunes of Alberoni contain five distinct bands that characterize the area. Each band can be identified by its characteristic vegetation, dune structure, and size. During a preliminary inspection of the area with our liaison, from the Venice Environment Department, we learned which plants and dune characteristics indicate the different bands. We walked along the lines that delimit the bands with two people, one behind the other. The person in front determined where the bands were separated, and the person in back recorded the coordinates with the GPS. We recorded the different aspects of the band determination process on field data collection sheets shown in Appendix D: Completed Field Data Sheets. Photographs of the vegetation species can be found in the Species Guide. The following sections describe the characteristics that help to identify each band.

3.4.2.3.1.1 Band 1 – Foredune Region

The first band is the band closest to the water, where up to three species can be found. However, only one is evident in the Alberoni, the *Cakile maritima*, or Sea Rocket.

This succulent plant holds water in its underground network of wide roots, and its presence indicates the beginning of the dune field.

3.4.2.3.1.2 Band 2 – Embryonic Dunes

Three species characterize the second band, as well as the first signs of dune formation. The vegetation of the second band is primarily located directly in front of the first dune and is comprised of *Amophile arenaria* (*litoralis*), *Xantium italicum*, and *Agropyron junceum*. The *Amophila arenaria* is the primary dune builder, and the second band is composed of individual small dunes.

3.4.2.3.1.3 Band 3 – Consolidated Dunes

In the third band, *Calystegia soldanella* is the dominant plant. It consolidates the first dunes that have elevation, working at connecting each individual dune to the others. Much of the vegetation located in the second band can be found here as well.

3.4.2.3.1.4 Band 4 – Dune Valley

The fourth band is located in the valleys between the dunes of the third band and the larger dunes of the fifth band. The fourth band is home to about six different species including *Euphorbia paralias, Oenothera biennis, Silene colorata, Medicago maritime, Echinophora spinosa* and *Ergynium maritimum*.

3.4.2.3.1.5 Band 5 – Large, Mature Dunes

The dune landscape of the fifth band is primarily the top of the largest dunes and their leeward side. The vegetation in the fifth and final band includes the *Populus alba*, or white poplar, *Scabbiosa gramuntia,* and *Apocynum venentum*.

3.4.2.3.1.6 Band 6 – Retrodunal Band / Pine Forest

The final band is the sixth band, which is actually the pine forest. This area has a very high concentration of pine trees and is separated from the rest of the dune field by fences. The concentration is very unnatural, and thus, many of the pine trees are dying since they are too close together. The pine trees also do not prosper in the valleys between dunes since water often collects there. These two facts in combination are the reason that many different clearings have formed within the forest. In these clearings, the indigenous vegetation such as *Juncus litoralis, Erianthus ravennae,* and *Schoenus nigricans*, can be found.

3.4.2.3.2 Mapping Ecological Bands

Feature	Type
Vegetated Point	Point
Band	Line
Profile Point	Point
Path	Line
Structure	Point
Fence	Line
Wall	Line
Vegetated Area	Area
Forest Clearing	Area
Miscellaneous	Line
Transept Area	Area

Table 3: Data Dictionary

In order to map the bands of the entire Alberoni region, we first divided the region into smaller, more manageable sections. Because the bands overlap, we cannot map a single band at a time for the entire length of the Alberoni. Instead, using human structures and other land characteristics, we were able to establish smaller areas in which we mapped out all the bands in that area before moving on to the next section.

Once a band was recognized, we walked the perimeter of the band using the line function of the GPS to take location measurements every 5 seconds to produce maps of the bands. Attached to the label of each area, we also indicate which plant species, obvious dune damage and structures. Table 3 represents the data dictionary that was used to take different types of coordinates.

3.4.2.3.3 Density of Vegetated Areas

Two kinds of measurements were taken: density and location. We identified the band first, and then measured the density of the vegetation of the indigenous species. We selected a random area of vegetation in each band that seemed most representative of the band. Two people would then determine what percentage of the band was covered with vegetation. These density measurements were recorded on a field data collection sheet, shown in Appendix D: Completed Field Data Sheets. We also recorded patches of specific species that are indigenous to the band using the GPS to identify their location.

The GPS coordinates taken were then downloaded and imported into MapInfo. A detailed procedure is outlined in Appendix E: GPS Instructional Guide. This data was then overlaid with our aerial photographs so we could best represent the layout of the vegetation.

3.4.2.3.4 Clearings

According to our liaison, the clearings in the pine forest were crucial because they were the only areas that consistently showed the re-growth of indigenous vegetation. We therefore located each clearing in the pine forest and mapped it with the GPS by using the point function in the center of the clearing. The center of the clearing was marked with a stick stuck into the ground, in order to provide a mark from where length measurements were taken, as well as an indicator of which clearings had already been mapped, to prevent redoing them. We measured the distance from the center to the outer limits of the clearing to get its general shape, using a tape measure. These measurements were necessary since we could not get enough satellites for the GPS to record on the outer limits of the clearings, due to tree coverage. We took length measurements in four directions from the center of the clearing: in the direction of the jetty, main path, cabanas, and beach. The lengths in the direction of the jetty and the cabanas make a diameter of the oval in one direction, the beach and the path the other diameter. Once we determined the general shape of the clearing, we filled out a data sheet on which we checked off important features. We looked for exposed sand, moss, and indigenous plants, such as *Eranthius ravennae*. This data collection sheet can be seen in Appendix C: Sample Field Data Forms. In order to get an overall picture of the forest, we made a hand-drawn map, showing the rough location of each clearing in relation to each other and major landmarks such as the beach, jetty, cabanas, and main path. We then examined the aerial photographs to determine the location of the clearings on them in order to create a map in MapInfo© of the clearing locations. The clearings were represented on the map by ovals, and their surface area was calculated.

3.5 Objective 2: Design the Sand Dune Database

To store all of the data we gathered in the field and compile existing data from other sources, we created a sand dune database. The database contains alphanumeric data, both published research and our collected field data. The database in conjunction with GIS (MapInfo©) and other types of visual information will be used by the Environment Department in order to assess the environmental impact of future development of land as well as function as a public educational tool. It will also be used in the future by the Environmental Department of Venice to create the *Environmental Atlas of the Lagoon*. The creation of this atlas will involve using our methodology as a template to gather and store information about the entire lagoon.

3.5.1 Data Organization

The database we created focuses on the dune sites of the outer islands, which are an important environmental aspect of the lagoon. Within the geographic focus of the Alberoni dune region, there are two distinct, biologically different areas (due to human impact). These areas have been termed the *pine forest* and the *dune band field*. These two regions defined separate areas of data collection that helped to organize the database. An image of these areas can be seen in Figure 17 on page 51.

3.5.2 Database and GIS

The database contains information pertaining to the dune band field and pine forest and consists of a vegetation catalogue, existing publications, and dune geomorphology data. The GIS contains information and mappings of objects and areas including the locations of clearings within the pine forest, existing structures, the ecological bands in the dune fields, topographic dune data, paths, and specific areas of vegetation. After the data was input into the database and GIS, the two programs were then linked to create an interactive way of visually representing textual data, as attached to the maps. An example of this is the representation of a band in the GIS, linked to the database of information pertaining to vegetation within that band. The GIS and database are both linked to a user interface that will allow easy input of new and updated material. The diagram in Figure 19 outlines the data collection and input.

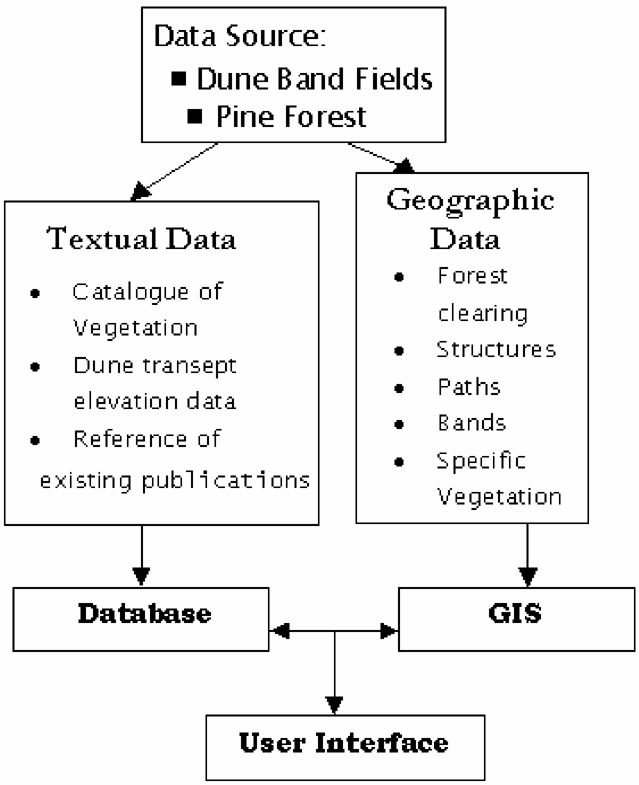


Figure 19: Flow Chart of Data Progression

We used Access to create tables containing fields for the vegetation, including: Latin and common names, photo identification, primary band, ID number, density of vegetation within each band, descriptions of each plant species, and related publication titles. The same database fields are used for the retrodunal band of the clearings in the pine forest. After entering all of this information for each species, we proceeded to link the information in the database to the MapInfo layers. In this way, by clicking on a band, all of the information about each species found in each will be accessed through a pop-up window. In addition to the layers for each band, we included layers for roads, permanent structures, paths, and fences. Also included are layers for the pine forest, which includes the clearings we mapped, the locations we feel are the best places for biological corridors, and a layer for the entire forest. Vegetation information was included for each clearing, as it was for each band. The information that we collected primarily pertained to vegetation, yet information about fauna, such as breeding/nesting grounds and migratory patterns can easily be added.

3.6 Objective 3: Developing a Prototype for the Environmental Atlas of the Lagoon

In order to provide the Environment Department with effective research methods for environmental information about the lagoon as well as with an Environmental Atlas that will later serve for both educational purposes and for Environmental Impact Analysis, we needed to evaluate our data collection methods at other dune sites and make those methods adaptable for research in other parts of the lagoon.

3.6.1 Research Methods Evaluation

Once we performed the majority of our data collection at the dune site of Alberoni, we traveled to the three other dune sites to test our data collection methods. On every dune site, we attempted to find the bands of vegetation present in the dune fields, recorded the density of flora in those bands, and produced maps of the areas based on our GPS data. We considered our methodology to be valid if we reproduced the same types of maps and data entries without any difficulties.

3.6.2 Relating the Sand Dune Database to the Atlas

The most important use of the database is its role in the creation of the *Environmental Atlas of the Lagoon*. The database will serve as a tool for consolidating existing information on the Venetian Lagoon for graphic representation in the *Atlas*. Our methodology will serve as a template for collecting published research and conducting fieldwork, which will result in mapping other areas of the lagoon of ecological importance. This ultimately will allow individuals to assess the impact of future development throughout the lagoon. The *Atlas* contains links to ecological characteristics of the area of study; in addition it provides titles of published information related to a selected area.

The study we conducted is a small, but integral part of the entire lagoon atlas. Our database will be incorporated into the atlas, but more importantly our methods will be applied to future research methods; however, it is important to recognize that field research must be conducted with slight alterations depending on specific areas (such as marshes, mentioned in 3.4.2) and their ecological characteristics. Depending on the area and its characteristics, impact assessment is managed differently.

We relied on tables and graphs created with our database to help us develop and present our recommendations to the Environment Department. The Environment Department will be able to more accurately determine a course of action in preserving all parts of the lagoon that need protection, not just the dunes. Our system makes it possible to compare information, both textual and geographical, from year to year in order to monitor the changes that occur in the lagoon over time. By using the *Environmental Atlas,* the Environment Department has the ability to catch destructive trends early on and propose conservation plans before restoration is needed.

Results & Analysis

We collected data on the two barrier islands that make up the *Lidi*, the Lido and Pellestrina, at the following dune sites: Alberoni, San Nicolò, and Ca'Roman. It encompassed the dune fields as well as the maritime forests, as applicable. We mapped the locations of ecological bands and catalogued vegetation species. We also assessed the density of the vegetation for each band and mapped areas of human interference and consistent use, such as paths, permanent and non-permanent structures. These maps were linked to a database containing data on the vegetation and other natural characteristics of the dune regions, providing a comprehensive data system for use in preservation and maintenance of the areas and for conducting environmental impact analysis for future commercial or residential development of the areas. This data system is the main deliverable of the project, to be used as a prototype for the *Environmental Atlas of the Venetian Lagoon.*

Our research produced the following results from each dune region: maps of the ecological bands and areas of human impact, tables and graphs containing information about the indigenous vegetation and vegetation density within different ecological bands. The data for each band was compared to the others for overall analysis of the current state of the dunes. Indices were developed to assess the condition and the value of each dune site. These values were and used to formulate recommendations for future use and preservation.

Our results provided us the tools to perform an analysis of the current states of each dune site. We compared the dune sites to each other using the data we collected on band surface area, vegetation density, and areas of damage. Through observation over the course of our field data collection, our group discovered that the raw data consisted of physical measurements and maps, analysis took this data a step further through calculated indexes and ratios.

The Environment Department must collect data for a series of years to effectively monitor the dune sites and predict the affect of future disturbances on the dunes. Through our study of the history and development of the areas, we know that the current state of the dunes was caused by past disturbances, and can compare their present state to what would have naturally occurred without these disturbances. Through the analysis of our results, we conducted a condition assessment of each dune site, allowing us to make recommendations on future research, assessment, and preservation techniques.

4.1 Results from Alberoni

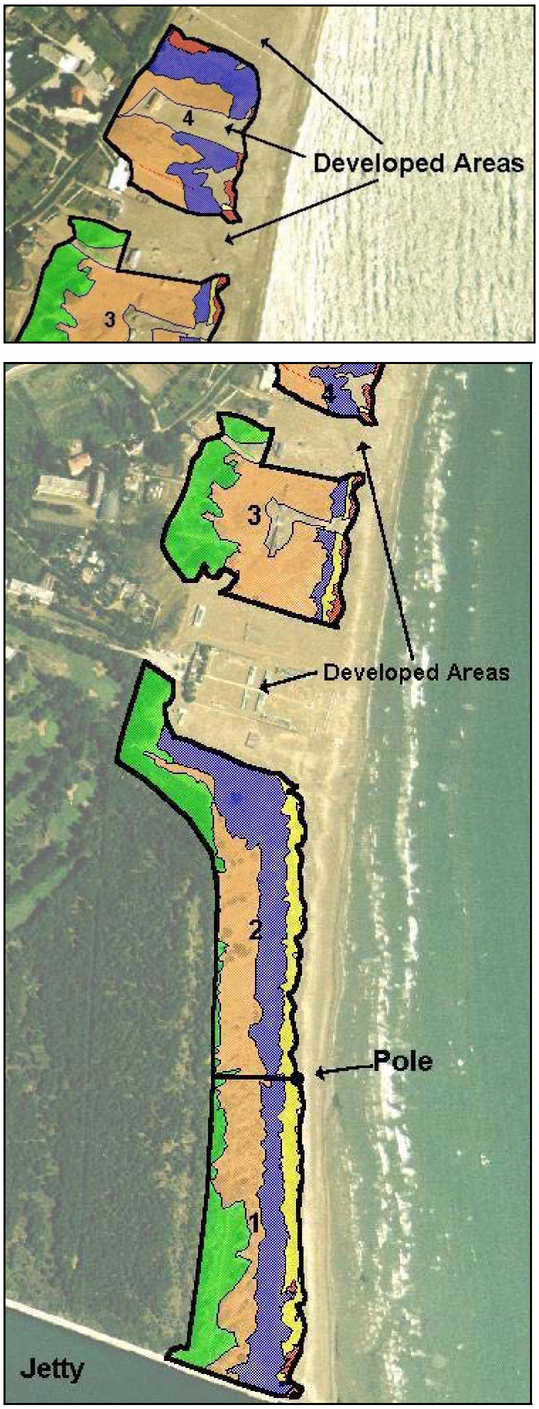


Figure 20: Alberoni Dune Site Sections

The Alberoni dune field is very large and separated into different parts by human impact. To make this area more manageable, we divided it into four different sections separated by permanent or semi-permanent structures. The first section spanned between the jetty and the pole. The second section ran from the pole to the cabanas, noted in Figure 20 as a developed area. The third and fourth sections are located on the other side of the developed area. The third section spanned from the cabanas to the next developed area, and the fourth section ran until the dunes ended near the next developed area. The sections were numbered increasing order from the jetty inland.

The Alberoni is a damaged site because of its proximity to Venice's historical center and to frequently running public transportation. Since the area is very accessible to people, it has been well developed with users of the area in mind. Cabanas were built for beach-goers by the city over large areas, destroying parts of the dune field and damaging others.

4.1.1 Ecological Band Determination and Measurement

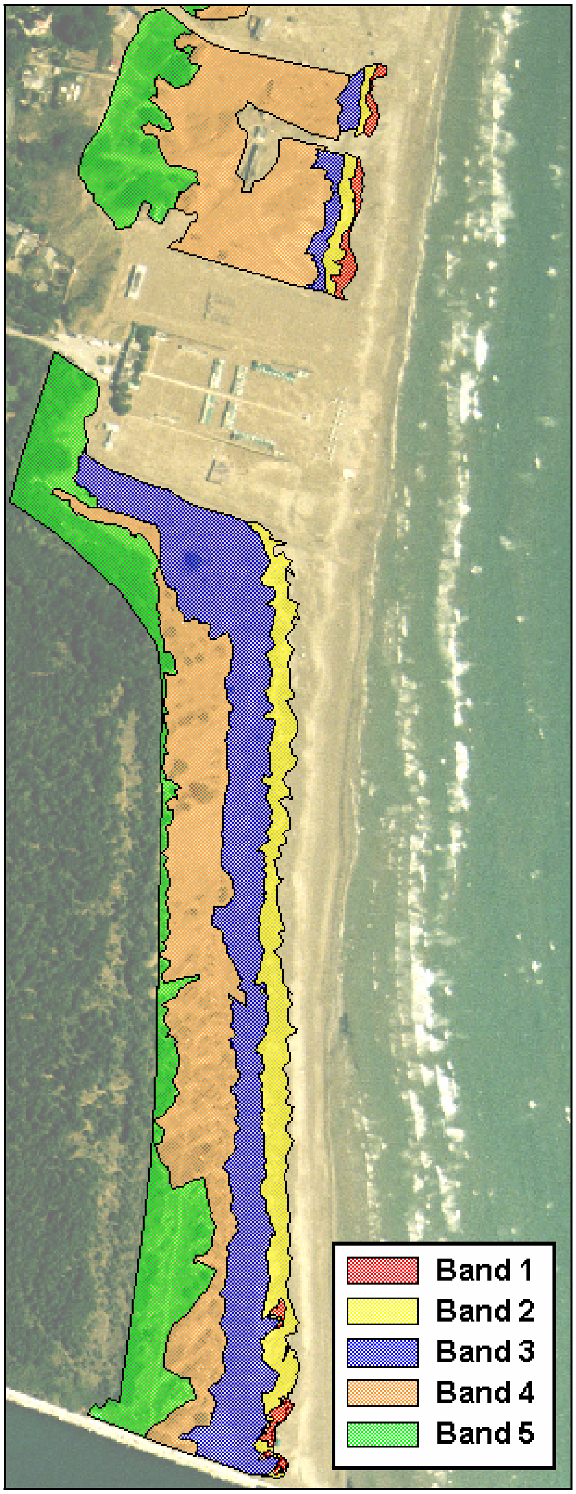


Figure 21: Map of Alberoni Bands for Sections 1 and 2

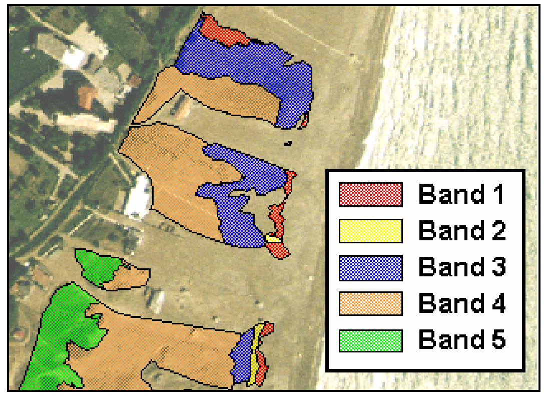


Figure 22: Map of Alberoni Bands for Sections 3 and 4

Figure 21 and Figure 22 show an aerial view of the ecological bands that we identified on the Alberoni dune site. The band numbers are color coded, and follow a decreasing number order from left to right, where the leftmost band is band number five shown in green, and the rightmost band is band number one, shown in red.

As shown in the image, band one is practically missing in this area. Bands two, three, and four follow a normal progression, but band 5 is cut short due to the presence of a fence that separates the dune field from the pine forest shown to the left of the bands. Each band also contains a series of ecotopes, denoted by a code number established by the Natura 2000[64] guidelines for preservation of areas

[64] No Author. *Natura 2000: Council Directive of 21 May 1992 on the conservation of the natural habitats of wild fauna and flora.* Available online: http://europa.eu.int/comm/environment/nature.natura.htm

deemed endangered by the European Union.

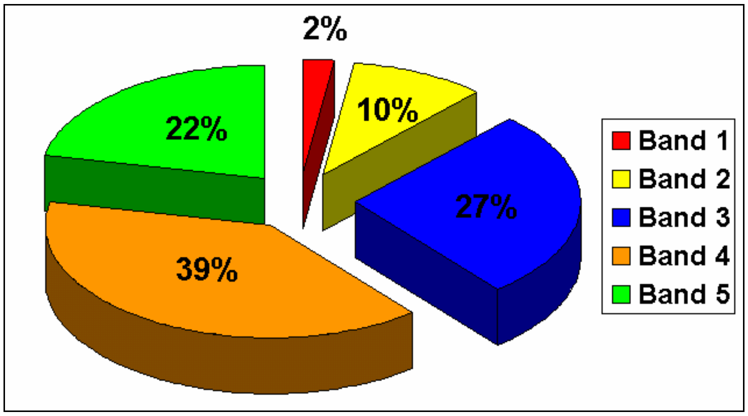


Figure 23: Percentage of Total Surface Area by Band at Alberoni

Once we determined the dune bands, we used MapInfo© to calculate their total surface areas and the total area of each dune site. Using this information, we calculated what percentage of the total band area each band comprised. Our results for sections 1 and 2 of Alberoni are shown in Figure 23. Bands 3 and 4 make up the greatest portion of the all the bands on the Alberoni, while Band 1 is the smallest.

4.1.2 Vegetation Density Assessment

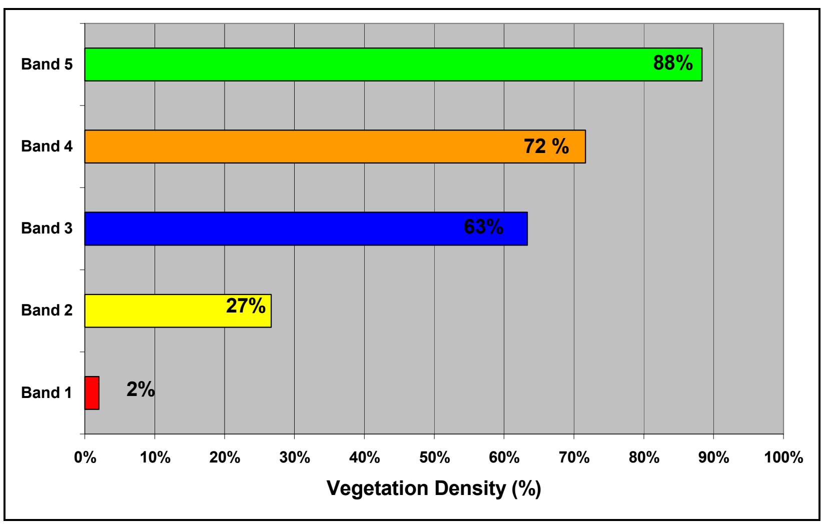


Figure 24: Vegetation Density by Band on Alberoni

We assessed the density of the vegetation in each band after determining the bands with the GPS. We recorded separate band density measurements for each section of the Alberoni region. Figure 24 shows the overall average vegetation density for each band of the Alberoni dune region. We found that the vegetation increased between bands from 2% to 88% from band 1 to band 5, suggesting that vegetation density has a positive relationship with the distance from the shoreline.

Species Latin Name	Band 1	Band 2	Band 3	Band 4	Band 5	Comments
Cakile maritime	Yes	No	Yes	No	No	
Ammophila litoralis (arenaria)	Yes	Yes	Yes	Yes	No	Dominant plant of 3rd band
Xantium italicum	Yes	Yes	Yes	No	No	
Agropyron junceum	Yes	No	No	Yes	Yes	
Calystegia soldanella	No	Yes	Yes	No	Yes	
Cyperus kalli	No	No	No	No	No	
Euphorbia paralias	No	Yes	Yes	Yes	No	
Oenothera biennis	No	No	Yes	Yes	Yes	Dominant plant of 4th band

Table 4: Vegetation Catalog on Alberoni

Each band was successively more vegetated, and contained different plant species, although a number of species did exist in more than one band. *Ammophila litoralis*, for example, is the primary vegetation of band 2, since it is the creator of dunes; however, it is also found in bands 3, 4, and sometimes in 5. Table 4, an excerpt from our database, illustrates this phenomenon. It shows which band each vegetation species was found in. The two most notable plants on the Alberoni are the *Ammophila litoralis* and the *Oenothera biennis*. Although they are the dominant plants in bands 3 and 4 respectively, they have spread throughout the dune field

4.1.3 Transect Assessment and Dune Profile

The first reference point for elevation measurements on Alberoni was the fence, at the back of the dune field. All other measurements were taken with respect to that point. The dunes on Alberoni grow to be very large in the fifth band. The profile illustrates the reason that band 5 is very small: the fence and the planting of the pine forest causes the band to end prematurely; however, one can still observe dune structure within the forest.

The stars in Figure 25 show the points at which elevation and GPS measurements were taken. Each star corresponds with a point on the dune profile. They do not exist in a straight line due to the presence of heavy vegetation and the difficulty of maneuvering the equipment around dune structure.

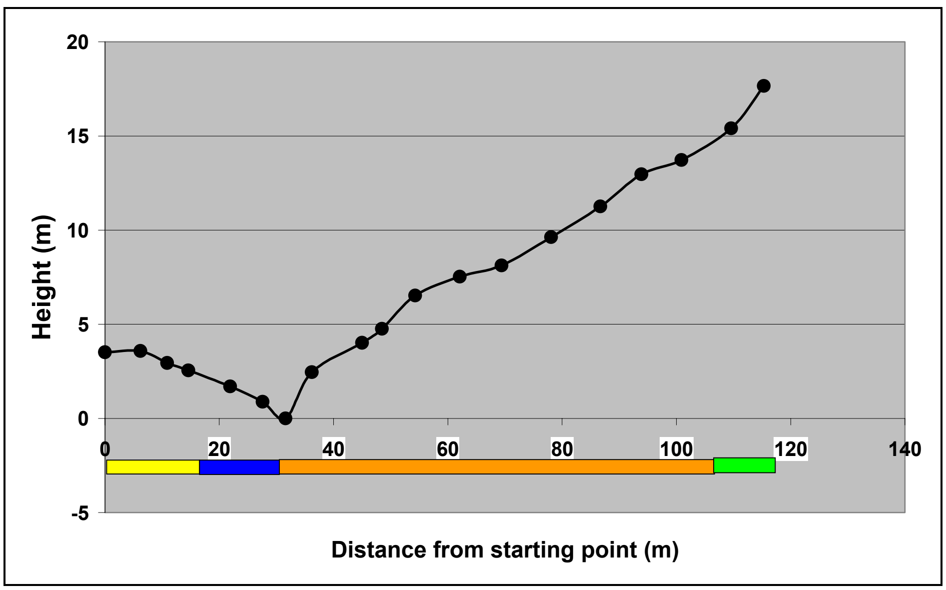


Figure 26: Alberoni Dune Profile

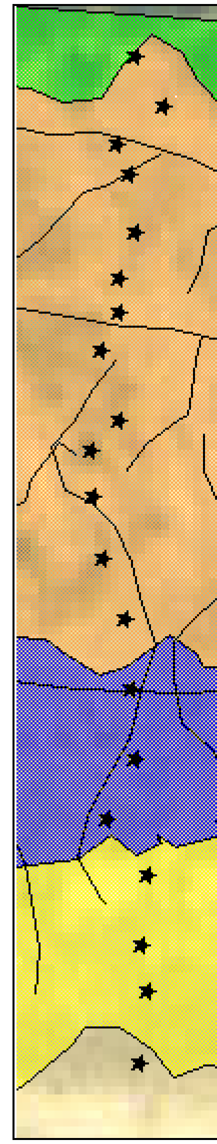


Figure 25: Alberoni Dune Transect

4.1.4 Damage Assessment

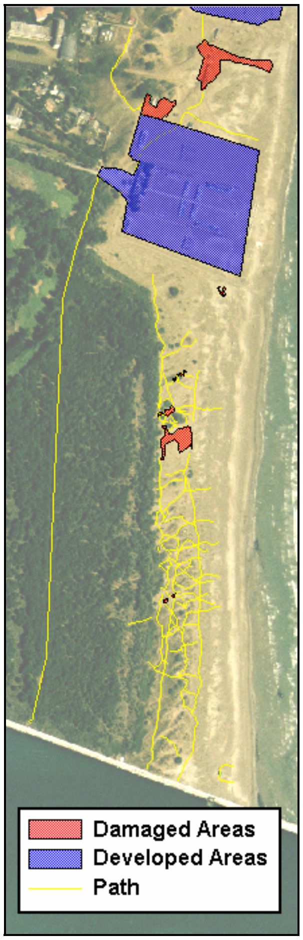


Figure 27: Map of Compromised Areas in Sections 1 and 2 on Alberoni

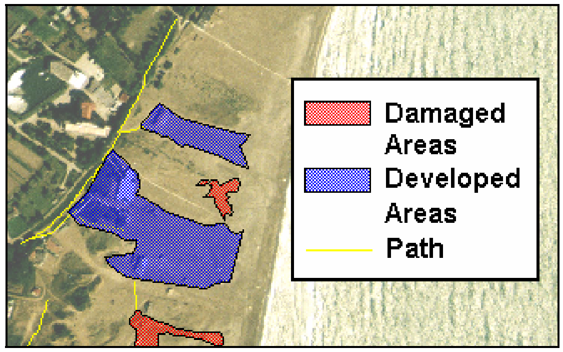


Figure 28: Map of Compromised Areas in Sections 3 and 4 on Alberoni

At Alberoni, there were three different classifications of areas with human interference: paths, damaged areas, and developed areas. Damaged areas are spaces that are relatively small and mostly bare of vegetation, generally caused by pedestrian traffic. These areas are generally found close to the active beach. Developed areas are larger areas that have been totally cleared of dunes and vegetation for the construction of permanent structures and necessary beach access. These areas were mapped with Mapinfo © and the total surface area for each classification was calculated. These compromised areas are shown in Figure 27 and Figure 28, and the colors correspond to the percentages shown in Figure 29. 32% of the surface of Alberoni has been compromised by human interference and damage.

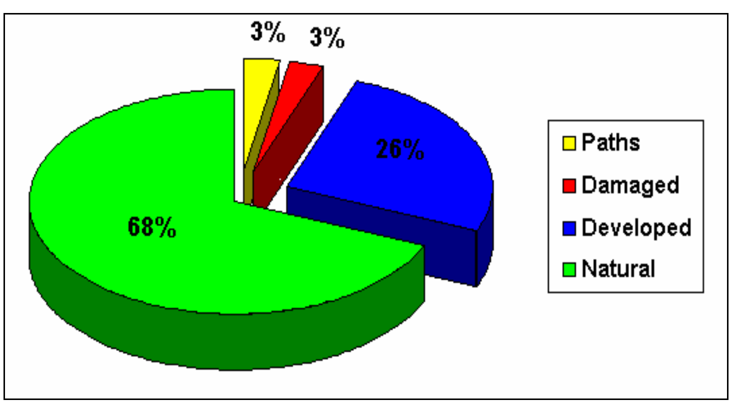


Figure 29: Percent Area Compromised on Alberoni

4.1.5 Pine Forest Clearings

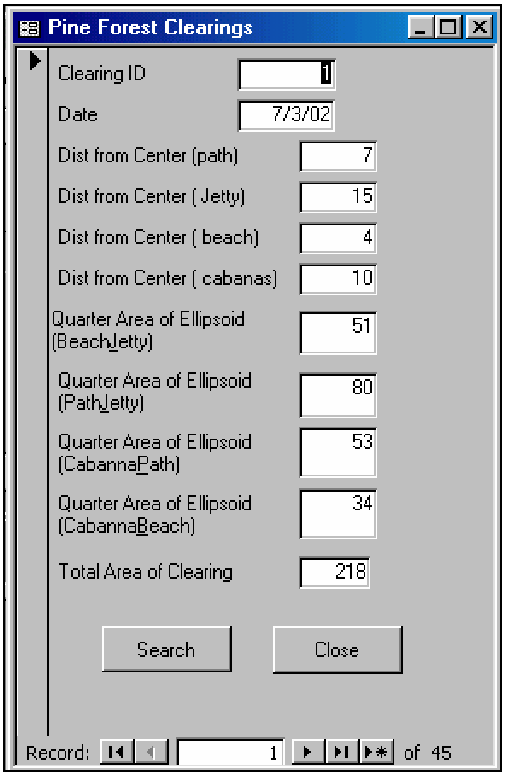


Figure 30: Form showing Measurements of the Pine Forest Clearings at Alberoni

We took several types of measurements in the forest clearings. Firstly, we marked the position of the clearing on a hand-drawn map. This map was then analyzed with the aerial photographs to create a map layer of the location of all the clearings. Distance measurements were taken from the center of clearing in four directions: towards the beach, main path, jetty, and cabanas. Figure 30 is an example of the form that we used to enter the data into the database. All measurements were made in meters.

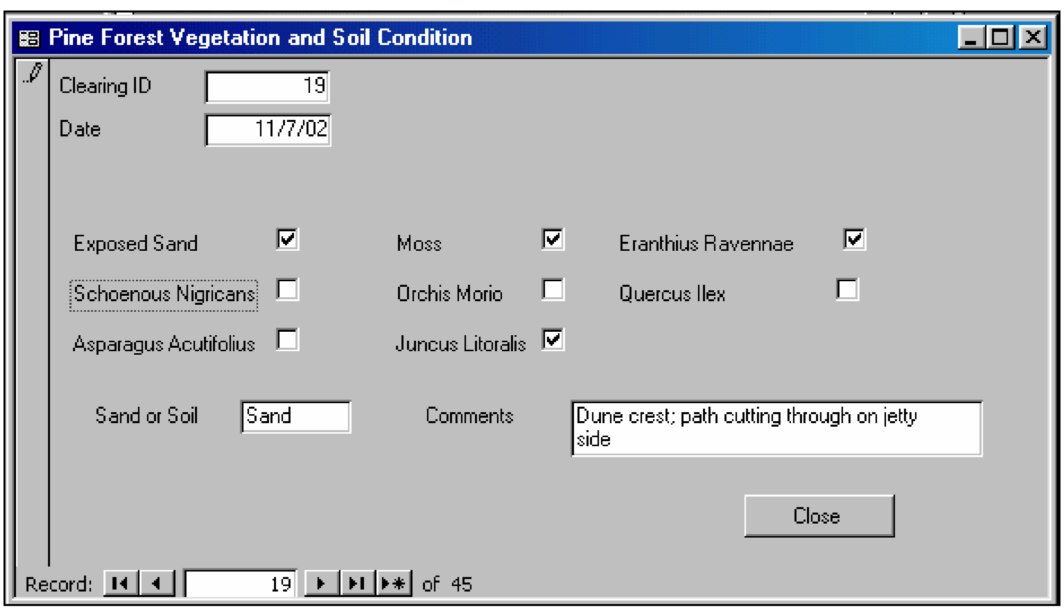


Figure 31: Pine Forest Vegetation Catalog Form

Figure 32 is a map of the forest clearings, the size of the circles indicating the location of the clearings also indicates the size of the clearings. We completed a worksheet indicating the species of indigenous vegetation and other indicators of good soil composition like exposed sand and moss. We also noted any distinguishable dune structure, such as whether the clearing existed on a dune trough or crest, if the pine forest had not grown over the dunes. The type of vegetation found in the clearing was an indicator of dune structure. For example: species like *Schoenus nigrican and Juncus litoralis* grow in wetter environments, or dune troughs, as opposed to the drier environments of dune crests. Figure 31 shows the form that we used to enter the characteristics of each clearing.

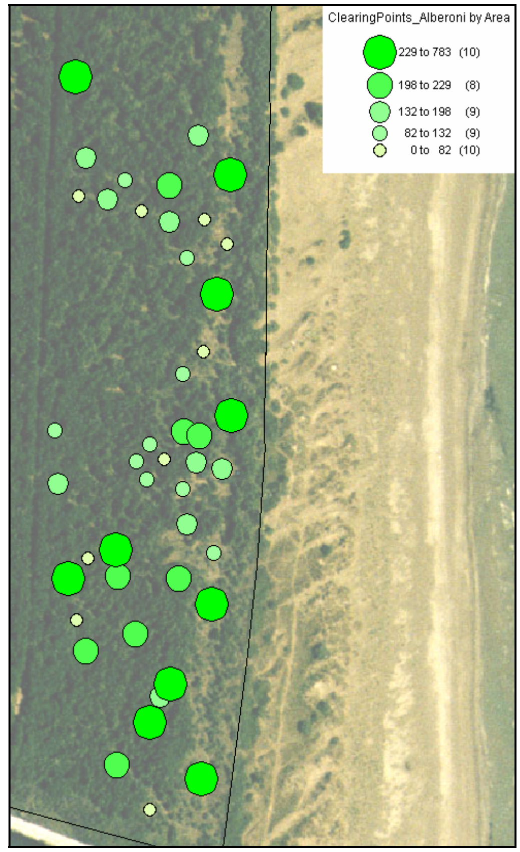


Figure 32: Map of Forest Clearings on Alberoni

We encountered two types of clearings during our study. The sandy, less vegetated clearings always had moss and usually had some dune plants from the 4th or 5th bands. The vegetated clearings were dominated by *Juncus litoralis* and *Eranthius ravennae*. In these, the vegetation was so dense that the ground could not be seen by simple inspection. The worksheet on which we detailed the presence of vegetation can be found in Appendix D: Completed Field Data Sheets. We relied on our surveys of indigenous vegetation and our maps of clearings to determine biological corridors in the pine forest.

4.1.6 Biological Corridors

To effectively restore the dune's natural environment, we chose to use biological corridors to connect groups of indigenous vegetation species in hopes that the indigenous vegetation will spread. Recording where indigenous vegetation lies, both within the dunes and the forest area, were essential to determining the orientation and location of these corridors.

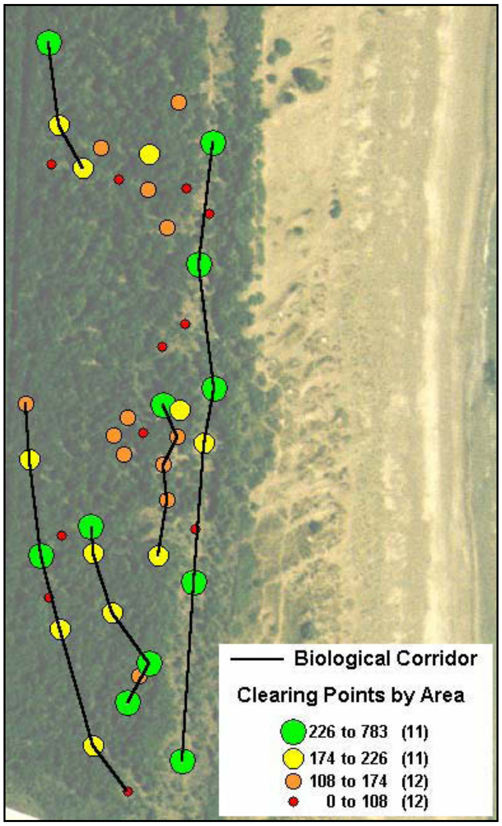


Figure 33: Established Biological Corridors in the Alberoni pine forest

In the forest region, we concentrated on connecting areas of indigenous vegetation, usually found in clearings. These areas indicate places where the soil has not been compromised by the acidity of the pine needles. Connecting these areas would promote the growth of indigenous vegetation and hopefully restore some of the dunes' natural environment.

To connect the clearings in the pine forest in the most efficient manner, we searched for indigenous vegetation between the different clearings that we found. If indigenous vegetation was present throughout the path we walked from one clearing to the other, then the link was made. If there was little or no indigenous vegetation between the clearings, the link was not made and noted.

Since the ecological bands run parallel to the coast, we established that the biological corridors, based on vegetation, should as well. The clearings were linked based on indigenous vegetation found in the forest clearings, such as *Eranthius ravennae* and *Schnoenous nigricans*, and on soil conditions such as whether or not there is exposed sand or moss. These biological corridors will aid the environment department in managing the pine forest so that the dune vegetation grow back, and eventually take back these areas.

It is important to remember that biological corridors involve entire ecosystems. Therefore, a certain region with non-indigenous species of any kind cannot be uprooted and changed without affecting the plants and animals that live there. Since the pine forest was planted, new flora and fauna have migrated into the area, changing the components of the ecosystem. Since we are only focusing on the vegetation aspect of the biological corridors, another analysis should be made for the fauna of the area before any alterations to the pine forest are made.

4.2 Results from Ca'Roman Region

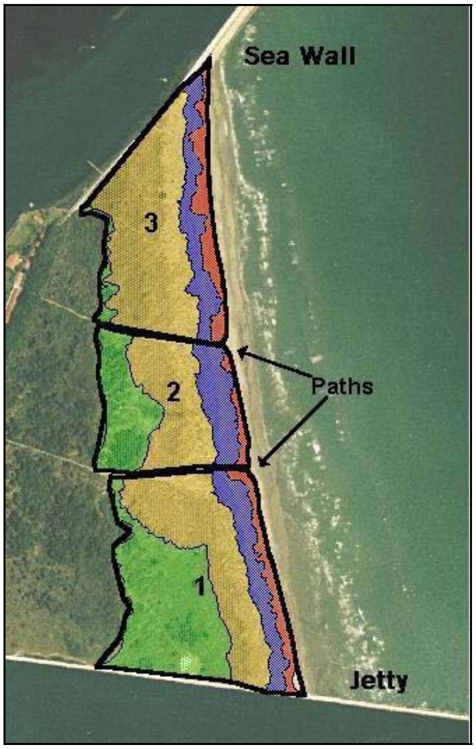


Figure 34: Spatial Break Down of Ca'Roman Region

The Ca' Roman dune site was further divided into three sections, separated by large paths that run from the maritime forest to the shoreline, as shown in Figure 34. The entire region was not hindered by human development and left very much in its natural state. We observed little evidence of damage to the dune field, only large sand accumulations near the jetty, which altered the surface areas of bands four and five. We suspect that this dune site is well preserved because of its distance from Venice's historical center and its limited accessibility without good public transportation. We therefore established Ca' Roman as a model dune site to be used in comparison with the two other sites we studied.

4.2.1 Ecological Band Determination and Measurement

The dune site of Ca' Roman was significantly more preserved than that of Alberoni; therefore, determining the ecological bands was not quite as challenging, and was more clear-cut. The dune site was also divided into three parts, two to the right of the main path (facing the sea), and one to the left, as shown in Figure 35. Overall, the dunes had the

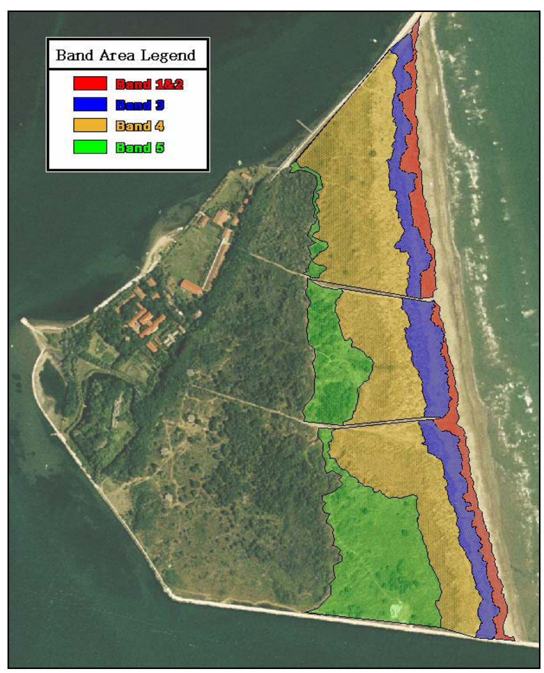


Figure 35: Band Area Map of Ca'Roman

same morphology and vegetation. We observed similar band sequences on each side of the main path, with bands 1 and 2 fused together throughout. The only variation came near the jetty, where the 5th band was extensive compared to both the other bands and to the rest of band 5 for that dune site. We also found that on this dune site the second band was hardly distinguishable in many parts of the dune field, present only in sparse areas of the first band; however, they were easily identifiable from band 3 and from the shoreline.

Again, using MapInfo©, we calculated the surface area of each of the bands, and compared that area to the total surface area of the dune band field to arrive at the percentages shown in Figure 36. Together, bands 4 and 5 make up over seventy-five percent of the total surface area of the dune field.

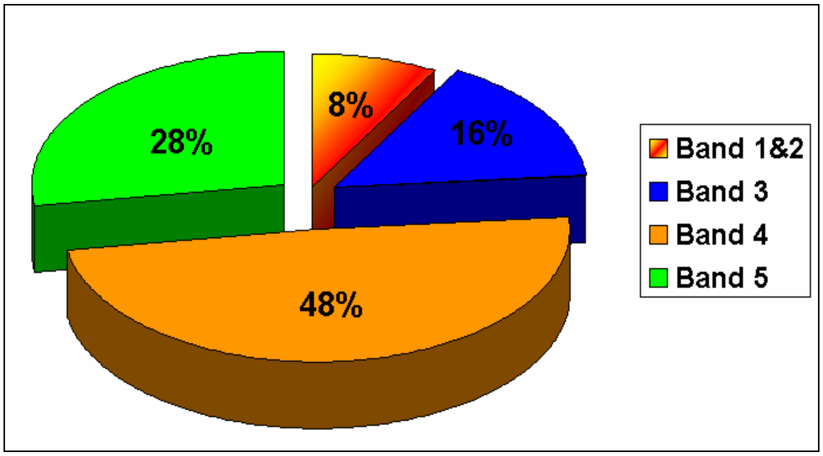


Figure 36: Percentage of Total Surface Area by Band at Ca' Roman

4.2.1 Vegetation Density Measurement

Density measurements were again recorded for each area of the Ca'Roman dune field, and were then averaged to determine the overall vegetation density for each band, shown in Figure 37.

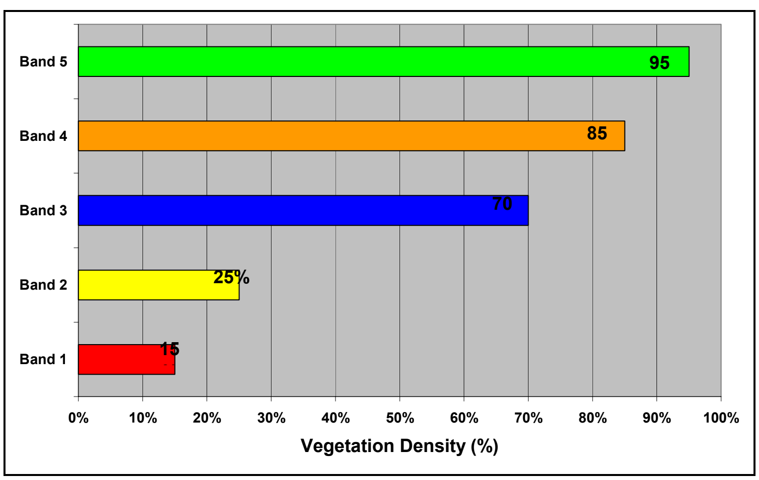
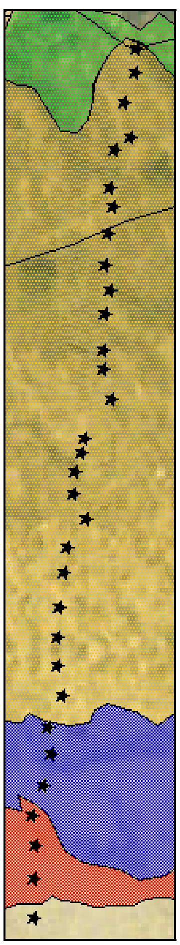


Figure 37: Vegetation Density by Band on Ca'Roman

Each band was successively more vegetated, and was more densely vegetated than the bands in the Alberoni dune region. Band 1was 15% vegetated, band 2 was 25%, and band 3 was on average 70% vegetated. Bands 4 and 5 were 85% and 95% vegetated, respectively. Both Alberoni and Ca' Roman's vegetation density more than doubles from the second band to the third band, a normal observation since band 3's role is consolidation of the vegetation to form larger dunes. This could be caused by several factors, both natural and unnatural. The wind, tide, and soil conditions could be different, due to the significant distance between the dune fields. These differences in environmental conditions can cause the differences in vegetation witnessed on the dunes; however, the differences in vegetation can also be caused by human interference factors. Fewer disturbances have allowed more vegetation to flourish in the Ca'Roman region.

4.2.2 Transect Assessment and Dune Profile



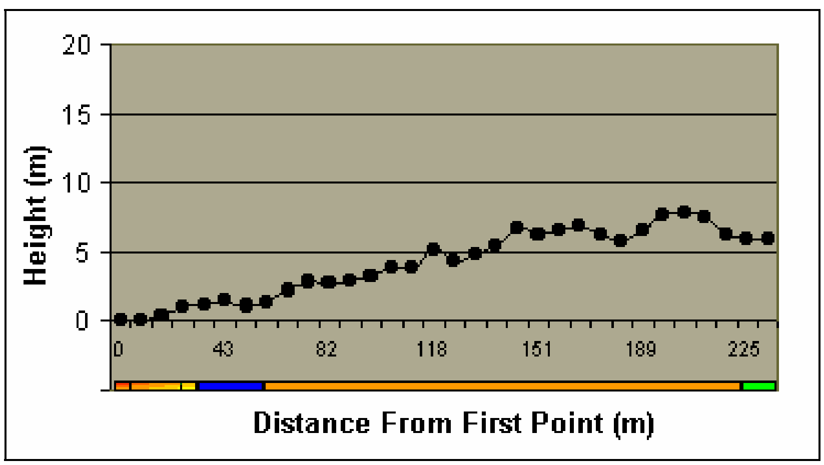


Figure 39: Ca' Roman Dune Profile

We marked a point on the concrete path to use as the reference point for which all the elevation measurements were based. The stars in Figure 39 correspond to the points in Figure 38, and are the locations at which elevation measurements were taken. We started taking measurements at the first band and worked through the band sequence. There was a normal dune structure of primary and secondary dunes with dune slack, and a very distinguishable fifth band of large dunes. Dense and tall vegetation tended to impede

Figure 38: Ca'Roman Transect

measurements using the laser. There was a really large band 4; it contained small undulations, but no vegetation that signified a reoccurrence of band 3 or an early appearance of band 5, so we classified the entire area as band 4.

4.2.3 Damage Assessment

Figure 40: Map of Compromise Areas on Ca'Roman

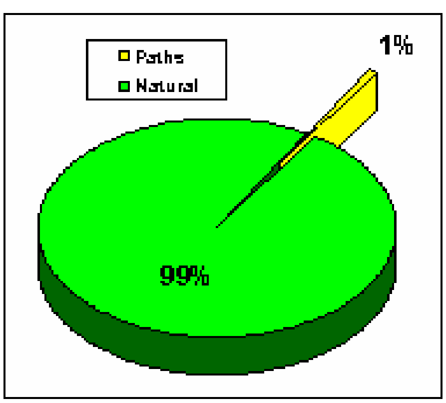


Figure 41: Percentage of Compromised Areas on Ca'Roman

The dune field of Ca'Roman was the least compromised of all three dune sites. There were no damaged or developed areas, and only a few paths, which granted access to the beach. These paths are shown in yellow on Figure 40. The surface area percentage consumed by paths was only 1% of the total surface area of the dune field, as shown in Figure 41. Paths that were present in the dune field tended to cause little damage to surrounding areas, and were necessary for access. There were no structures on the dune field to take into account at Ca' Roman, although there were benign structures in the retro-dunal band, where bunkers had been built for World War II. These structures were too far from the dune field to cause it any damage.

4.3 Results from San Nicolò Region

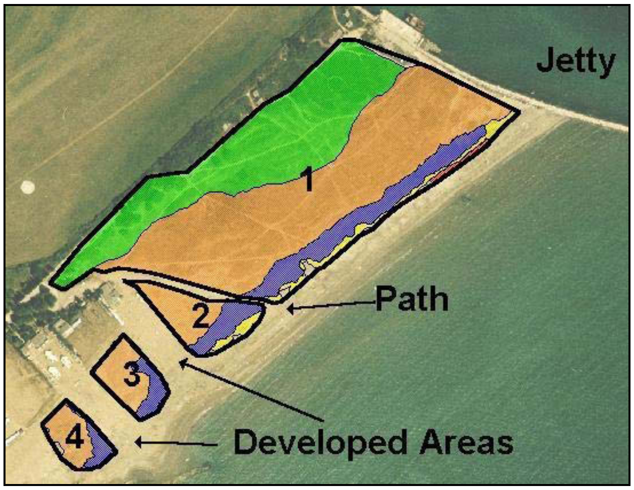


Figure 42: Spatial Break Down of the San Nicolò Region

The dunes at San Nicolò are much smaller and more embryonic in nature, in comparison to the other dune sites. The jetty has prevented the ocean currents from replenishing the area with sand, thus interrupting the normal littoral drift of sediment that allows the dunes to grow very large, like on the Alberoni. San Nicolò also showed the greatest instance of human impact of the dune sites we visited. It is so commercially developed that the dunes were, for the most part, very damaged. These circumstances made evaluating the dunes very challenging. We found very little dune structure and many of the bands were misplaced, or completely missing; however, the vegetation was just as dense as the other dune sites.

4.3.1 Ecological Band Determination and Measurement

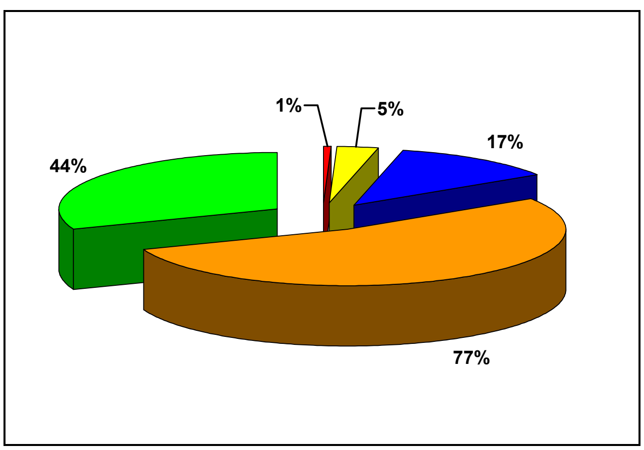


Figure 43: Percentage of Total Surface Area by Band at San Nicolò

When we calculated the surface area of the bands at San Nicolò, we found that band 4 was the dominant band throughout the area, as we had previously observed in the field. Band 1 was present only in small area in section 1. The 5th band was cut short at this site by a well-defined gravel path that was parallel to the shore and lead to the jetty. Shortly after the path existed heavy vegetation, cut once again by human intervention, but this time a fence bordering an airfield.

4.3.2 Vegetation Density Assessment

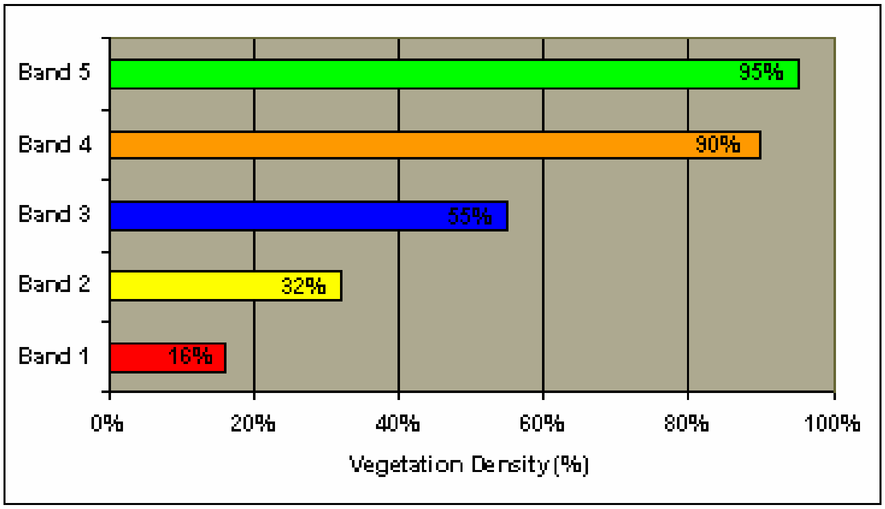


Figure 44: Vegetation Density for San Nicolò

There was a standard vegetation density common to the other dune sites; band 1 being the least vegetated and band 5 being the most vegetated. A large increase in vegetation density could be noted from band 3 to band 4 as shown in Figure 44, typically due to the use that the preliminary bands receive with respect to recreational use.

It was difficult to distinguish bands by characteristic vegetation because the dune field lacked structure causing vegetation to spread across bands. This was particularly evident between bands 4 and 5.

4.3.3 Transect Assessment and Dune Profile

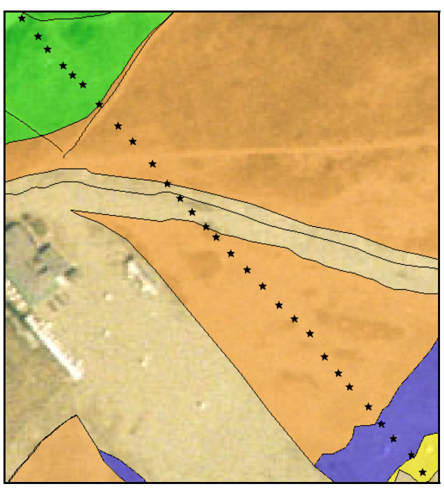


Figure 45: San Nicolo Transect for Section 2

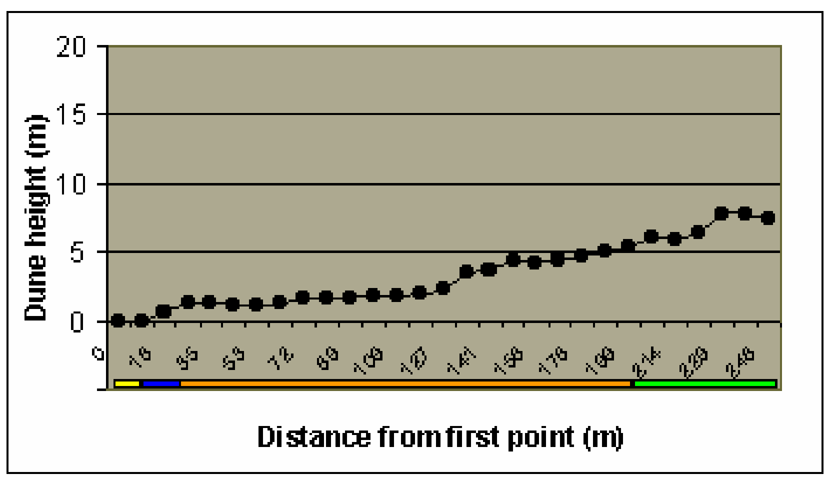


Figure 46: San Nicolò Dune Profile for Section 2

Transects were taken in two sections of the San Nicolò dune site. These were chosen based on slightly differing dune structure found in section 1 and section 2. Section 3 and 4 were not included in the transect analysis because the areas were extremely compromised by development of the area. The first profile and transect is shown in Figure 46 and Figure 45, respectively. The profile shows natural band progression with appropriate structure corresponding with characteristic band.

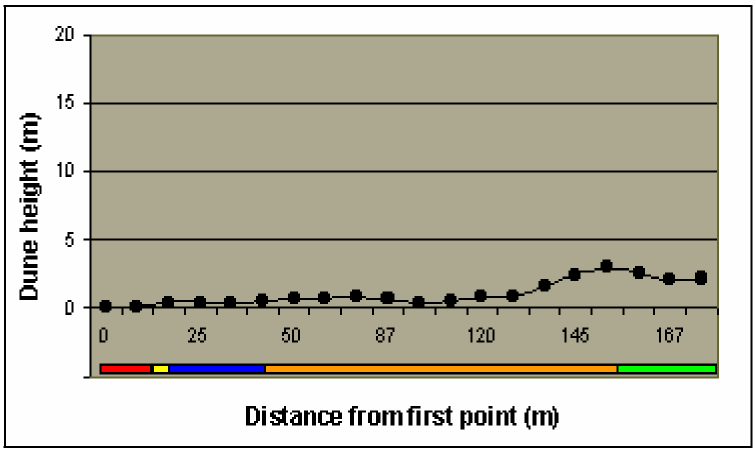


Figure 47: San Nicolò Dune Profile for Section 1

Band 2 is relatively level, as shown in the profile, and then small foredunes begin to starting with the appearance of band 3. Band 4 contains relatively low slack tendency with larger dunes existing up to the 5th band, which then drop back down when reaching the gravel path.

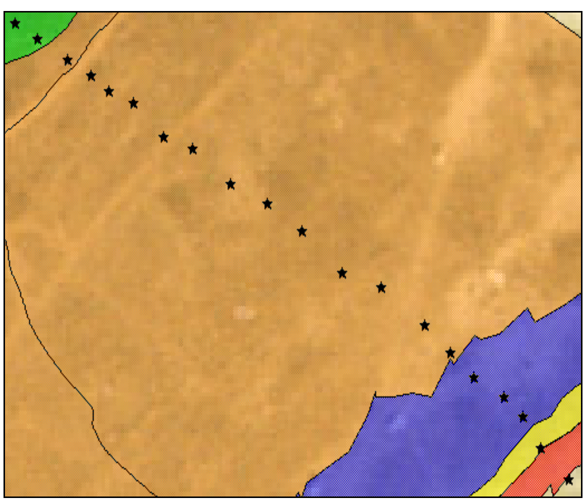


Figure 48: San Nicolo Transect for Section 1

The dune profile for section 1 of San Nicolò showed very little dune structure and only about 3.5 meters of elevation, as shown in Figure 47. Although the band sequence in this area was correct, as seen in Figure 48, the dune structure does not reflect changes in dune morphology.

4.3.4 Damage Assessment

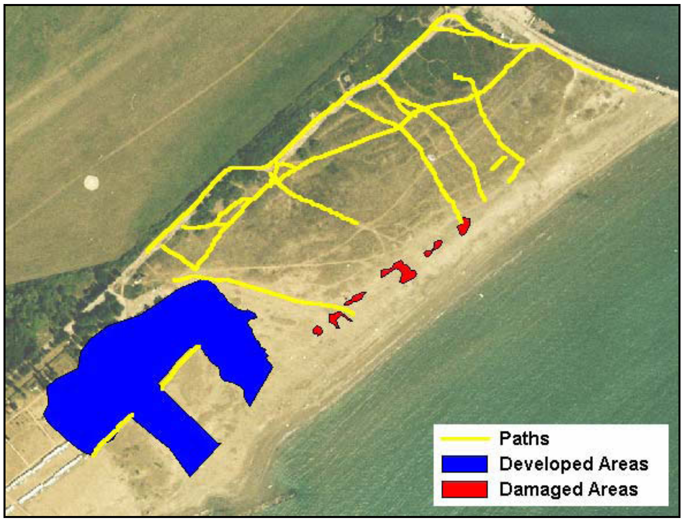


Figure 49: Map of Compromised Areas on San Nicolò

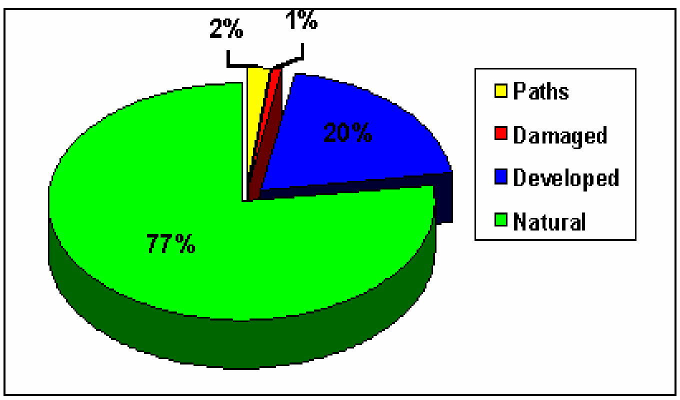


Figure 50: Percentage of Compromised Areas on San Nicolò

The total surface area of paths, damaged areas, and developed areas was calculated for San Nicolò, and compared to the total surface area of the dune field. We found that 23% of the dune field has been compromised by human interference and damage, as shown in Figure 50.

The path that runs parallel to the coast at the back of the dune field does not damage the dune field because it allows access to the jetty, and therefore the beach, without trampling vegetation or separating the band sequence.

4.4 Comparison of the Dune Sites

Analyzing several different factors that contribute to dune health assesses the overall condition of the dune site. These factors include: vegetation density, band width and surface area in ratio to the entire dune area, the ratio of damaged area to the entire area, and the presence of key vegetation within bands. Each of these factors has quantified by our project, to serve as a baseline to be used for comparison as future data is collected.

4.4.1 Vegetation Density

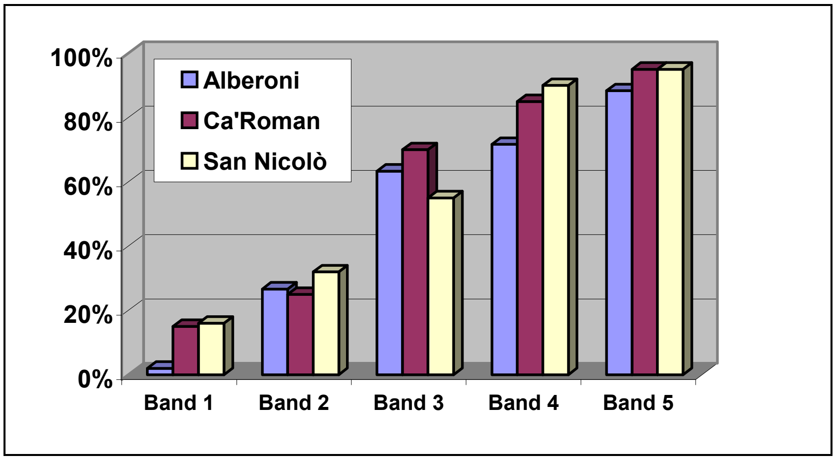


Figure 51: Vegetation Densities of Alberoni and Ca' Roman

We noticed that the only significant difference between the vegetation densities of Alberoni and Ca' Roman was in Band 1, where Alberoni's first band is 2% vegetated while Ca' Roman's first band is 15% vegetated. This difference in vegetation could be attributed to natural factors like variations in wind, tide, and weather patterns. However, we believe that these differences are caused by differences in the levels of usage between the dune sites.

4.4.2 Surface Area of Bands

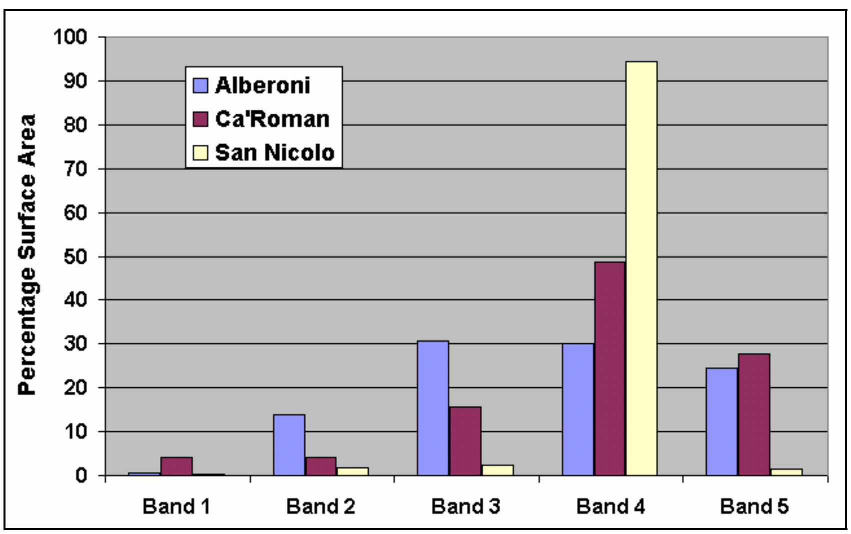


Figure 52: Comparison of Band Surface Area Percentages by Dune Site

By looking at the surface areas of the bands at each dune site, we observed that Ca' Roman had the most consistent line of data, followed by Alberoni, and then San Nicolò. Since Ca' Roman is the most natural of the dune sites, we established it as our model site. The surface areas of the bands get progressively larger starting with band one, and peak at band four, the valley between the small dunes and the large dunes, only to decrease by about half in the fifth band. We believe that this is the natural progression of band surface area, since a large fourth band is needed to establish the structure and size of the larger dunes. We can see from the figure above that the bands at Alberoni follow the same pattern, except for the fact that bands three and four have nearly the same surface area. This suggests that some damage has been done to these two bands. On San Nicolò, the band areas do increase from the shoreline inwards, but these areas are very small, suggesting that a great deal of damage has been done. The fourth band is also unusually large compared to the other bands on the site, showing that the area is very disturbed.

4.4.3 Human Impact on Dune Sites

When assessing damage, we created three categories: large developed areas, smaller damaged areas, and paths. The large developed areas were defined as existing structures, typically still in use, in locations where the dunes and vegetation had been cleared all the way to the beach. An example of a large developed area the region of cabanas that separates sections 2 and 3 on the Alberoni, is shown in Figure 20, on page 66. Smaller damaged areas were in general due to smaller structures built into the dunes, abandoned buildings where dunes started to retake the area. Many of the smaller damaged areas were also caused by pedestrian traffic and use on the dunes; thereby killing the vegetation that stabilizes the dune and causing areas that lacked a substantial amount of vegetation.

Damage to the dunes is created by the physical characteristics of the structures that disrupt wind, sand, and vegetation movement. The damaged area on the dune site is comprised of two factors: the ground area of the building itself and the surrounding area that it has affected. Structures also contribute to damage because it promotes the creation of paths leading to it, which destroys vegetation and gives rise to areas of mobile sand.

4.4.3.1 *Damage Caused by Structures*

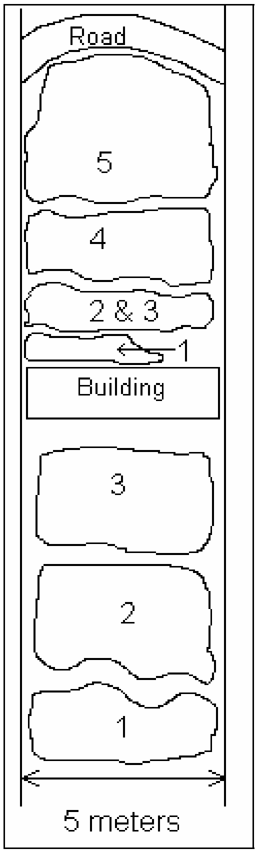


Figure 53: Disturbed Transect View

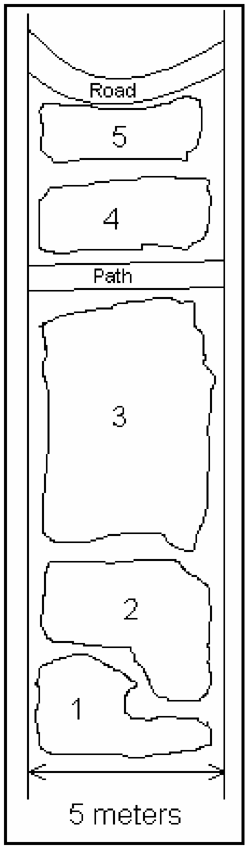


Figure 54: Normal Transect View

The effect of the permanent structures was most evident when examining transepts, cross sections of the dune field perpendicular to the coastline, as shown in Figure 54 and Figure 53. We chose to look at five-meter wide cross sections, including areas with permanent structures, and areas without them, to more closely evaluate human impact on the dunes. Figure 54 is a dune profile on the Alberoni to the north of the cabanas that has not been largely affected by human impact, since the ecological bands still follow their normal sequence. Figure 53 shows the same area of the Alberoni with a structure built in the middle of the dune field. Here, the sequence of ecological bands is interrupted, causing damage to the equilibrium of the ecosystem.

In addition to the interruption of the band sequence, damage caused by structures can also be observed by looking at un-vegetated areas near structures, or areas that have been bulldozed for construction or beach cleanup.

Damage caused by structures on the Alberoni dune site is shown in . From the image, we can see that about 40% of the total dune field has been developed. In the figure, the red indicates areas near the structures that have been damaged as a result of the construction of the structures. These damaged areas were easily identified because they did not have any vegetation present.

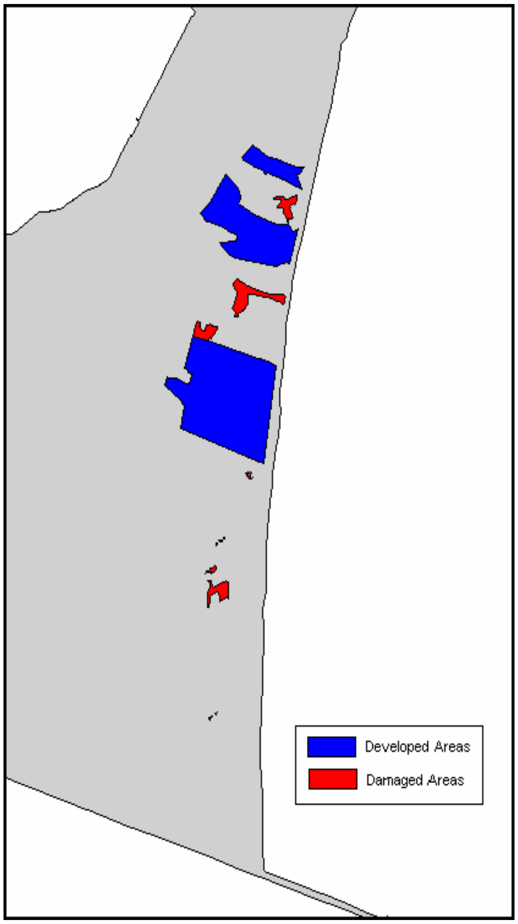


Figure 55: Damaged and Developed Areas on Alberoni

San Nicolò's developed areas, shown in blue in Figure 56, are due to the construction of cabanas. These dunes were bulldozed to allow this development to take place. The sand and vegetation was piled onto adjacent dunes, damaging sections 3 and 4 by interrupting the band sequence. The areas shown in red represent areas bare of vegetation, most likely caused by pedestrian use. At these sites, we found remnants of bonfires and trampled vegetation.

At Ca' Roman, we found no evidence of developed or damaged areas. The dune field was undisturbed and free of all structures.

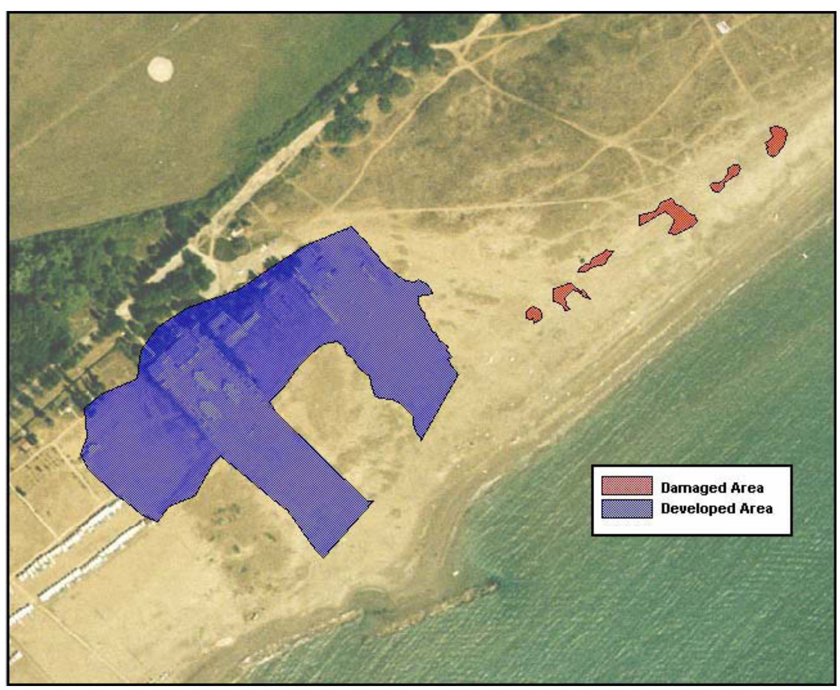


Figure 56: Damaged Areas on San Nicolo

4.4.3.2 Damage Caused by Pedestrians

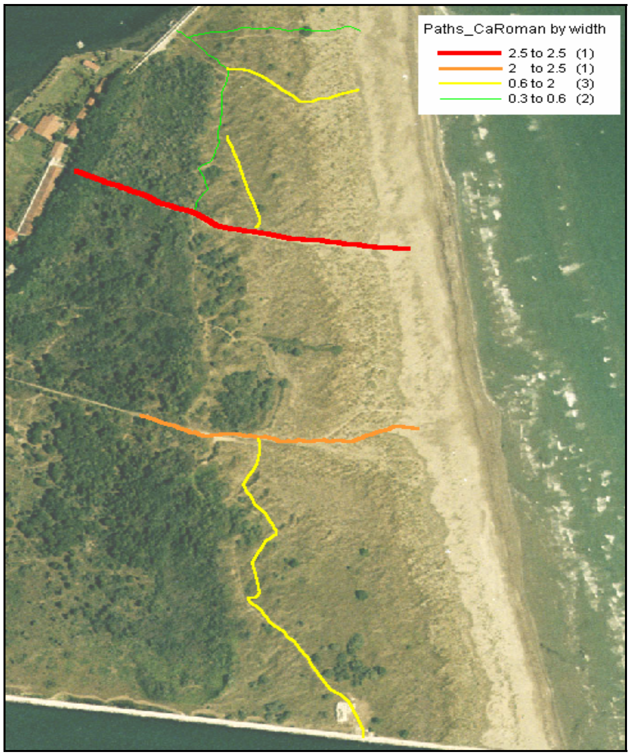


Figure 57: Thematic map of paths by width at Ca' Roman

People also cause damage by walking on and around the dunes, killing vegetation and altering dune structure, allowing for increased natural erosion of the dunes. Damage by people is quantified by the amount of damage per person. In this way forecasting can be done on the amount of damage done to an area based on the number of people known to be in that area.

The lack of first band in the Alberoni dune field, and the presence of it in the Ca'Roman dune field, suggests that the number of people that use the beaches has a direct impact on the formation of dunes. The people that use the beach walk through the first band, disturbing the growth of the vegetation, thereby directly damaging band one. The indirect effect of these people using the beach is that their presence necessitates the cleaning of the beach, which also destroys the first band, and can wipe out the second band as well.

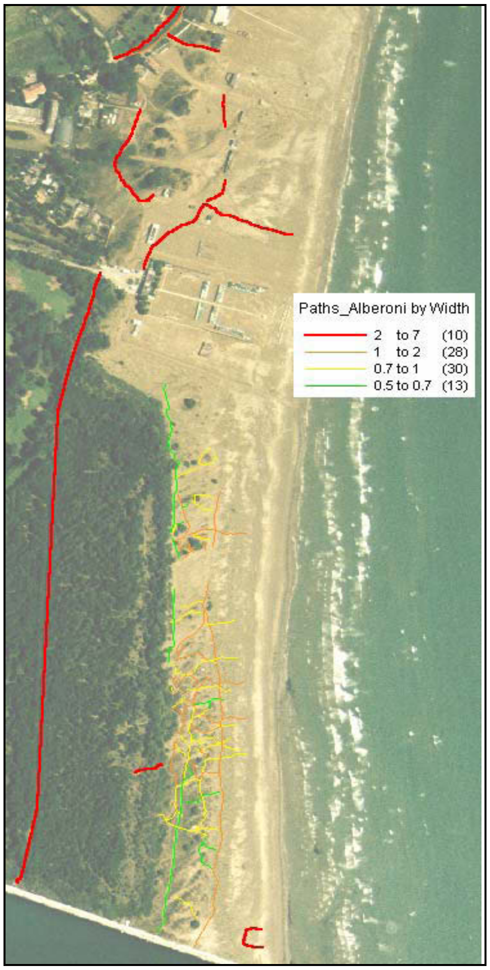


Figure 58: Thematic map of Paths by Width at Alberoni

We observed that paths running perpendicular to the shoreline do not cause much damage to the dune field. However, paths that run parallel to the shoreline cause damage to both the structure of the dunes and to the vegetation by interrupting the ecological band sequence. Pictured below are the paths on each dune site and their total surface areas.

On the dune site of Alberoni, the majority of the paths ran parallel to the shore and was mostly located in the 4th band, as shown in Figure 58. These paths were created by locals that seek shade under trees in the dune field and walk back and forth from one end of the dune field to the other, wearing down the vegetation and creating new paths on each walk.
At San Nicolò, the paths that are widest and most used run parallel to the coast, interrupting the band sequence and disrupting the dune field. The only path that does not damage the dune field is located behind the dune field and runs between the road and the jetty, as shown in Figure 59. Paths such as the yellow one that run from the back of the dune field to the beach are not nearly as destructive. Since the green paths are becoming overgrown and retaken by vegetation, this yellow path would be an ideal path on which to construct a walkway from the road to the shore.

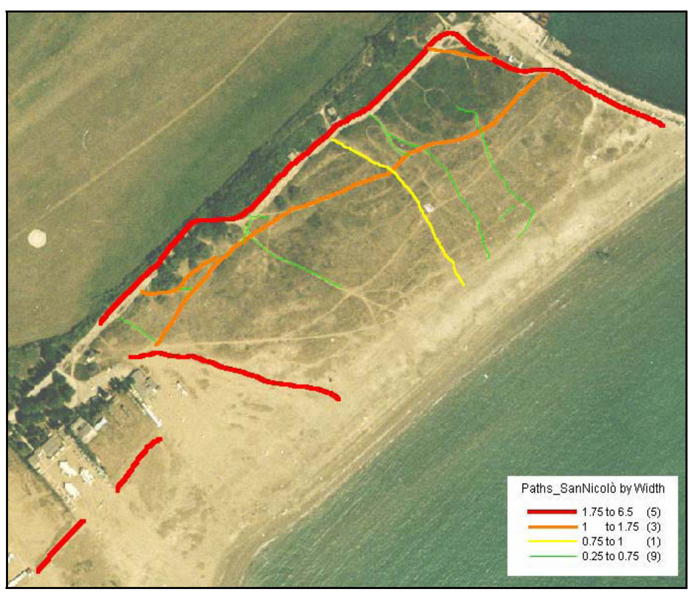


Figure 59: Thematic maps of paths by width at San Nicolò

4.4.3.3 *Total Damage Comparison*

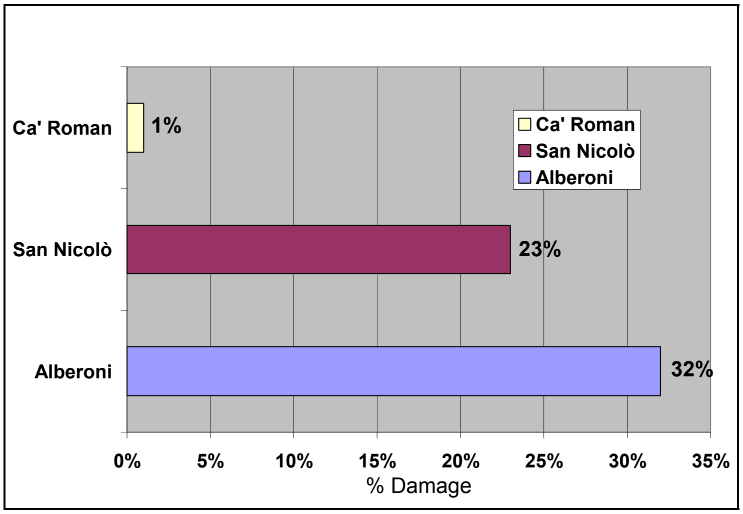


Figure 60: Comparison of Total Damage by Dune Site

By looking at the total damaged areas for each dune site, we observed that the most damaged dune site was Alberoni.. In addition to having the most total damaged area, Alberoni also had the most damaged caused by paths because of its high incidence of pedestrian traffic. The developed areas at San Nicolò and Alberoni contributed to the most damage on their respective dune sites. The only contributor to Ca' Roman's damaged areas were the paths, since none of the dune field has been developed.

4.4.4 Observed fauna

Although we did not study fauna in any of the dune sites, we observed several different species during our data collection. In the pine forest on Alberoni, we observed a snake and many lizards. In the dune field, we saw a field mouse in section 3 in band 2, and a deer in section 4 in band 5. On the beach, we found 2 dead sea turtles that had washed up. According to a gentleman who has lived on the beach for over 15 years who has been keeping track of this phenomenon, stated that the sea turtles were approximately 10 years old and most likely died of disease. He also mentioned that approximately ten sea turtles wash up on the Alberoni each year. At Ca' Roman, we observed a black rabbit in the 4th band of section 1. We did not observe much wildlife on San Nicolò, except for some birds that we could not identify. We observed little lizards on each dune site.

4.5 Qualitative Assessment

The data that we collected is mainly going to be used in the realm of protection and preservation of the sand dunes. However, there are several different agencies that will be looking to use the data in different ways in order to accomplish this. The Planning Department must create a shoreline protection plan by the summer of 2003, as mandated by the Environmental Agency of the European Union. The sand dunes will be included in this plan, and the data that we have collected and the recommendations that we made will be included in the creation of this plan. The Environment Department is responsible for all of the natural aspects of the Venetian lagoon, and is looking to create an Environmental Atlas to manage all of the data on all of the different aspects, in order to have a comprehensive source from which to do impact analysis on future development. The database that we created to manage the data we collected will be used in part as a prototype for the Atlas. The methods we used in collecting and organizing the data, and the ways that we analyzed and represented our data in reports will all be incorporated into the creation of the Atlas.

The landscape architects working with the Planning Department for the barrier island of Pellestrina are interested in knowing characteristics of the area such as visibility, aesthetics, and naturalness when making plans. Indices are assigned to these characteristics in order to determine the overall value of the area, which is generally broken down into sub-sections, rather than examining the area as a whole. The dune sites that we studied are easily broken down into sub-sections. We sectioned off the dune fields in order to more easily map and catalog them, which would have been much harder to do if done only by band, because bands run the entire length of the dune field. Each of these indices to be evaluated based on the context of the goal of the proposed plan.

4.5.1 Natural Index

The Natural Index refers to how natural, or undisturbed an area is. In the case of the dune sites, it refers to the "normalcy" of the band sequence, dune structure, vegetation density, lack of human impact, and the species of vegetation present. This characteristic is more easily measured on a low, medium, high scale. It essentially quantifies the overall aspect of the dune field, or sub-section of the dune field. To make this assessment, we needed to assign ranges to the attributes that make up the Natural characteristic.

Attribute	Low	Medium	High
Band Sequence	Missing bands and remaining bands not in sequential order	Missing a band, but the rest are still in sequential order	All bands present and in sequential order
Dune Structure	Dune structure is not distinguishable, or is very small throughout	Dune structure is distinguishable, but slightly irregular. There may be no "largest" dunes, but still larger dunes	Perfect progression from foredune to secondary dunes
Vegetation Density	Irregular progression and/or lack of vegetation	Normal progression with a small irregularities	Normal progression with the largest density in the 4th band
Human Impact	Many structures or areas of no vegetation caused by human interference	Non-permanent structures are present that do not affect the area, or very few permanent structures with minimal damage	Little or no structures or bare areas caused by human interference
Vegetation Species	Dominant or secondary plants are missing, and are in the wrong band	All dominant and most secondary plants are present, mostly within the correct band	All dominant and secondary plants are in the correct band

Table 5: Natural Index Rubric with Definitions

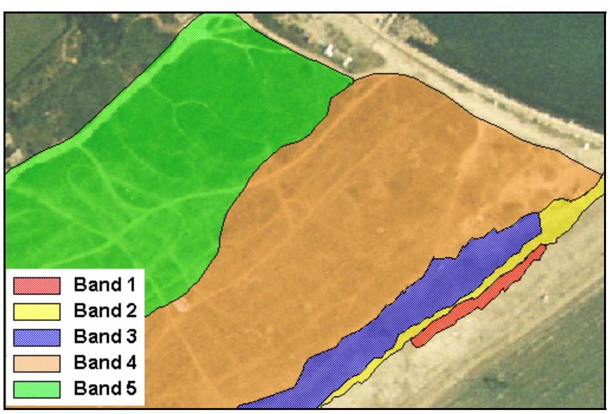


Figure 61: Example of Good Band Sequence

A High rating for the attribute Band Sequence would show all of the bands in correct sequential order, as shown in Figure 61, while a low rating would show missing bands and no or little sequential order, as in Figure 62.

The first figure shows is a good progression from the 1st band by the shore to the 5th band inland, indicating both a good evolution in structure and a good evolution in characteristic vegetation.

The second figure shows only two of the five bands, suggesting poor dune structure and large human impact. Bulldozing is evident by the wrapping of band 3 around band 4, suggesting that the band was bulldozed and moved onto a 4th band area.

Figure 62: Example of Poor Band Sequence

4.5.2 Natural Trend

Associated with the Natural Index is the tendency of the area towards its natural state or towards its destruction. This means that whether or not the area looks to be going back to its natural state, or whether it is becoming more heavily used, and therefore more damaged or destroyed. Movement towards a more natural state is a positive tendency, and movement towards more usage is a negative tendency. This can be determined by observation of the area, and more effectively, observation over time, noting how many people use the area and the changes in vegetation presence and density, and determining the trend.

4.5.3 Naturalistic Importance

In addition to the Natural Index and the Natural Tendency is Naturalistic Importance. Depending on the context, certain areas are more important than others, therefore the naturalness and tendency should be more closely monitored, and restored if necessary. On the dune sites, and in the context of preservation effort, these would be areas of medium naturalness with a negative tendency. These are areas that can be restored, provided that steps are taken to protect them. These would be the areas of most importance in terms of preservation effort. Another type of importance would be areas that are currently in a state of high naturalness that may be isolated, or surrounded by areas of low naturalness. These would be more important than other areas since they are the remaining natural areas, and thus must be protected for future educational use.

4.5.4 Aesthetics Index

The Aesthetics Index quantifies how pretty or aesthetically pleasing an area is. Vegetation density, dune structure, structures, and presence of garbage are the attributes that make up the Aesthetic characteristic. Rather than having a scale on which to measure visual aspect of the dune fields, we created a low to high system for the rubric of attributes.

Attribute	Low to High
Vegetation	Whether vegetation is sufficiently covering the dunes
Dune Structure	Whether the dunes are of a normal rolling shape, as opposed to having areas dug out or are misshapen
Natural State (Lack of Human Impact)	No structures that detract from the landscape
Garbage	No garbage in the dune field or on the beach in close proximity

Table 6: Aesthetic Index Rubric with Definitions

The best possible scenario is a dune site with all of these states determined as High. This would mean that the vegetation covers the dune site abundantly; the dunes would also have a strong dune profile with good elevation and topography, as shown in Figure 63. The area would have no structures or garbage that might detract from the landscape.

Only areas that are given a low rating on the naturalness index, and are not showing a tendency to reverting back to naturalness or are not of natural importance, and that are not aesthetically pleasing should be given zoning for development. Permission for development should only be given provided that the developer can show that he will not damage any other areas in the process of developing this area.

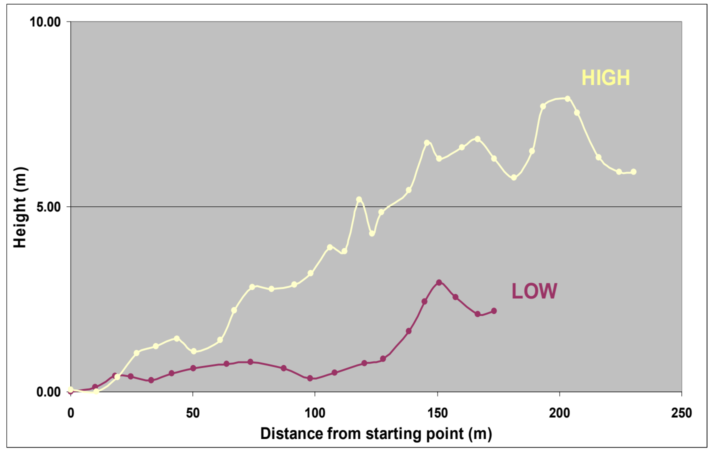


Figure 63: Examples of dune topography ratings

4.5.5 Evaluation of San Nicolò

Attribute	Section 1	Section 2	Section 3	Section 4
Band Sequence	Med	Med	Low	Low
Dune Structure	Med	Med	Low	Low
Vegetation Density	Med	Med	Low	Low
Natural State (Lack of Human Impact)	Low	Med	High	High
Vegetation Species	Med	Med	Med	Med
Trend	Natural			
Naturalistic Importance	Section 1&2, moving towards natural state; 3&4 highly compromised by developed areas			

Table 7: San Nicolò Natural Index Evaluation

Attribute	Evaluation (Low to High)
Vegetation	High
Dune Structure	Low
Natural State (Lack of Human Impact)	Low
Garbage	Medium

Table 8: Aesthetic Index Evaluation of San Nicolò

4.5.6 Evaluation of Alberoni

Attribute	Section 1	Section 2	Section 3	Section 4
Band Sequence	High	Med	Med	Low
Dune Structure	High	Med	Low	Low
Vegetation Density	High	Med	High	High
Natural State (Lack of Human Impact)	Med	Med	Low	Low
Vegetation Species	High	High	Med	Med
Trend	Towards damage			
Importance	Medium			

Table 9: Alberoni Natural Index Evaluation

Attribute	Section 1	Section 2	Section 3
Vegetation	High	Low	High
Dune Structure	High	Low	Low
Natural State (lack of Human Impact)	Low	Medium	High
Garbage	Medium	High	High

Table 10: Aesthetic Index Evaluation of Alberoni

4.5.7 Evaluation of Ca' Roman

Attribute	Section 1	Section 2	Section 3
Band Sequence	High	High	High
Dune Structure	High	High	High
Vegetation Density	High	High	High
Natural State (lack of Human Impact)	Low	Low	Low
Vegetation Species	High	High	High
Trend	Natural		
Importance	High		

Table 11: Ca' Roman Natural Index Evaluation

Attribute	Evaluation (Yes/No)
Vegetation	High
Dune Structure	High
Natural State (Lack of Human Impact)	High
Garbage	High

Table 12: Aesthetic Index Evaluation of Ca'Roman

Conclusions

The primary objective of this project, The Dunes of Venice: A Prototype for the Environmental Atlas of Lagoon, was to develop the basis for the Environmental Atlas of the Venetian lagoon for the Environment Department of Venice, to be used in environmental monitoring, preservation, and impact assessment. We used the sand dunes on the outer islands of the Lagoon to create the prototype of the Atlas. After we analyzed the data we had collected, we found that the there were significant differences between the dune sites. These differences included natural characteristics such as dune structure and vegetation, and also differences in usage, accessibility, and damage.

Of the three dune sites studied, Ca'Roman was the least damaged, used or accessible. There is one main, concrete path that is about 2.5 meters in width, which allows easy access to the beach. This is the one of the very few paths at Ca' Roman, and it does not cause much damage (it runs perpendicular to the coast) and is necessary for beach access. Most beach goers at this site use this main path and do not venture into the dune field, allowing dunes and vegetation to thrive. Due to the low number of people that visit Ca'Roman, there is enough room on the active beach that very few individuals move into the embryonic dune area. This allows for the vegetation of band 1 and 2 to grow undisturbed, which in turn promotes natural growth throughout the rest of the dune field. As a result of this, Ca'Roman's vegetation was present in a greater density and the individual plants were much larger than in either of the other two dune fields. Ca'Roman also has a maritime forest, where as the other two dune fields are cut off at band 5 by human intervention.

Alberoni is the most used dune site, seeing a greater amount of pedestrian traffic and recreational usage. Increased pedestrian traffic has created and maintained many paths throughout the dune field. We used the number of paths and calculated the surface area each covered as an indication of usage. This replaced the meticulous method of counting the individuals that used the area. Alberoni has an extensive network of paths within the dune field, and contains paths that cover the most surface area as compared to the other dune sites. We concluded that Alberoni sees the most recreational use . People not only use the active beach, but also the actual dune field. Dunes found between the fourth and fifth bands had consistent use. Individuals that frequent the area have increased privacy among the trees and the larger vegetation, with a greater vantage point.

The sections of the Alberoni farthest from the jetty, designated as section 3 and 4 found under the heading Results from Alberoni, were highly developed and damaged. We observed a number of abandoned permanent structures, many which had been taken over by unnatural dune structure, resulting in bands containing uncharacteristic vegetation. Other structures were inhabited and had access roads and paths, cutting the fifth band short. The land in front of some of these structures had been leveled in order to maintain clear access to the beach. These areas, because of their consistent use, can not regenerate to a natural state.

Figure 64: Abandoned Building

Other areas that contain permanent structures may be reutilized, with some cleanup effort and maintenance; wooden boardwalks could be used to walk over the sections of dune fields that remain. If the abandoned structures remain unused, it seems unfeasible to demolish these structures because of the cost. Eventually, as we have observed with some existing buildings and fences, as shown in Figure 64, nature takes over the structure, often destroying parts of it or totally covering it, eventually superceding the structure and continuing dune natural growth. This may take a significant period of time, as dunes take many years to grow even in a natural setting.

San Nicolò is also a heavily used area, but the dune field is less used than that of Alberoni. Many of the paths that were visible on the aerial photograph of the area have been overgrown by vegetation, indicating less traffic and use. In general, parallel paths cause more damage than perpendicular paths; however, the parallel path that runs at the back of the dune field is a good path because it gives beach-goers access to the jetty without causing them to walk through the actual dune field. San Nicolò is a small area, so the path offering access to the jetty, in conjunction with a path that provides direct beach access from the public transportation stop, will be sufficient for beach-goers. If only these two paths are used, the rest of the paths and dune field can be restricted, which will allow it to move towards a more natural state.

It was apparent that the first band in both Alberoni and San Nicolò had been substantially damaged and often was totally absent in parts of the band sequence. We attributed this damage to the proximity to the recreational beach. We often observed beach-goers moving into the preliminary bands, setting up towels and chairs. At the Alberoni region, a complex network of paths was used to move among the secondary dune area (among the larger dunes), as well as to the active beach and coast.

We determined that the number of people that use an area is dependent upon its accessibility, or distance from major population densities and public transportation. Damage is directly and positively related to use, the more an area is used, the more damage that occurs. The location of the sand dune environment, abutting the active beach, guarantees that the area will be used by people, in one form or another, for recreation. To limit damage done to the dunes by the recreational users of the beach, it is important to control the areas that they are allowed to use and provide environmental education and awareness to users of the area.

We found that the paths that run parallel to the coastline in the dunes cause more damage to the dunes than the paths that perpendicular to the coastline and are used as access paths from the road or forest to the beach. The reason that the parallel paths cause more damage is because the run the length of the dune field, and disrupt the movement of vegetation, and thus break up the bands. The perpendicular paths separate the dune field into large sections, but these paths do not break up the band sequence; therefore, the perpendicular paths are less disruptive and cause less damage than the parallel paths.

The goal of the *Atlas* is to manage environmental information about all aspects of the Venetian Lagoon. The information must be integrated so that broad impact on different areas can be assessed. This means that the methods used to generate the *Atlas* must be able to be adapted for diverse environments. In developing the methodology for mapping ecological data and cataloguing vegetation that make up the database, we determined that our methods would be adaptable for other ecotopes in the lagoon, not only the sand dunes. In general terms, the methodology we developed breaks down the larger area or areas that one is studying into smaller areas. Defining characteristics were determined for each area, and mapped accordingly. Indices were established in order to determine the overall value of smaller sections of the larger sites, based on the defining characteristics. The defining characteristics and important attributes of each area of the lagoon will be very different, and the methods for actually collecting the data will thus be different, however the underlying idea is the same for the entire lagoon.

Recommendations

This project has completed only the first step in creating a comprehensive tool for environmental impact analysis for the Environment Department of the City of Venice. We have recommendations for extensions to, and further research on, several areas of our project. These recommendations fall under the categories of the sand dunes themselves and also the larger picture of the Environmental Atlas of the Venetian Lagoon.

6.1 The Sand Dunes of the Outer Islands

A large portion of our project dealt with the collection and analysis of data on the sand dunes of the outer islands of the Venetian Lagoon. This data can be used in a number of different ways, and supports work done by the City of Venice Environment Department and Planning Department for the preservation, protection, and restoration of these areas. Based on our results and analysis, we have designed a series of recommendations concerning the usage of the sand dunes.

6.1.1 Designating Areas of Usage

Each dune site has a different level of usage and corresponding level of degradation due to human impact. To best preserve the dune ecosystem, we believe that certain sections should be preserved on the dune sites, while others can be designated for pedestrian or recreational use.

6.1.1.1 Ca' Roman

Ca'Roman has far less people visiting it daily, it is therefore affected less by human presence. Since Ca' Roman is also a bird sanctuary, this dune field should be protected and development should be prevented. Wooden fences around the periphery of the dune field should be built to preserve this area. The area could be used for educational purposes and non-destructive activities like bird watching.

6.1.1.2 Alberoni

The situation of the Alberoni dune field is very different from that of Ca'Roman. Alberoni is more accessible, more developed, and sees more people each day. For these reasons, it is also more damaged. The area to the southwest of the cabanas, towards the Bocca di Porto di Malamocco, in particular, can still be preserved, despite the current usage of the area. We recommend that sections of this area be placed off limits to the public at different times of the year, so that it may recover from the damage already caused. Since the area is heavily used for recreational purposes, it should not be closed off totally so that its current users do not lose access for their recreational activities. Instead, one area should be chosen for regeneration, and then another designated for use. This can be rotated among as many areas as necessary from year to year. We recommend the sections as shown in Figure 65. Since there are traces of band 1 existing in section 1 (in red) of Figure 65, we believe that if this area is inaccessible first it will allow first band vegetation to regenerate, spreading consecutively to sections 2 and 3, which will come a season or two later in the preservation rotation. The preserved area also should still contain established paths, made of wood planks, to connect the forest to the beach area, as described in Section 6.1.2.

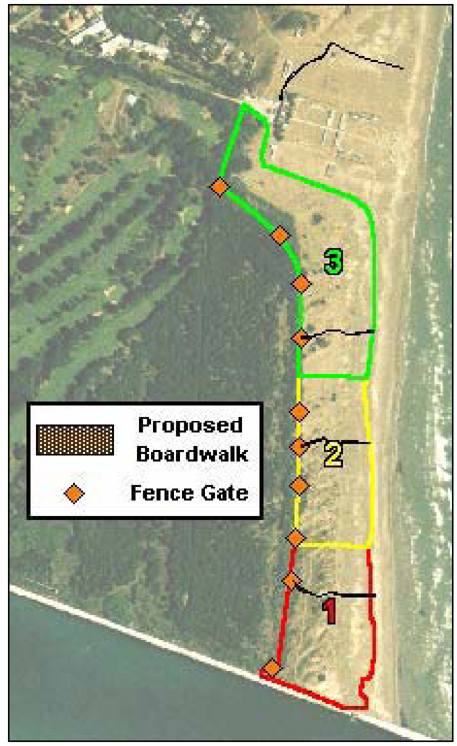


Figure 65: Proposed Preservation Section Rotation

6.1.1.3 San Nicolò

San Nicolò, in sections 3 and 4, is so degraded that there is little chance that primary dunes can form, and because structures are already built behind them, no secondary dunes exist. Preservation and restoration efforts should therefore be concentrated in sections 1 and 2. After overlaying the paths we mapped on the aerial photographs, we observed that many of the paths on the aerial photograph had been taken back over by vegetation in these two sections. This shows that this area is able to regenerate itself once the level of usage has been sufficiently lowered to allow it to do so. By funneling people towards the last sections, where the area is so compromised there is little hope for recovery, and preventing people from using sections 1 and 2 where recovery is already in progress, the preservation and conservation of the most area possible would be achieved, without severely restricting beach-users to small areas. To discourage pedestrians from trampling the dune field, wooden fences should be put up around the dune field (sections 1 and 2).

6.1.2 Wooden Walkways

The paths that run parallel to the coastline in the dunes cause more damage to the dunes than the paths that perpendicular to the coastline, because they interrupt the ecological band sequence. These paths are unnecessary for users of the beach area since people can use the beach itself to walk the length of the coastline, rather than walking through the dune field. The perpendicular paths that give access to the beach from the road or forest can continue to be used, and their use should be promoted by building the paths out of wooden planks. This would make the surface easier for walking, and would keep more people from walking into the dunes and over the vegetation, thus destroying it. Fences should also accompany the paths, preventing people from straying into the dunes. These paths would provide beach-goers a clear access to the beach while preventing further damage to vegetation and dune structure and

Figure 66: Proposed Boardwalks for Ca' Roman

Figure 67: Proposed Boardwalk for San Nicolò

preserving the aesthetic aspects of the dune field.

The proposed walkways for Ca' Roman and San Nicolò are shown in Figure 66 and Figure 67. The proposed walkways for Alberoni can be seen in Figure 65 and a close-up of one of these boardwalks is shown in Figure 68. These boardwalks were chosen based on the size of existing paths and convenience for users to access different areas of the beach. The widest paths were used, providing even spacing with respect to the entire dune site. These proposed boardwalks will also allow users to see the entire dune site and learn about its different environmental aspects; these steps can also increase awareness about what actions can destroy the dune field.

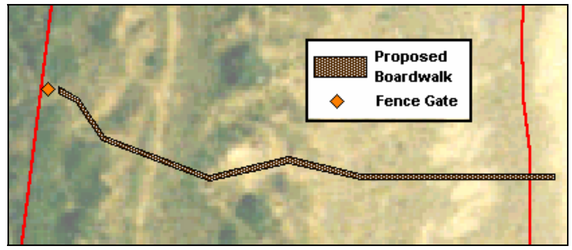


Figure 68: Close-up of Proposed Boardwalk for Alberoni

6.1.3 Dune Clean-up Efforts

One of the first observations made about the Alberoni beach and dune region was the large amount of garbage lying on the ground for the entire length of the beach, and the fact that approximately ninety percent of it was recyclable plastic. The clean up program in place up until a few years ago involved bulldozing the area. This was effective in removing the garbage, but destroyed the dunes in the process. Clean up has been suspended to protect the dunes, but the garbage is piling up along the wrack-line. This garbage on the beach is largely composed of plastic items that are recyclable. We recommend establishing a program, volunteer or otherwise, that uses manpower as opposed to machine power to collect the trash and recycle it as much as possible. The largest piece of machinery that should be used is a truck, into which the garbage or recyclable items can be thrown, that is only driven on the active beach and not near the dunes or dune vegetation. This program can be established as a volunteer service, or sponsors can be found to take responsibility for a particular area, and in return are able to advertise themselves by putting up a sign indicating their service to the environment, as shown in Figure 69. This second system, known as "Adopt-a-Highway" in the United

States, is used for highway cleanup. A system such as "Adopt-a-Dune" could be put in place in much the same manner so that the beach and dune field can be well maintained with a minimum of resources expended on it by the city.

Figure 69: Adopt- A- Dune sign

6.1.4 Future Updating and Maintenance of Data

For monitoring purposes, data must be collected periodically to determine the trends of the different variables used to establish the state of the dune sites. We recommend that the Environment Department measure damaged areas annually, to monitor whether preservation efforts are effective in preventing additional damage and reversing the damage that had already been done. Data must be collected at the same time each year so that the data is consistent and can be compared over time. If data is collected at different times of the year, other environmental aspects must be taken into account.

6.1.5 Research Methods

During our field collection, we discovered that not all of our research methods were the most efficient due to equipment problems and time constraints. We recommend to the Environment Department that future monitoring be conducted in the following way:

- Proper equipment such as an auto-level and surveying tools should be used to record dune topography.
- An assessment of the use of the different dune sites by counting the number of people that use it per day should be performed.
- To best monitor dune geomorphology, aerial photographs should be taken every two years and overlaid on each other using transparencies to determine changes.

- Because the GPS did not receive signals in the pine forest on Alberoni, a compass and accurate measuring instruments should be map the location of the clearings.
- Vegetation assessment should be done by ecotope rather than by band on the dune field. This would remove ambiguity between ecological bands and would conform to the Natura 2000 standards for environmental monitoring.
- Transects should be taken in each section of the dune sites, instead of just one transect for each site.
- Based on our data collection experience, we also believe that the Environment Department should dedicate about three weeks to one month of time for reevaluation of the dune sites.

6.2 Environmental Atlas

We recommend that the Environmental Atlas be available to users online: one area that is password protected and reserved for data update and environmental monitoring, and a second area devoted to environmental education and awareness. The Atlas should contain information about flora and fauna, general information about their habitat, related publications, and links to information on the European Union's environmental policies.

The Environment Department will be using the data contained in the Atlas extensively for environmental impact analysis throughout the Venetian lagoon, to establish its current state, determine any imminent threats to specific areas, and forecast how these threats could affect the area. The Environment Department can propose preservation plans based on this information. The data that we collected on the sand dunes will be used in creating the coastal management plan for the Lido, since the area falls under the Sites of Ecological Importance (SIC), a denomination given by the European Union. The environmental data and impact assessments will aid the Planning Department in making urban development decisions in the future.

While the data incorporated in the Atlas is likely to come from many different sources and be provided by different agencies, the Atlas will be the centralized location for all data on the Lagoon. This will allow the effects of development on dynamic ecotopes to be more accurately forecasted, thereby preventing the need for restoration.

In addition to the data our group collected, the Environmental Atlas will contain links to numerous studies conducted on small parts of the lagoon. We believe that this information is best kept linked to, and not included in, the Atlas because it would prevent the data from being disjointed and difficult to integrate and analyze. A good example of this type of Atlas structure is the Atlas tool created by the city of Berlin, Germany.

6.2.1 Data Structure

To use the Environmental Atlas in the most efficient way possible, the data must be broken down into different levels of detail. To best represent the diversity of the Venetian Lagoon, the Environmental Atlas should be first broken down into different sections by SIC location. These locations should be further divided into 8 different sections :

- Soils
- Water
- Air
- Climate
- Biotopes
- Land Use
- Traffic/ Noise
- Energy

Each subsection will contain more specific information. Our collected data fell under the categories of Biotopes and Land Use for each dune site. The database was thus organized in the following way:

- Biotopes
- Vegetation Catalog
- Vegetation Density by Band
- Ecological Bands
- Ecological Band Areas

Extensions to this structure could include:

- Records of fauna and breeding grounds
- Maps of vegetation by ecotope
- Land Use
- Damaged Area Maps
- Paths Data

- Maps of Paths

Possible extensions to this section could be:

- Maps of all permanent structures and the damage they caused in their general vicinity
- Abandoned structures and currently used structures in a thematic map
- Study of number of people per square meter at each dune site
- Thematic map of permanent and semi-permanent structures on each dune site

6.2.2 Data Collection

To prevent the unnecessary expenditure of resources for data collection, we recommend that the city contract out to different scientific or educational organizations that already conduct this type of environmental research. Institutions in Venice or its surroundings include:

- Corila
- Museum of Natural History
- Istituto Veneto

These organizations would conduct the environmental research for the city of Venice, who would in turn analyze and organize the data. The data would then be entered into the *Environmental Atlas*. This system could save the Environment Department a great deal of time and money since it would not need to purchase expensive surveying equipment, and could use its resources for other research while the data is collected. The City of Venice would therefore simply synthesize the data and coordinate research efforts. The only data the city would directly be responsible for would be information regarding any development plans that the city allows, and what the consequences of the proposed plans are expected.

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Appendix A: Annotated Bibliography

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Appendix not included in original submission

IQP/MQP SCANNING PROJECT

Appendix B: Vegetation Catalog

Appendix C: Sample Field Data Forms

Appendix D: Completed Field Data Sheets

Appendix E: GPS Instructional Guide

Appendix F: Environment Department Mission Statement

Appendix G: Laws and Regulations Pertaining to Coastal Dune Use