Monitoring Sand Dune Processes at the Oregon Dunes National Recreation Area: Can Pre-Vegetated Conditions be Restored?

by

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Monitoring Sand Dune Processes at the Oregon Dunes National Recreation Area: Can Pre-Vegetated Conditions be Restored?

Abstract: The Oregon Dunes National Recreation Area is managed by the Siuslaw Forest division of the United States Forest Service (USFS). This area has gradually been overcome by vegetation since the 1950's, originating with the exotic European Beach Grass (*Ammophila arenaria)*. The invasion of this exotic vegetation has resulted in a decline of sand movement and the growth and expansion of a wetland in the deflation plain. The Siuslaw division has removed and replaced a section of foredune to remove the stabilizing vegetation, in order to study the potential restoration of sand dune processes. Sand movement and wind data, combined with aerial photograph analysis aid in assessing physical changes caused by this treatment and subsequent management. A geographical information system (GIS) template has been designed from aerial photographs and surveyed profiles in order to record and monitor the stages of geomorphic change. Continuing studies of the area will build upon the GIS database developed as part of this analysis.

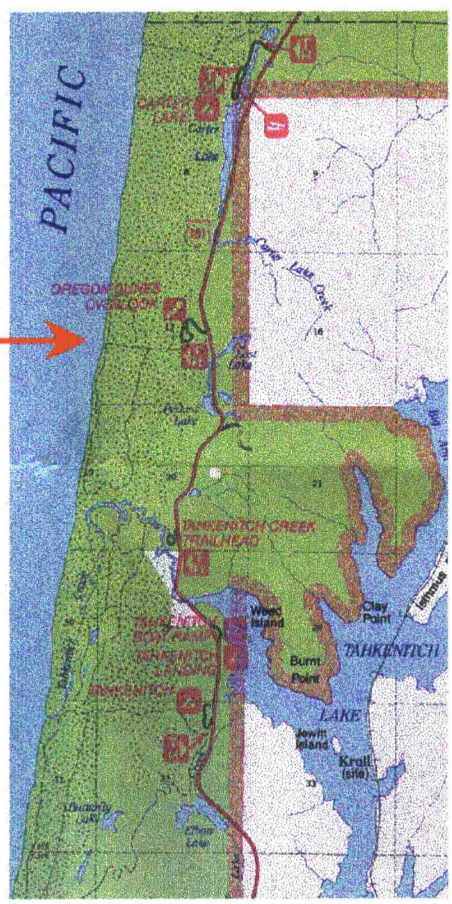
Introduction

In 1972 the Oregon Dunes National Recreation Area (ODNRA) was established. The National Recreation Area extends 55 miles north to south along the Pacific Ocean from the Siuslaw River in Florence on the north to the Coos River in Coos Bay on the south and averages two miles in width (Orr et. al. 1992). The study site (the treatment area) is located between the towns of Florence and Reedsport. It is located one mile directly west of the Oregon Dunes Overlook site, accessed by Highway 101 (see Figure 1, 2).

The treatment area (Figure 3) was previously vegetated by European beach Grass (*Ammophila arenaria)*, similar to the bordering foredunes, and was bulldozed to disturb the beach grass root mat in the upper three feet and to smooth the foredune profile during the period from June 11th to July 10th 1998. The purpose of this action is to monitor the subsequent movement of sand in hopes of restoring normal dune processes. The seasonal winds are expected to flow with less turbulence over the smoothed area and to move sand inland toward the deflation plain. The increasing recreational pressures on coastal dunes and the consequent management demand a higher understanding of dune processes and dynamics so that desired results may be achieved (Pye 1983).

Figure 1

Figure 2



Treatment Area
Figure 3

Physiographic Setting

Morphology of the dunes is influenced by several factors: wind patterns (direction and speed), sand supply, vegetation, and physiographic setting (Pye 1983). The treatment area is part of the Coos Bay Dune sheet which is an 86-km long low-lying coastal area between Coos Bay and Sea Lion Point and is the largest open dune sheet on the Oregon coast. This area backs the longest continuous beach on the Oregon Coast. It spans about 52 km from Cape Arago (near Coos Bay) northward to Heceta Head (near Florence), forming a littoral cell that theoretically restricts sand movement within this area (Komar 1992). Researchers are currently studying the possibility of "leaks," allowing sand to travel around the headlands into other littoral cells. The only sand sources to this beach are from the Siuslaw and Umpqua Rivers, which drain the Coast Range, and portions of the Cascades and the Klamath mountains. During the Pleistocene, when sea level was about 300 feet lower, sand could migrate freely with the currents without headland restrictions; this explains how minerals from the Columbia River (to the north) can be found in the Coos Bay to Heceta Head littoral cell (Komar 1992).

The sand dunes have developed as a result of continental glaciation and transport of this glacial sediment by rivers to the coastal area. Currently, the Siuslaw and Umpqua Rivers bring sediment to the Oregon Dunes. This sediment is moved up and down the Oregon coastline, within the littoral cells, seasonally. During the summer season, sand is transported south by the California current; during the winter season, sand travels north with the Davidson current. The winter season beach dynamics tend to erode the beach sand and move it northward, and in the summer season the beaches are built back up restoring their previous summer conditions.

The foredune forms a ridge that borders the water edge and is vegetated due to the introduction of European Beach Grass (*Ammophila arenaria)*. Extending eastward, bordering the foredune, is a deflation plain, which is a low, flat, vegetated strip. Seasonal transverse dunes were previously located on its eastern edge. Wetlands have developed in the deflation plain because the sand supply from the foredune has been cut off since the stabilization from the invasion of European Beach Grass (Hunter et. al. 1983).

The height of the foredune depends mainly on the wind energy and the rate of progradation; high foredunes usually exist on stable beaches and are rarely found on eroding shorelines (Pye 1983). The foredune in the treatment area is relatively high, suggesting stable conditions (Figure 4).

Extending eastward from the deflation plain are the oblique dunes, which are unvegetated. The transverse dunes are low-lying, small, southward-facing and are

Figure 4

formed by the summer winds; in the winter they are flat. The active oblique dunes migrate an average of 3.8m/yr towards an azimuth of 26° (north-northeast) (Hunter et. al. 1983). At the western, landward boundary of the oblique dunes is the precipitation ridge, defined by Cooper (1958) as "a ridge due to precipitation of sand at a forest edge." The precipitation edge is measured to be migrating eastward at a rate of 1.6 m/yr on average (Cooper 1958). The western boundary of the transverse dunes are also migrating eastward at this rate as the deflation plain grows (Hunter et. al. 1983). The deflation plain is growing larger on both the eastern and the western edges and is encroaching in on the foredunes and on the active dune field. The oblique dunes, the previous location of the transverse dunes, and the precipitation edge in the field site area are shown in Figure 5.

Climate

The coastal zone has relatively mild temperatures, wet winters and dry summers. Winds hit the coastal zone generally from the west and bring heavy rains from the Pacific

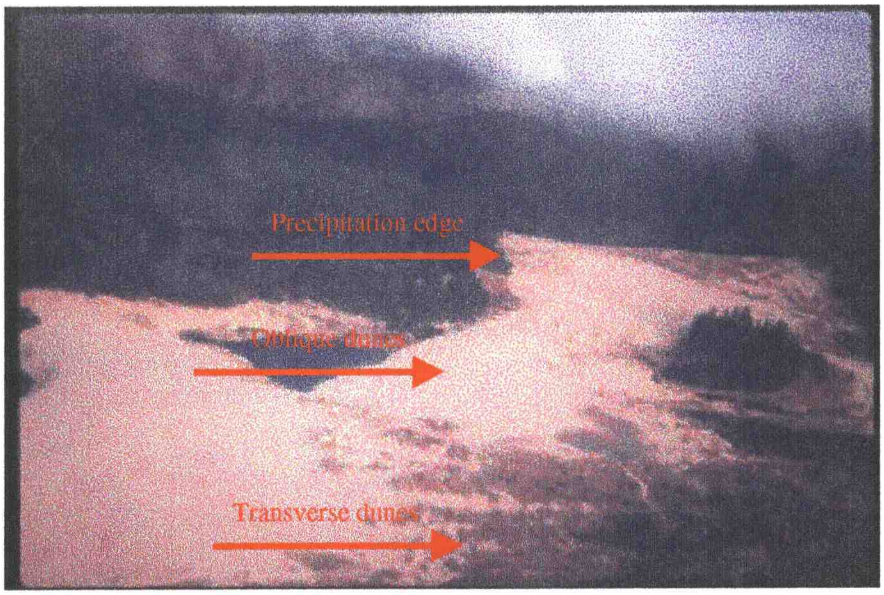


Figure 5

Ocean. It is classified by Trewartha as a Cb climate (Humid Meso-Thermal, Marine West Coast) (Espenshade 1992).

Pressure and wind patterns generally have two major variations. A high-pressure cell in the northeastern Pacific generates Northwestern winds in the summer (Figure 6). This brings in cooler, dryer air causing the mild summer temperatures and lack of precipitation. In the winter, a subtropical high and a north Pacific low generates warm, moist winds from the Southwest, bringing precipitation to the coast (Figure 7).

The temperature range on the coast is smaller than any other region in Oregon. Coastal temperatures rarely reach 90° or above, or 32° or lower (Oregon Climate Service 1998). The mild winters are due to moderate temperatures from the Pacific Ocean carried inland by the strong westerly flow. The jet stream is the strongest and the farthest south in the winter, bringing the coast its maximum precipitation. Unstable air masses from the west contribute to the maximum rainfall in winter.

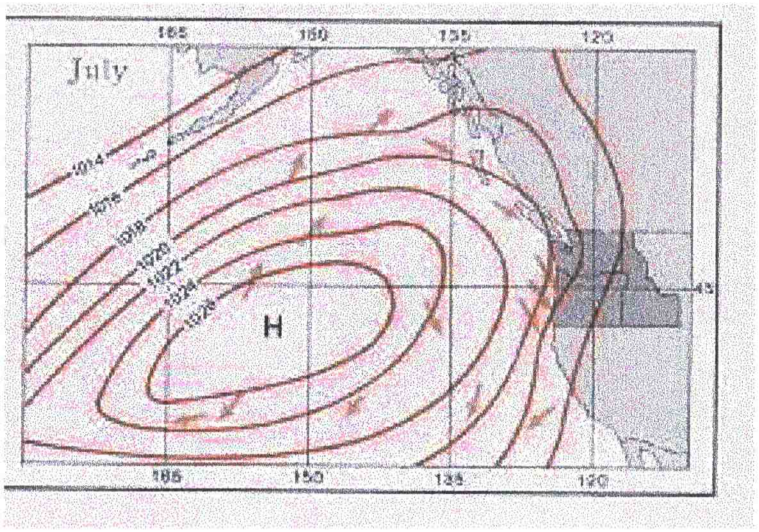


Figure 6

(Kimerling and Jackson 1985)

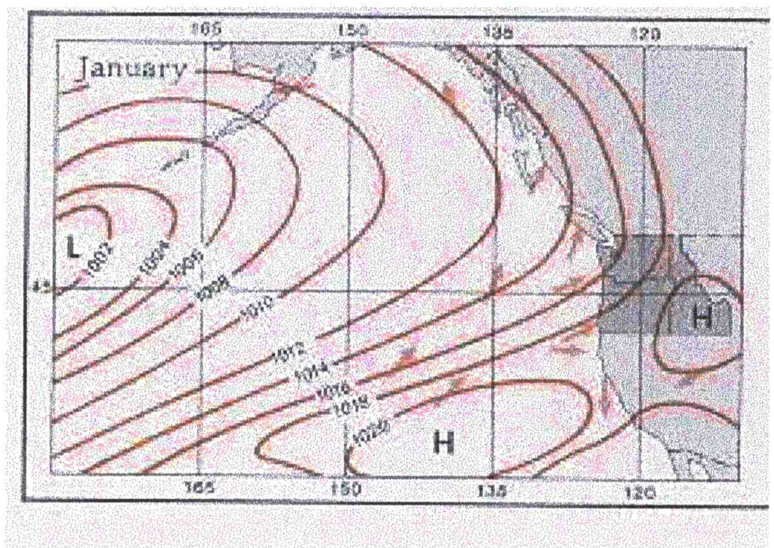


Figure 7

(Kimerling and Jackson 1985)

The summers are characterized by cool, stable marine air from the northwest, which does not provide much rain to the coast. The jet stream is weaker and farther north, also augmenting the dry summer (Kimerling and Jackson 1985).

The coastal zone has relatively high annual precipitation with 46% falling from December to February in the form of winter storms. During the wet winter months the predominant wind is from the south or south-west and speeds are much higher than the summer winds, ranging about 30 to 50 mi./hr. During the dry summer months, winds are predominantly from the north or north-west with speeds often ranging from 15 to 30 mi./hr (Oregon Climate Service 1998).

The winds are extremely important in understanding sand dune processes on the coast; the dunes are transverse to the SW winds, which are responsible for their basic form, orientation, and migration. The summer winds affect the dune form, but not the dune trend (Hunter et. al. 1983).

Annual precipitation is about 70 inches on the coastline. Coastal stations usually record their maximum temperatures in August. Gardiner (south of the treatment area) receives an average of 69.16 inches of rain annually, with the maximum in November and December (Oregon Climate Service 1998).

Rainfall and Sand Transport

Rainfall has an effect on sand transport; the winter season brings the strongest winds, but also the most rain. Significant wind erosion on dunes has been measured during rainfall (Jungerius et. al. 1981 and De Ploey 1980). The effect of rainfall is two-fold: 1:) wind-driven rain will transport sediment at a higher rate than normal due to the "splash-saltation" process (Van Duk et. al. 1996) until a moisture saturation level of 14% (Sarre 1988); and 2:) after a moisture content threshold is met, additional rainfall will cause cohesion of the particles and sand transport will decrease.

The splash-saltation process causes movement of sand grains that would not normally be transported. A raindrop falls on the sediment and causes the grains to bounce up off the surface, allowing the wind to carry it away. After the moisture content threshold is met, the raindrops no longer put the sand in motion due to the strong cohesion effect (Van Duk et. al. 1996). When rainfall ceases, the top sands dry out first, and transport is restored. Sometimes the drying out of top sands by strong winds can happen even during precipitation events, allowing for sediment transport.

European Beach Grass

European Beach Grass (*Ammophila arenaria*), was introduced onto Oregon beaches in the 1880's in order to stabilize areas of the beach. This grass spreads rapidly, and its root system and dense foliage mat stop the movement of sand. This exotic species has succeeded too well in some areas along the coast. One of those areas is the Oregon Dunes between Florence and Reedsport, near the Oregon Dunes Overlook. It has stabilized the sand to the point where other vegetation has thrived and the deflation plain wetland area is growing. Initiation of sand transport by wind is not possible on a vegetated dune (Chapman 1990). Stabilization of sand changes the dynamics of the dune processes in a way that is not desirable for recreationists.

Even though the stabilizing vegetation was removed in the treatment area, it does not necessarily stop the Beach Grass from invading once again; the treatment area is bordered by vegetated foredune. Sparse plant cover is already seen in the treatment area; species include mainly the native species, Sea Lyme Grass (*Elymus mollis*), which does not have a detrimental effect on sand transport because its root system is less extensive and its foliage is often less dense or matted. European Beach Grass is also colonizing on the foredune. Knowledge of the precise effect of this vegetation on the transport of sand is crucial to understanding the morphology, evolution, and stabilization of the dunes.

"Direct experimental measurement is the simplest and most reliable approach to measure the effects of plant cover" (Buckley 1987).

Objectives

Objectives for this research include aerial photography analysis, collection of sand transport and wind data, and developing a geographic information system (GIS) template for future studies. The foredunes in the ODNRA have been completely vegetated since the introduction and spread of the exotic species, European Beach Grass (*Ammophila arenaria*). As a result, normal sand dune processes have been changed and other abnormal features have developed such as wetlands in the deflation plains. The main goal of the USFS is restoring the Dunes to its pre-vegetated, open sand condition. The Dunes possess major recreational value for the public and the USFS want the Dunes to retain this value. Less than 15% of the population reside in Oregon's coastal areas year-round. Tourism throughout the year, particularly during the summer, dramatically inflates the number of people coming to the coast. This influx of people during the summer augments coastal communities' economies. It is important to restore the Dunes so that recreational activities such as hiking and riding all-terrain vehicles (ATV's) will still attract tourists.

This particular phase of the restoration project is the first portion of a long-term study. A historical overview of the area using aerial photographs provides a broad understanding of the progression of vegetation cover and its effects. Sand and wind data were collected to form a base of data and establish methods for monitoring the area. Data were then placed into digital format and displayed using GIS 3-D visualization techniques to show the morphology and better understand sand movement. Not enough data were collected to demonstrate any trends in sand transport.

Methods

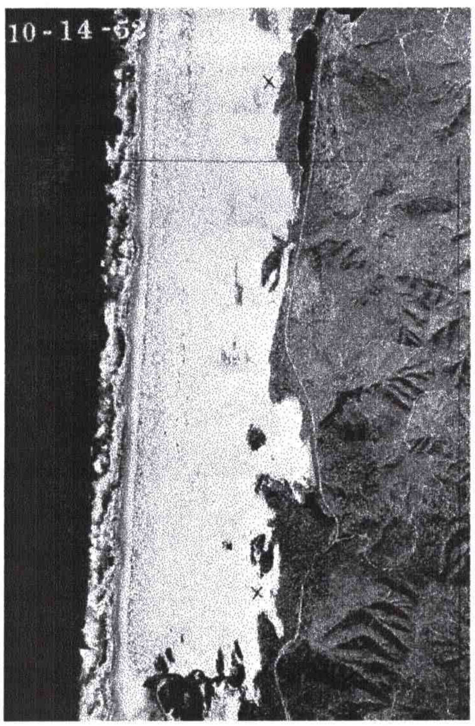
Aerial photography analysis, wind speed and direction, and sand trap data were all used to assess the conditions of the treatment area. GIS technologies were used to visualize the data on a 3-D plane. Sand and wind data were collected over a period of two months (mid-March to mid-May) at intervals of about seven days. These data will provide the initial information needed for this long-term project.

Aerial Photography

Aerial photographs have proven to be essential tools in the study and mapping of shoreline features for use in coastal zone management. Over a significant period of time these photos can demonstrate long-term trends which aid in planning (El-Ashry 1977). Both black and white panchromatic and true color air photos were used to do a historical analysis of the field area.

The two photos displayed (Figure 8 & 9) demonstrate the long-term trend of stabilizing vegetation. In 1952 there was only about 8% vegetation cover in the foredune area; by 1989 European Beach Grass has invaded, stabilized the sand, allowed other vegetation to thrive (an increase to 73% cover), and a wetland in the deflation plain has developed. Figure 10 shows the percent change of vegetation cover from 1952 to 1989. Air photos were used for this analysis. The formation of slip faces and direction of sand movement seen on the photos demonstrate the dominant wind patterns (N-NW) which form the dunes.

Current photos were also analyzed to determine the effectiveness of venturris that were established on the treatment area. Venturris are small "ditches" that funnel wind through this narrow gap. They were constructed in order to direct the wind and aid in sand transport. Two venturris were placed perpendicular to the dominant wind direction and have now been filled in by sand. They are not detected on the aerial photography nor are they seen when physically on the ground.



Pre-vegetation, 1952
Figure 8

Post-vegetation, 1989
Figure 9

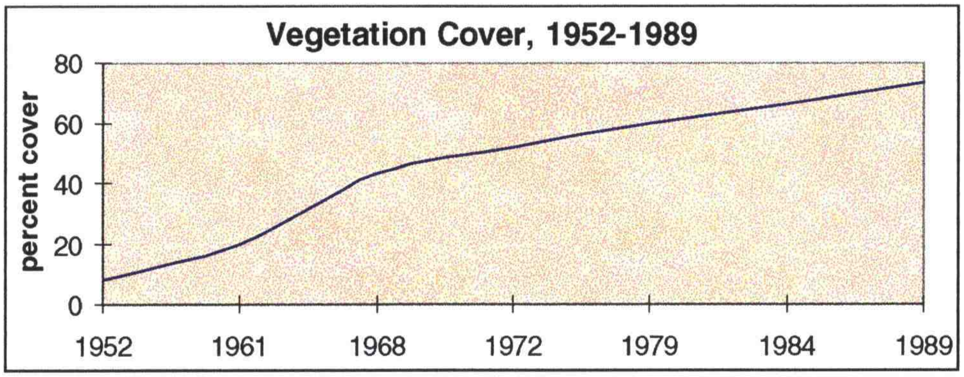


Figure 10

Sand Transport Analysis

There are two major sand sources for the dune sand; the Siuslaw River to the north, near Florence, which drains the Coast Range volcanics and sedimentary units; and the Umpqua River in the central area, near Reedsport, which drains the Coast Range and the Klamath mountain metamorphic units (Komar 1996). Sand collected will most likely be from one of these sources, assuming that the sediment is restricted within this littoral cell.

Sand particles are moved by three methods: surface creep, saltation, and suspension (Blumberg et. al. 1996). According to Bagnold (1941) saltation is the dominant sand-transport process. When wind shear stress exceeds the threshold shear stress for the sand particle, the entrainment of sand particles occurs. The European Beach Grass stabilizes the sand so that the wind cannot entrain the particles. The treatment area is monitored to assess if sand transport processes are restored.

Sand traps made of PVC piping were used to trap and collect the wind-transported sand. Figure 11 shows the sand traps (before they were placed in the ground) and anemometer used to collect data. The sand traps were placed in the sand so that approximately 1/3 of the trap was above ground. The open portion of the sand trap was placed at an azimuth of 60°, towards the dominant wind direction.

Figure 11

The trap design (Figure 12) was developed by Leatherman (1978), who states:

> The unit consists of a section of PVC pipe, with two slits cut in one end. The trap is buried so that the base of the slits is flush with the sand surface. One slit serves as a collection orifice, while the other is covered with 65 um screening to provide maximum flow-through of wind with little disruption of air flow and with little back pressure. All sand-sized material is collected in the inner sleeve (insert) of the sub-surface chamber. The collection chamber is filled with an insert of pipe which rests flush with the base of the slits. The sand can be removed quickly by retrieving the tube.

Dominant wind direction and speed were determined by using a 3-cup anemometer at a height of two meters above the surface. Wind data collection was limited to only one day out of the 7-day periods that the sand traps were in operation. In the future, a permanent recording anemometer should be purchased and placed at the field site to obtain continuous wind data.

Sand was collected and analyzed over a two month period in intervals of about one week each. Samples collected mainly consisted of well-rounded light-colored minerals such as quartz with only small amounts of well-rounded hornblende and jadeite.

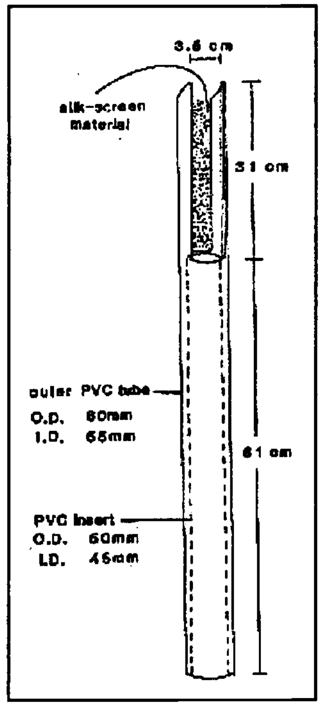


Figure 12
(Hanna 1985)

Other minerals found included pink garnet, augite and hypersthene. All of these minerals are commonly found in sediment eroded from the Coast Range and Klamath Mountains (Clemens and Komar 1988). The graph (Figure 13) shows one sample demonstrating sizes and amounts captured by sand traps. Traps A, B and G were on the crest (west side) of the foredune; C and D were at the base (east side) of the foredune (Figure 14). Phi (ϕ) is a unit used to measure sand grains and can also be expressed in mm. The smallest size minerals (<3ϕ) consisted mainly of hornblende; the largest sized minerals (2ϕ and 1.5ϕ) consisted mainly of quartz. Most of the sand that is being transported is 2ϕ or larger.

The sizes of the sediment were determined by using a Ro-Tap sieve. Sand trap data are displayed in Appendix A. The USFS will continue this sand collection in order to assess if normal sand transport processes have been restored.

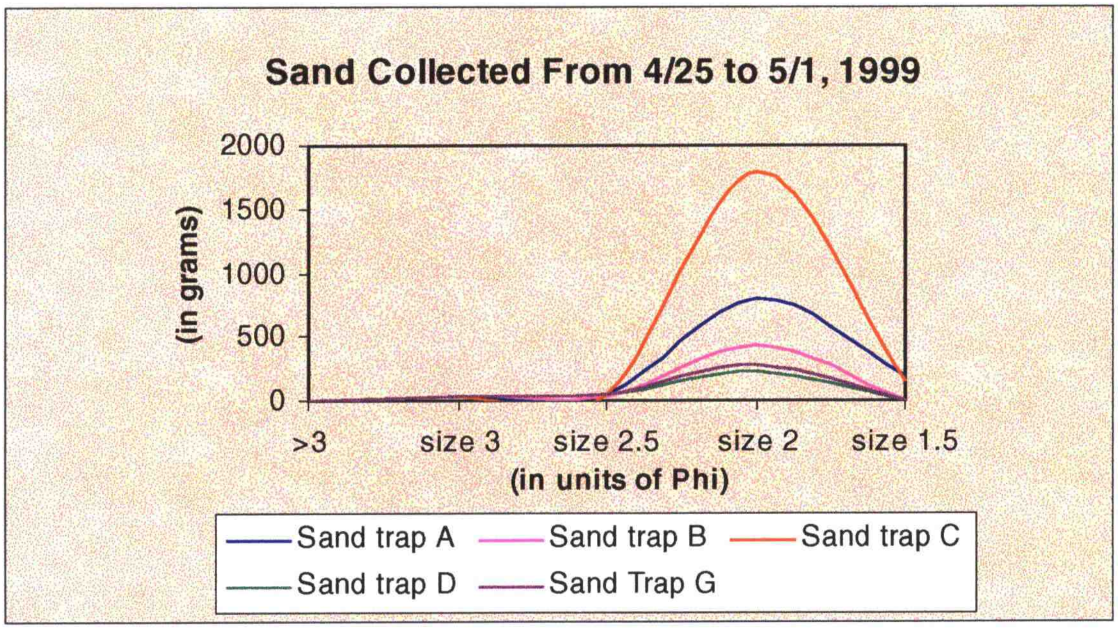
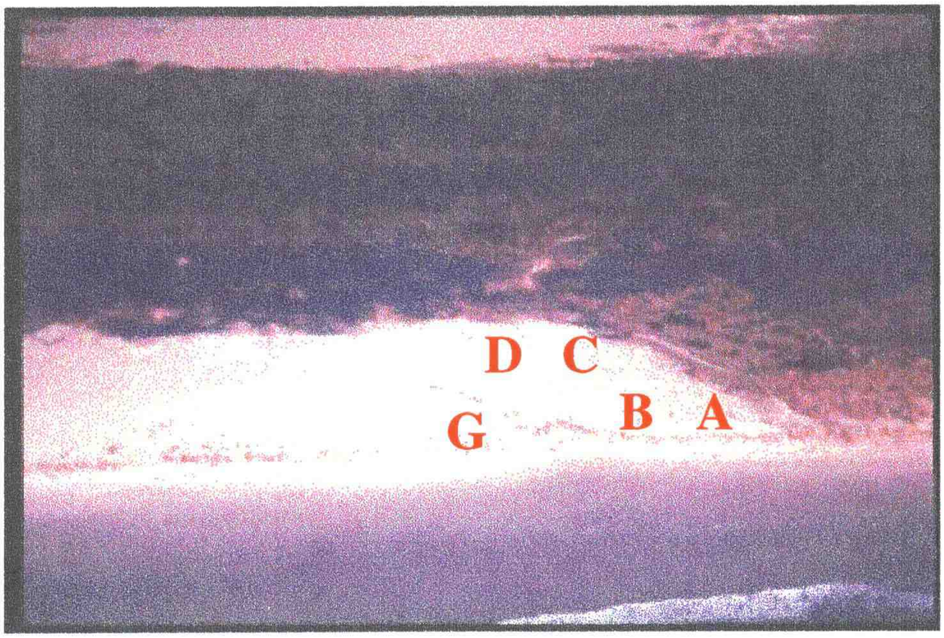


Figure 13



Treatment Area, Sand Trap Locations
Figure 14

Human disturbance of the sand near the traps was not a major concern. Hikers are not normally in this specific area. The trails lead to the beach through the vegetated portion of the foredune immediately to the south. Hikers are also discouraged from reaching the beach because unavoidable pools of water, 3 feet and deeper, covered many portions of the trail during this study.

Surface Maps

Surface maps were generated from survey data to demonstrate the morphology of the treatment area. A longitudinal profile of the crest was generated (Figure 15), and a cross-section of the south end of the dune was generated (Figure 16). A 3-D surface map was also generated (Figure 17) of the treatment area. The data from which these maps were made are in Appendix B.

These views will provide the on-going research a morphologic stage of the treatment area; it will be compared to maps made in the future to better understand the dynamics of the foredune.

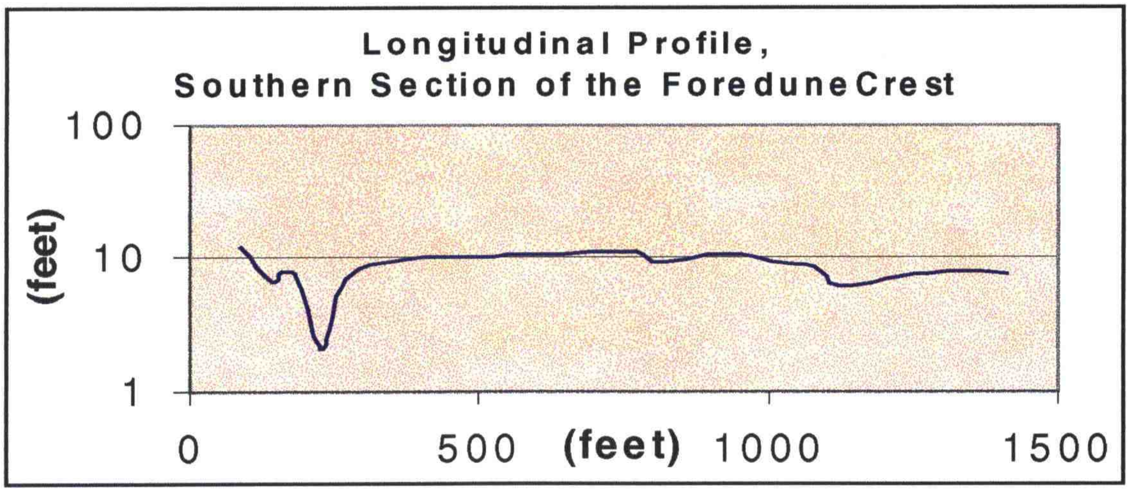


Figure 15

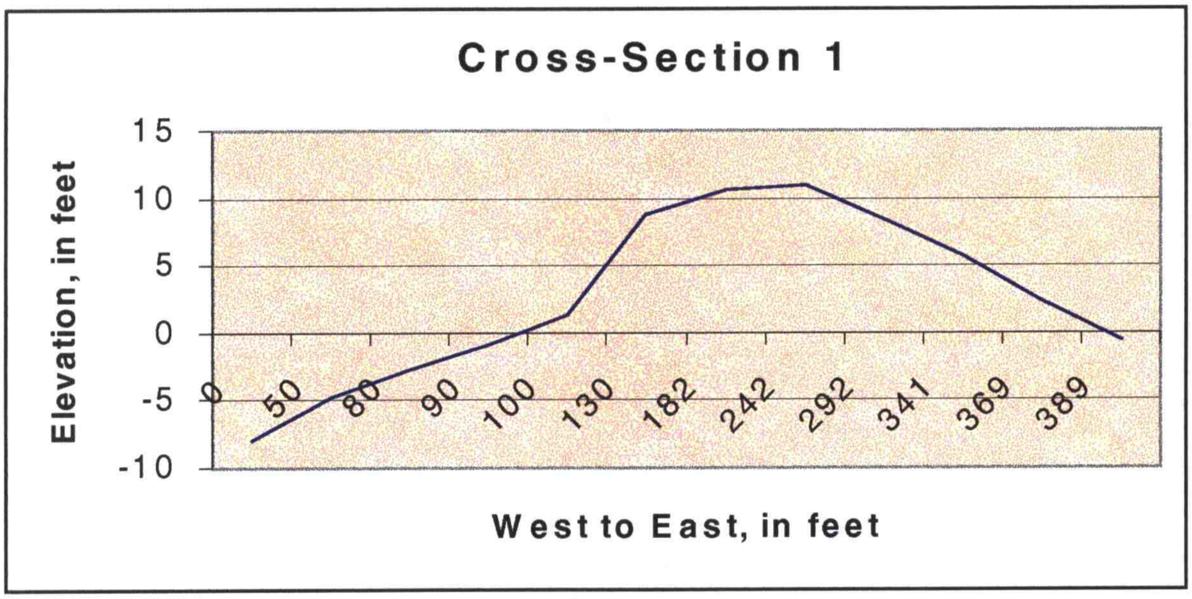


Figure 16

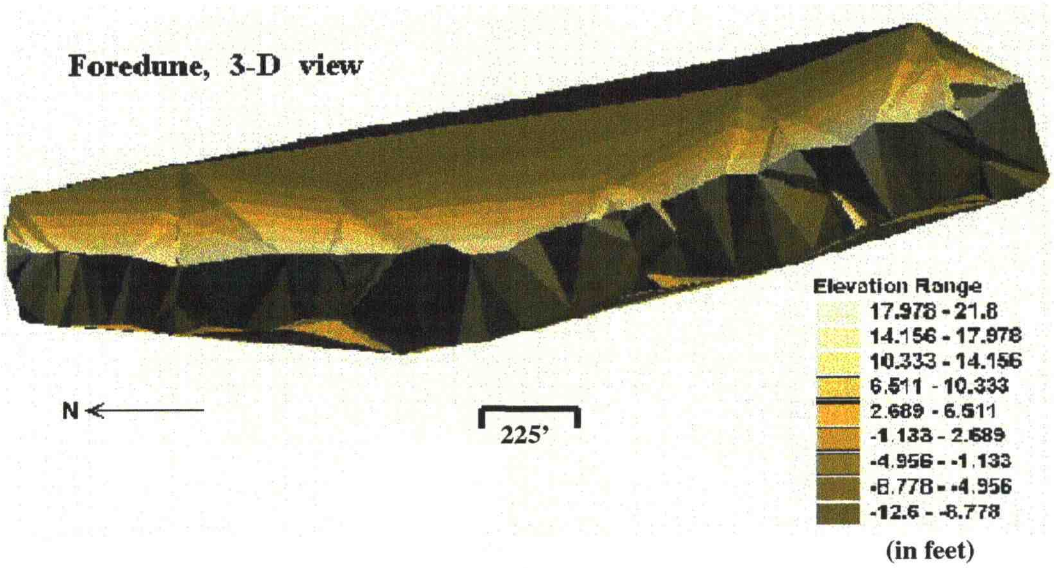


Figure 17

Summary

This phase of the project aimed to analyze the aerial photography, monitor sand transport, and use GIS techniques to display data and better understand the local morphology. The long-term study, managed by the USFS Siuslaw National Forest, will use the database and GIS template created in this project.

Aerial Photography

The historical analysis of the area using aerial photography demonstrates the rapid take-over of European Beach Grass, the expansion of the wetland area, and the dominant wind patterns. In 1952 the foredune was sparsely vegetated. The sequential photos show a gradual change in vegetation cover from 1952 to 1962, then a rapid spread of European Beach Grass and other vegetation after 1962. Encroachment and growth of the wetland in the deflation plain is observed in the 1970's and 1980's.

Sand Transport Analysis

During the months of April and May sand transport rates are approximately 114 grams per day on the crest (western edge) and 214 grams at the base (eastern edge) of the foredune. Figure 18 shows sand transport data collected in April and May and averaged to demonstrate daily movement; the two periods of collection had different wind velocities and may explain the differences in transport. These data will have more meaning as more data are compiled throughout the next year and compared to wind speed and precipitation information.

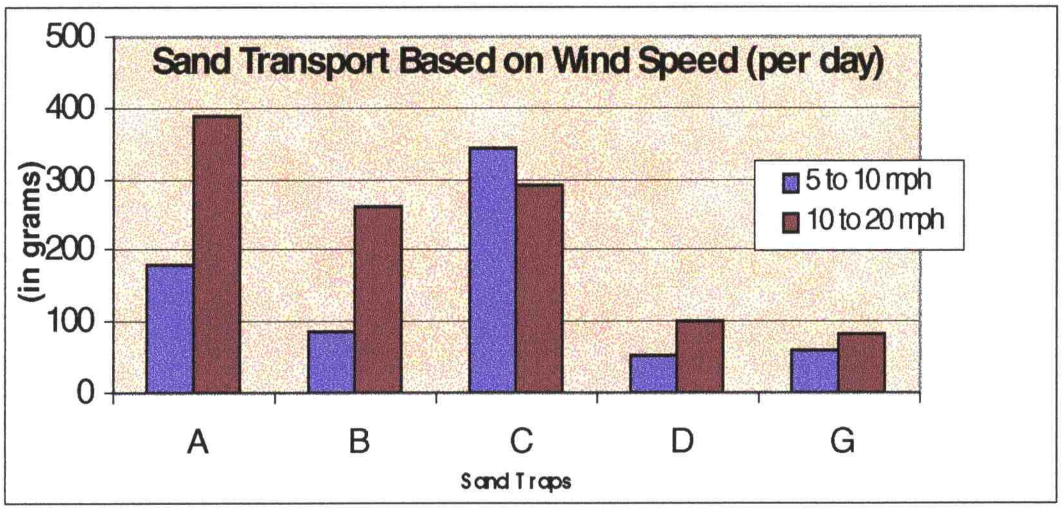


Figure 18

Stabilizing Vegetation

Initial observations suggest that sand is occurring in the treatment area; however patches of European Beach Grass and Sea Lyme Grass (*Elymus mollis*) have developed on the foredune area. The patches, generally one meter by two meters, consist mainly of Sea Lyme Grass which does not stabilize the sand to the same extent as European Beach Grass. The Sea Lyme Grass is also more prone to drought and is not as hearty as European Beach Grass.

Future Studies

Further studies are needed to determine the success or failure of this restoration project. According to Buckley (1987), there is no way to measure sand transport over a short period of time, relate it to fluctuating wind speeds, and consequently make any judgements on the sand transport processes. During sand trap operation wind speeds ranged from 5-20 mph. Future studies should collect sand during various wind conditions. Different precipitation and drought events should also be captured considering that varying conditions will affect sand transport. Venturris, used to direct wind flow, should be placed in a direction more parallel to dominant wind flow. The surface maps generated with survey data using GIS technologies will aid future studies by showing one step in the morphological progression of the foredune.

Similar research has been conducted in another area of the National Recreation Area by James M. Hanna. Hanna (1985) studied the effects of a foredune breach near the Siltcoos beach and dune access road, north of the Dunes Overlook site. Sand transport and wind data were collected to understand the dynamics of the dune after the breach; in the future it would be useful to compare it to the Overlook data to further understand dune dynamics.

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Appendix A

	sand trap	date					
	A	5/1/99					
Phi size	pan	3	2.5	2	1.5	Total	per day
in grams	1.66	36.4	49.17	799.47	185.72	1072.42	178.7367
	B	5/1/99					
Phi size	pan	3	2.5	2	1.5	Total	
in grams	5.35	41.92	41.78	429.06	0.92	519.03	86.505
	C	5/1/99					
Phi size	pan	3	2.5	2	1.5	Total	
in grams	4.84	42.96	59.47	1788.48	160.61	2056.36	342.7267
	D	5/1/99					
Phi size	pan	3	2.5	2	1.5	Total	
in grams	0.76	26.99	52.12	220.92	5.73	306.52	51.08667
	G	5/1/99					
Phi size	pan	3	2.5	2	1.5	Total	
in grams	3.18	36.67	54.62	271.41	1.74	367.62	61.27
	A	4/24/99					
Phi size	pan	3	2.5	2	1.5	Total	
in grams	1.68	15.4	49.19	892.68	1360.97	2319.92	386.6533
	B	4/24/99					
Phi size	pan	3	2.5	2	1.5	Total	
in grams	8.13	76.14	99.98	1354.19	22.07	1560.51	260.085
	C	4/24/99					
Phi size	pan	3	2.5	2	1.5	Total	
in grams	5.66	54.13	87.02	1551.75	42.93	1741.49	290.2483
	D	4/24/99					
Phi size	pan	3	2.5	2	1.5	Total	
in grams	1.61	41.51	59.01	498.22	14.17	614.52	102.42
	G	4/24/99					
Phi size	pan	3	2.5	2	1.5	Total	
in grams	3.18	36.67	54.62	406.73	1.74	502.94	83.82333

Appendix B					
Longitudinal Profiles					
Crest	from TS 1				
	azimuth	Horiz.	vertical	actual vert	acc.horiz
	190.61	572.5	-2.5	11.7	
	194.4	489.5	2.1	16.3	90
	194.8	443.4	-3.4	10.8	140
	194.3	421.2	-2.3	11.9	160
	193.8	403.9	-2.6	11.6	180
	193.5	390.5	-5.9	8.3	200
	192.3	366.2	-7.9	6.3	230
	194.1	330.1	-3.1	11.1	270
	194.5	227.7	-0.6	13.6	370
	179.6	110.2	-0.7	13.5	500
	99.7	19.6	0.4	14.6	610
	6.7	82.9	0.8	15	770
	17.9	163.9	-0.7	13.5	800
	9.8	280.5	0.5	14.7	930
	10.1	364.5	-0.8	13.4	1010
	10.1	429.7	-1.4	12.8	1080
	9.5	465.3	-4.1	10.1	1120
	6.8	576.5	-2.9	11.3	1230
	11.3	651.9	-2.2	12	1315
	10.1	751.9	-2.7	11.5	1415
	From TS 2				
	azimuth	horiz.	vertical	actual vert.	acc.horiz
to TS 1	169.9	1216.1	3.9		
crest					
	173.2	465.4	0.7	11	
	178	385.8	-0.7	9.6	
	176.9	257.3	1.9	12.2	
	178.2	211.6	0.1	10.4	
	180.5	137.7	1.7	12	
	189.2	75.2	0.7	11	
	191.8	50.8	-2.6	7.7	
	228.5	34.7	0.6	10.9	
	328.4	58.1	1.5	11.8	
	335.8	152.7	0.8	11.1	
	348.1	211.6	1.2	11.5	
	343.6	357.9	1.2	11.5	
	349.4	482.2	5.2	15.5	
	346.3	567.8	3.9	14.2	
	350	667.1	3.1	13.4	
	348.6	752.7	3.2	13.5	
	348.9	769.9	0.02	10.32	
	349.5	790.2	2.3	12.6	
	349.1	924.6	3.3	13.6	

Appendix B, continued				
Base	from TS 1			
	azimuth	horiz	vertical	actual vert
	170.7	550.9	-14.4	-0.2
	167.5	505.8	-12.7	1.5
	165.9	479.9	-14.5	-0.3
	164.1	448.8	-12.8	1.4
	160.8	397.2	-13.5	0.7
	156.7	371.2	-14.1	0.1
	154.2	329.7	-15.6	-1.4
	150.4	295.6	-14.9	-0.7
	148.5	281.7	-13.9	0.3
	146.1	266.9	-13.6	0.6
	140.3	249.7	-13.7	0.5
	119.9	228.9	-16.2	-2
	110.3	213.2	-16.1	-1.9
	99.1	197.8	-14.6	-0.4
	90.7	228.4	-14.1	0.1
	77.7	250.9	-15.3	-1.1
	66.7	269.6	-12.8	1.4
	59.6	273.7	-15.5	-1.3
	51.8	289.7	-13.8	0.4
	44.8	349.2	-15.3	-1.1
	From TS 2			
	azimuth	horiz	vertical	actual vert.
base				
	157.5	885.8	-12.2	-1.9
	156.6	815.9	-12	-1.7
	153.6	752.4	-10.3	0
	151.3	667.6	-11.9	-1.6
	148.8	574.1	-9.9	0.4
	142.2	449.3	-11.1	-0.8
	133	371.5	-11.9	-1.6
	125.1	315.5	-12.4	-2.1
	112.9	279.7	-9.9	0.4
	97.9	242.3	-12.8	-2.5
	72.3	271.4	-12.1	-1.8
	50.1	328.8	-12.1	-1.8
	35.8	369.4	-12.1	-1.8
	25.7	436.9	-12.2	-1.9
	21	503.2	-12.1	-1.8
	17.5	546.1	-12.2	-1.9
	14.1	631.3	-12.4	-2.1
	10.9	703.5	-12	-1.7
	10	770.3	-12	-1.7
	10.5	847.7	-12.4	-2.1
	9.7	918	-12.1	-1.8
	7.3	955.6	-12.5	-2.2

Appendix B, continued					
control points		(from TS 2)			
	azimuth	horiz	vertical	actual vert.	
	4.8	404.1	-4.9	5.4	
	347.2	405.3	2.9	13.2	
	88.7	104.4	-5.4	4.9	
	349.1	978.1	3.4	13.7	
sand traps	(from TS 1)				
	azimuth	horiz	vertical	actual vert.	
ST A	193	555.7	-3.6	10.6	
ST B	192.6	459.2	-2.7	11.5	
ST C	179.6	495.4	-8.4	5.8	
ST D	179.9	432.4	-9.2	5	
ST G	193.9	213.1	-1.1	13.1	
cross-sections					
	CS 1	(from TS 1)			
	azimuth	horiz	vertical	actual.vert.	acc.horiz
	211.3	581.7	-22.2	-8	0
	206.1	570.9	-18.9	-4.7	50
	203.7	565.7	-16.9	-2.7	80
	202.8	565.1	-15.1	-0.9	90
	202.8	565.2	-15.1	-0.9	
	202.5	564.9	-12.9	1.3	100
	202.3	565.2	-10.6	3.6	
	198.1	559	-5.5	8.7	130
ST A	193.1	556.4	-3.6	10.6	182
	186.9	557.4	-3.2	11	242
	181.5	553.4	-5.8	8.4	292
	177.6	549.6	-8.5	5.7	341
	175.1	552.4	-11.9	2.3	369
	172.4	556.9	-14.7	-0.5	389
CS 2	(from TS 1)				
azimuth	horiz	vertical			
261.4	333.2	-26.8	-12.6		
256.6	245.7	-23.3	-9.1		
240.2	158.5	-15.1	-0.9		
237.8	152.7	-11.9	2.3		
233.7	146.1	-10.4	3.8		
216.2	126.4	-5.5	8.7		
195.3	117.3	-1.8	12.4		
176.7	119.8	-1.1	13.1		
141.1	187.4	-11.9	2.3		
129.3	252.3	-15.8	-1.6		

Appendix B, continued								
CS 3	(from TS 1)				CS 6	(from TS 2)		
azimuth	horiz	vertical			azimuth	horiz	vertical	
339.3	377.7	-23.2	-9		330.1	850.1	-20.6	-10.3
346.1	355.2	-19.3	-5.1		334.5	829.9	-17.5	-7.2
351.1	343.8	-15.1	-0.9		338.5	815.5	-12.7	-2.4
352.1	342.7	-12.2	2		338.9	814.9	-11.8	-1.5
358.1	330.5	-7.3	6.9		339.2	814.2	-8.4	1.9
3.9	321.3	-3.1	11.1		343.9	799.9	-2.9	7.4
10.2	318.5	-0.7	13.5		347.2	791.7	-2.2	8.1
20.9	320.6	-3.5	10.7		348.2	789.4	-0.2	10.1
28.2	331.8	-8.1	6.1		349.6	789.5	1.9	12.2
28.2	331.6	-8	6.2		353.1	786.3	-1.7	8.6
34.6	350.1	-12	2.2		357.4	788.8	-7.2	3.1
38.3	368.2	-13.8	0.4		2.1	796.4	-9.3	1
42.2	384.6	-15.4	-1.2		6.8	806.4	-11.3	-1
					10.5	810.2	-11.7	-1.4
CS 4	(from TS 2)							
azimuth	horiz	vertical						
231.2	140.8	-14.9	-4.6					
209.4	188.5	-7.4	2.9					
196.5	167.4	-2.8	7.5					
182.7	159.9	0.8	11.1					
164.1	160.5	-2.6	7.7					
147.4	177.1	-4.4	5.9					
133.6	204.2	-7.7	2.6					
124.6	239.1	-9.7	0.6					
118.8	291	-12.1	-1.8					
CS 5	(from TS 2)							
azimuth	horiz	vertical						
308.7	418.1	-21.8	-11.5					
320.6	379.2	-18.1	-7.8					
327.9	353.6	-13.1	-2.8					
328.9	348.9	-9.2	1.1					
334.3	345.9	-6.3	4					
344.9	354.53	0.9	11.2					
1.5	366.9	-4.1	6.2					
11.1	397	-7.2	3.1					
22.7	455.2	11.5	21.8					