Monitoring Shorebird Habitat Using Softcopy Photogrammetry: The Case of Western Snowy Plover in the Coal Oil Point Reserve, Santa Barbara, California

by
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Abstract

The goal of this study was to determine how softcopy digital photogrammetry can be used to describe and monitor shorebird habitat. I focused on applying monitoring methods previously used for beach erosions studies of tourist beaches to shorebird habitat concentrating on the habitat requirements of Western Snowy Plovers. I investigated how the physical habitat of Western Snowy Plovers has changed over time at Sand Beach, which is part of Coal Oil Point Reserve in Santa Barbara, California, from 1928 to the present day, using width, area, and elevation data gathered from a series of aerial photographs. For two-dimensional analysis, I used single georeferenced photographs to measure width at regular intervals and area for each year a photo was available. Next, for three-dimensional analysis, I employed digital elevation models (DEMs) built from stereo photographs to explore whether the available photos can be used to document changes in the elevation of Sands Beach.

The results were mixed. Georeferenced aerial photographs can be used to obtain quality measurements of beach area and width. Orthorectification is not necessary if photos can be georeferenced with minimal error. The amount of error present in the georeferenced images was indicated by the root mean squared error. A higher root mean squared error in the referencing process resulted in lower accuracy. Given the available photos and ground control points, I was unable to build digital elevation models with high enough quality to compare elevation from one year to the next. This was more likely due to a need for more ground control points than to the image scale or image errors.

The area of Sands Beach was found to be increasing in area. This was due mainly to the retreat of the vegetation line as the mouth of Devereux Slough shifted in 1992 rather than an accumulation of sand on the beach.

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Introduction

Throughout their entire range, Western Snowy Plovers are threatened by habitat degradation and loss caused by shoreline development, resource extraction, and encroachment of invasive species (see Figures 1 and 2; U. S. Fish and Wildlife Service 2001). The Pacific population of Western Snowy Plovers was federally listed as threatened in 1993 and includes individuals breeding from Damon Point, Washington, USA, to Bahia Magdalena, Baja California, Mexico (Page et al. 1995).

Available habitat is considered a limiting factor in the success of Western Snowy Plovers (Warriner et al. 1986; Page et al. 1983), but I was unable to find any literature on the change in size of specific sites or any accepted method of monitoring for important factors like erosion or exotic vegetation encroachment. Powell (1996) studied southern California beaches historically used by Western Snowy Plovers and found that many were abandoned due to inadequate habitat and heavy human recreational use. Another study focuses on population size, but found that Snowy Plovers don't breed or winter in areas affected by humans (Powell 2002). Neither of these studies directly addressed habitat size.

Understanding how habitat availability has changed is important throughout the entire range. Monitoring beach area and width is one way to accomplish this. Remote sensing, particularly with aerial photos, is an ideal source of data for mapping large areas over time. In spite of the potential utility of such a study for understanding changes in Plover habitat, no such study has been done.

In a number of studies, historical aerial photos have been used to quantify erosion through measuring the movement of high water line (e.g., Crowell et al.

1991; Crowell et al. 1997; Fletcher et al. 2003; Leatherman 2003; Moore 2000; Pajak and Leatherman 2002) and vegetation line (Fletcher et al. 2003). Historical aerial photographs have also been used to build digital elevation models (DEMs) to monitor erosion hazards on beaches (Hapke and Richmond 2000), changes in sand dune fields (Brown and Arbogast 1999), and changes in geomorphology in general (Baily et al. 2003). These studies have all focused on the size of the beach for application to human uses like development or tourism. I expect that these techniques also can be profitably applied to shorebird habitat.

The goal of this study was to determine how softcopy digital photogrammetry can be used to describe and monitor shorebird habitat. I focused on applying monitoring methods previously used for beach erosions studies of tourist beaches to shorebird habitat, concentrating on the habitat requirements of Western Snowy Plovers. I investigated how the physical habitat of Western Snowy Plovers has changed over time at Coal Oil Point Reserve in Santa Barbara, California, from 1928 to the present day, using width, area, and elevation data gathered from a series of aerial photographs. The methods developed here can be applied to any beach and habitat for beach-dwelling shorebirds by making minor adjustments to beach boundary definitions.

Analysis took place on two levels: A three-dimensional analysis and a two-dimensional analysis. For the three-dimensional analysis, I employed DEMs built from stereo photographs to explore whether the available photos can be used to document changes in the elevation of Sands Beach. I used single georeferenced photographs to measure width at regular intervals and area for each year a photo was available for the two-dimensional analysis.

Western Snowy Plover Habitat Requirements and Threats

Western Snowy Plovers can potentially breed at any number of locations throughout their range. Their preferred breeding habitat includes sand-spits, dune-backed beaches, unvegetated strands, open areas around estuaries, and beaches at river channels. The birds prefer to nest in areas of limited cover, usually 6-18% vegetative cover and 1-14% inorganic cover, and build their nests within 100 meters of the ocean's high water line, lagoon, or river mouth (U.S. Fish and Wildlife Service 2001). They forage for insects between their nesting area and the high water line (Tucker and Powell 1995; Page et al. 1995).

Structures built on and near beaches create uninhabitable conditions. People building near the beach often try to immobilize the sand with structures like jetties and breakwalls. These stabilizing structures can make habitat undesirable for nesting and wintering Plovers (U.S. Fish and Wildlife Service 2001). Urban development in general contributes to degradation by increasing noise and vibration levels as well as the amount of ambient light at night. With development often comes an increase in predators like domestic cats. Manipulation of water courses, such as diversion or impoundment, reduces sand transport to the beach, reduces water quality, and can impair hydrologic processes. The natural migration of river mouths and water outfalls is an important means of maintaining open habitat free of dense vegetation (U.S. Fish and Wildlife Service 2001).

Various forms of resource extraction also negatively affect the quality of shorebird habitat. Sand mining removes the habitat's substrate and destroys dunes.

Equipment used to remove the sand contributes to increased levels of noise, vibration, and pollution as well (U.S. Fish and Wildlife Service 2001).

Beachgoers influence the birds and their habitat directly. People walking on the sand disturb feeding and nesting birds and can crush nests (Warriner et al. 1986). Visitors collecting driftwood from the beach also pose a problem for Plovers. The birds often nest near beach debris to protect their nests from wind and blowing sand (U.S. Fish and Wildlife Service 2001). Driftwood also facilitates dune formation on many beaches, so removing it can negatively affect beach topography. Beach cookouts and campsites attract scavengers that can later turn their attention to Plover nests once the food left by people is gone (U. S. Fish and Wildlife Service 2001).

Encroachment of invasive species on Plover habitat reduces the amount of available habitat area and the overall desirability of the habitat. Beach grasses (e.g., *Ammophila* spp.), introduced to stabilize dunes, are common dune invasives. They bind sand in their roots, immobilizing the dunes and preventing the movement of sand that is necessary for regenerating areas of low sand. Beach grasses also reduce the overall species diversity on dunes (U. S. Fish and Wildlife Service 2001). Other problematic species include scotch broom (*Cytisus scoparius*), gorse (*Ulex europaeus*), South African iceplant (*Carpbrotus edulis*), iceplant (*Mesembryanthemum* spp.), and shore pine (*Pinus contorta*) (U.S. Fish and Wildlife Service 2001). These species have effects similar to those of the beach grasses.

The amount of habitat directly affects the number of birds able to nest at a particular site. The density of nests varies depending on the location (Warriner et al. 1986), but maintaining a low nest density reduces predation (Page et al 1983).

Density of nests at a site can also be a limiting factor for the size of a nesting Plover population (Warriner et al. 1986), so the size of available habitat is crucial.

Not only is the overall size of the habitat important, but also the width. Narrow beaches potentially have a greater area of overlap between Plover habitat and areas of human recreation, leaving less undisturbed areas for nesting and foraging. This situation leads to reductions in the number of breeding pairs (Lafferty 2001).

This anthropogenic loss of habitat is worsened by California's beach erosion trend. The majority of beaches in California are actively eroding (Surfrider Foundation 2005). The California Coastal Commission estimates that of the 1,120 miles of coastline, 950 miles are actively eroding, 10 miles have no dry sand at high tide, and only 150 miles are accreting sand or stable (Surfrider Foundation 2005). Surfrider Foundation (2005) cites change in shoreline position and beach width as vital to understanding coastal problems, but this information has not been consistently gathered by any agency.

Study Area

Coal Oil Point Reserve, a part of the University of California Natural Reserve System since 1970, is located on the University of California, Santa Barbara's west campus. The 158 acre site includes many different habitats, including Devereux Slough (a flooded tidal lagoon that dries out forming mudflats and hyper saline ponds in the summer), coastal dunes with dune vegetation, back dunes with coastal scrub, and intertidal habitat (see Figure 3; Coal Oil Point Reserve 2005).

The reserve is a home for many different plants and animal species, not the least of these is the Western Snowy Plover. In 1999 the United States Fish and Wildlife Service identified 12 areas of critical habitat for these birds in Santa Barbara County, California. Critical habitat was defined as "specific areas that have physical or biological features essential to the conservation of the species and that may require special management consideration or protection" (Santa Barbara County Planning & Development 2003). One of these areas is Sands Beach at Coal Oil Point Reserve.

Sands Beach does not have many of the problems that are common throughout the range of Western Snowy Plovers. The beach's natural processes are left unimpeded. The sand is not groomed nor are carcasses of ocean animals removed or buried when they wash ashore. Beach stabilizing structures and beach grass are also absent from this site (Lafferty 2000). Heavy winter storms can drastically affect the beach, but the beach usually rebuilds by the summer. Lafferty (2000) notes that the rebuilding processes seem somewhat impaired at this site.

At this site birds are mainly threatened by harassment by people and their pets (especially dogs) as well as predation, beach erosion, and encroachment of their preferred sites by exotic vegetation (Lafferty 2000). Currently, the Plovers' habitat at Sands Beach is managed to control the amount of nest disturbance by people visiting the beach for recreation and, to a limited extent, to control the amount of nest predation by animals like ravens (*Corvus corax*), crows (*Corvus brachyrhynchos*), and red foxes (*Vulpes fulva*); it has thus far been successful (Santa Barbara County Planning & Development 2003).

Since 2001, a three-part management plan has been used at the reserve to protect the Plovers. This plan utilizes fences, signs, and docents to shield the Plovers from disturbances. Fences made of posts and a one line of rope at the top are set into the sand around the breeding and wintering areas to discourage beach visitors from walking in the area where Plovers and their nests tend to be. Signs secured to the fence and those posted around the beach alert the public to the presence of the birds and inform them that their dogs must be leashed at all times. Docents are charged with educating beachgoers and scaring away crows or other predators that might disturb the nests. This approach has increased the birds' breeding success immediately, raising the number of chicks fledged from zero before the plan began to 27 fledglings over the first four years (Sandoval 2004).

Sands Beach's high quality habitat is partly to thank for the larger population of Plovers compared to other sites. However, the beach is small compared to others that the Plovers use (Sandoval 2004), and beach size is not managed. For this reason, it is important to identify how the beach is changing. Future success could easily be undermined if Sands Beach is experiencing steady erosion reducing the available habitat area.

Methods

Stereo Pair Photograph Selection

I used photos from 22 flights of nadir-looking photos spanning almost 80 years, 1928 to 2004 (see Table 1). For each year, two photos were obtained in stereo, if available, to be used in the three-dimensional analysis. Photos from 1929 and 2004 were unavailable in stereo. Camera calibration reports were only available for four recent stereo pairs: 1986, 1989, 1992, and 2001. These reports were obtained from I.K. Curtis Services, Inc., of Burbank, CA. The calibration reports for the older photos were unavailable because of their age. The limited availability of this necessary information reduced the number of digital elevation models (DEMs) that could be made.

Photos were used only if taken between May and October, when the beach is most stable. Given the Southern California beaches' sand cycle, winter beach area is significantly smaller than summer area, due to sand migration and winter storms (Leatherman 2003). Also, winter shorelines tend to be variable and often can be quite different from day to day (Douglas 2002). Photos taken during the winter storm season were, therefore, unsuitable; winter photos were not used.

Summer photos are particularly useful in studying Plover breeding habitat. Sands Beach is known to erode with winter storms, but usually rebuilds by May (Sandoval, personal communication). This time frame also roughly corresponds to the Western Snowy Plover breeding season of early March through late September (Page et al. 1995) and would make the data resulting from this study useful in investigations of Western Snowy Plover breeding populations.

All of the photographs were scanned at 600 dots per inch (dpi) and stored as tagged interchange format (TIFF) images either at the UCSB Map and Imagery Laboratory or in the University of Michigan's Environmental Spatial Analysis Lab, with the exception of one. The photo from 2004 was purchased by the County of Santa Barbara's department of Planning and Development from a commercial air photo company, Airphoto USA, and was provided by the county for use in this study. Ground resolutions and flight information are presented in Table 1.

Ancillary Data

Ground control points (GCPs) are necessary for georeferencing photos and for building DEMs. Twenty-two GCPs total were collected at the site in November 2005 and January 2006 with a hand-held Trimble GPS receiver. Locations of these points are shown in Figure 4. The points were corrected with data from the nearest base station (located on the UCSB campus). Points were not taken on the sand at Sands Beach due to the variability in height, but measurements were made at landmarks in the vicinity of the beach that were visible in many photos. Chosen landmarks mostly included road and trail intersections. GCP coordinates were measured in latitude & longitude and later reprojected to Universal Transverse Mercator (UTM) zone 11 north with North American Datum (NAD) 1983.

Information about depth of precipitation was necessary to determine the relationship between rain amounts and the size of the habitat area. The depth of precipitation (in inches) was obtained from the Santa Barbara County Public Works Department website. These data were taken daily at the weather station in downtown Santa Barbara, and were compiled by the county into monthly and water year totals. The data were converted from inches to meters to make the units consistent with the beach measurements.

Shoreline Indicator

Identifying an appropriate feature to indicate the shoreward extent of the beach is critical. Boak and Turner (2005) outline a variety of shoreline indicators, but high water line (HWL) is the most appropriate in this case. HWL is the mark left on the beach by the last high tide. It delineates the limit of the beach by marking where the sand and the water meet and is a good estimate of mean high water line (Pajak 2002). HWL approximates the mean high water line with sufficient accuracy regardless off the tidal condition (Donlan et al. 1980). In an aerial photograph, HWL is visible as a change to a darker tone of sand near the water or as the line of wrack washed up on the shore (Crowell et al. 1991; see Figure 5).

Of all the options available for this study, HWL is visible in all the photos (some manipulation of contrast and brightness was necessary in some of the photos to make it clearer), and gives a good indication of the seaward extent of the beach. HWL is also an important factor in determining potential Plover habitat because Snowy Plovers tend to nest within 100 meters of the HWL on beaches and the wrack that accumulates at the HWL provides hunting grounds and nest-building materials (U.S. Fish and Wildlife Service 2001). Delineating beach extent by HWL will make the data collected here relevant to comparisons with counts of nesting birds, something that will have to be left for later as recent management efforts would complicate such a study.

A change in tone is more useful than the wrack line for indicating beach extent at Sands Beach because it is clearly visible in all the photos and was unquestionably made the day the photo was taken. Given that the sand at the reserve is not groomed (mechanically raked to remove wrack and other debris; Coal Oil Point Reserve 2005), wrack lines from previous high tides, and debris in general, clutters the beach. In some photos several wrack lines are visible. It is not clear if even the line closest to the water was recently formed or if it was the result of an earlier high tide.

Two-Dimensional Analysis

One photo from each stereo pair was selected for the process of determining beach width and area. Moore (2000) suggested that photos should be orthorectified to minimize error before shoreline detection is performed. However, due to the age of most of the photos used, the camera calibration reports were no long available, so orthorectification was impossible. To minimize radial distortion, which increases with distance away from the center of the photo, photos with Sands Beach nearest to the center were preferred (Crowell et al. 1991). If the distance from the center was roughly the same, the photo with better visibility of beach features was selected. One exception to this rule was made. For 1989, the photo with Sands Beach nearest the center was too bright, obscuring the beach features, so the other photo was used. The beach area is not expected to be greatly impacted by relief distortion because the features on and around the beach are of low elevation (Anders & Byrnes 1991).

The selected photos were georeferenced using ERDAS IMAGINE 8.7 (Leica Geosystems, Atlanta, GA). Photos from 1983 to 2004 were referenced to the GCPs taken at the site in 2005 and 2006 (see Table 2). All other photos were referenced to the 1983 photo, because many of the older photos did not show the features represented by the GCPs. The 1983 photo was best for referencing to the older photos because this photo had the most identifiable points in common with the older photos. All photos were referenced with a first order polynomial geometric correction, and were resampled using the nearest neighbor setting.

Once the photos were georeferenced, the perimeter of Sands Beach was digitized in ESRI's ArcMap 9.0. The perimeter was bounded by the HWL, the dune vegetation line, and two arbitrary lines that were held constant in all the photos and that marked the area of interest (see Figure 6). Each photo differed in the degree to which the HWL and vegetation line were visible, so adjustments to the brightness and contrast were made to maximize visibility of HWL and the vegetation line in each photo separately (Shoshany and Degani 1992).

The dune vegetation line was visible in all the photos as a scattered mass of dots. These dots represented clumps of vegetation growing on the sand dunes. The vegetation line was digitized along the farthest extent (towards the ocean) of the dots. While digitizing, I avoided small dots in the areas of otherwise open beach, assuming that they were debris rather than vegetation. When the vegetation line neared the slough, I avoided including extraneous areas of sand lining the edge of the slough channel by cutting across the sand where the channel began.

It is possible that the area of the beach is driven in large part by the amount of precipitation received in the winter preceding the dates of the photos. Both U.S. Fish and Wildlife Service (2001) and Lafferty (2000) note that winter storms remove

Plover habitat and the beach does not necessarily rebuild back to a normal size by the following spring. Hapke and Richmond (2000) found that between 1997 and 1998 during the most severe part of the El Niño storm period, Cowell Beach in northern California lost nearly half of its volume of sand. Since all the photos used here are taken in the spring and summer, comparing the depth of rain to the beach size will determine if the amount of rainfall in a given year affects the size of the beach available to breeding Western Snowy Plovers. Of particular concern are the heavy rainfall and violent storms associated with the El Niño phenomenon.

To test whether a relationship exists between the amount of precipitation in the water year preceding the photo and the area measured in the corresponding year, I performed a linear regression between the precipitation data and the areas measured on the referenced photos.

Using photos taken after a storm event could make the long-term trend in erosion rates, which is what I wished to measure, seem greater than it actually is. If beach area is not correlated with rainfall, this potential source of error probably is not a problem. I also assumed that the long record of photos will help to minimize the effects of one or two anomalous years' data (Leatherman 2003). Comparing the area to the amount of precipitation will also test this assumption.

Two other potential sources of errors could be an issue in this study: digitizing mistakes and image distortions (Crowell et al. 1991). Discrepancies in digitizing can be minimized by reducing the number of people interpreting the location of the high water and vegetation lines. This potential source of error is minimized by limiting the number of people digitizing to one. After digitizing was completed, the shapefiles were compared and discrepancies in HWL and vegetation line were corrected.

To test the assumption that using referenced images rather than orthorectified images introduced an insignificant amount of error to the measurements, I compared the beach area obtained from the referenced photo and the orthorectified photos. I calculated the percent difference in area measurements between the non-rectified photo area and the rectified image area to be able to compare the differences from year to year on the same scale. Using ERDAS IMAGINE's OrthoBASE, I made orthorectified photos for the four years with available camera calibration reports. Table 3 contains flight information, cell size, and RMSE for the orthorectified images.

The final step in data collection for the two-dimensional analysis was to construct transects of the digitized beach area (Figure 6). These transects allowed me to measure the width of the beach and assess for directional change over time, and also to evaluate local changes in different geographic parts of the beach. Using a method similar to that of Fletcher et al. (2003), forty-five lines were constructed across each beach twenty meters apart in ArcMap. The lines were parallel to each other and perpendicular to an arbitrary line in the ocean and one on shore (Fletcher et al. 2003). These lines crossed the beach roughly perpendicular to the HWL making it possible to measure the width of the available habitat. The width of the beach is important to Western Snowy Plovers, but Sands Beach's historical width was not surveyed regularly so air photos are likely the only record and source of information about the beach's width. The lines were cut where they intersected the beach perimeter, breaking each line into three separate segments: water, beach, and vegetation transects. The segments were labeled for the area of the photo they cross. Where the entire length of a beach transect was disconnected because of the curvature of the slough mouth, the two lengths were added together.

This method varies somewhat from those of Crowell et al. (1997) and similar studies. In these papers the authors describe transferring all the shorelines to one map, constructing transects perpendicular to one shoreline, and measuring the distance to the next year's shoreline. Sometimes, because of the bends in the shorelines, transects cross and add confusion (Fletcher et al. 2003). This method would be computationally cumbersome if it were necessary to compare shorelines to more than one or two others, such as is the case here.

I have chosen to create transects perpendicular to an arbitrary line that is roughly parallel to the set of shorelines. A measurement along these transects can easily be compared to any other transect measurement. An added benefit is that the transects only need to be constructed once instead of individually for each year. A master set of transects was constructed over a georeferenced photo and then copied onto other photos and cut where the lines intersect the perimeter of the beach. This ensures that transects are measured in the same location on each photo because the transect coordinates are recorded when the master set is created. This method also had the benefit of creating a more consistent sampling scheme. Measurements made to the alternative shoreline in the method with transects perpendicular to the shoreline could be rather unevenly spaced if the curve of the shoreline has changed between the two measured years.

The temporal trends in the lengths of the water, beach, and vegetation transects were analyzed using a linear regression equation that for transect length as a function of time. The length of the water transects were compared as a measure of the movement of HWL. Similarly, the vegetation transects were used to detect changes in the movement of the vegetation line. The beach transects directly measure the beach width. Decreasing vegetation or water transects means that respective feature is contributing to an increase in the beach width.

The linear regression analysis was found to be the most accurate method of determining trends in shoreline change compared with other commonly used methods, like endpoint rates (Honeycutt et al. 2001 and Crowell et al. 1997). A major advantage to this analysis, aside from increased accuracy, is that storm-affected shorelines do not need to be removed from the analysis (Honeycutt et al. 2001). Since there are only 22 photos providing measurements, keeping all measurements is advantageous for more accurate statistical tests. Further, this method allows the calculation of R2 to reflect the fit of the data (Crowell et al. 1997). Other common shoreline assessment methods lack an equivalent measure of fit.

While the slough may not affect the entire beach, it certainly has a local effect. Taking transects that intersect the slough separately from the others allowed for an investigation into whether the slough mouth itself plays a role in shaping or moving the HWL or vegetation line. To test if the HWL or the vegetation line is moving, I performed a linear regression with the average of the length of the appropriate transects using and the year the photo was taken. This method, however, damps the effects of the most dynamic portion of the beach. For this reason it is necessary to look also at the average transect lengths both with and without the slough transects. Because the beach transects are affected by movement of both the vegetation and HWL, they are not as useful for identifying the causes of changes. To be able to single out which line, if either, is changing the habitat, I will focus on the vegetation and water transects.

Transects were also constructed for the beach polygons digitized from the orthorectified photos and compared the results with those obtained from the referenced images. The percent difference between the two measurements for all three segment types was calculated to be able to compare the different segments.

I did not compare the number of nesting birds to the beach area because of the recent management program to reduce human impacts. The increase in birds (Sandoval 2004) is more likely due to the reduction in human interaction than to changes in the size of the beach. Given that the number of birds increased dramatically after the management plan began and appear to be changing yearly, it would be inappropriate to try to draw conclusions about the number of birds and the available area at Sands Beach at this time. As this management program continues and more aerial photos are taken of the site, the beach area and width should be measured again and compared to the number and location of nests.

For all statistical tests, the alpha level selected was 0.01. Because the photos could not be orthorectified, introducing some added error, a low alpha level was selected to reduce the chance of rejecting hypotheses falsely. Measurements from year to year are not independent because they are temporally autocorrelated. The size of the beach at any time is somewhat dependent on the size of the beach in previous years. The lower alpha level will help mitigate the likely overestimation of the linear regression significance tests resulting from the lack of independence.

Three-Dimensional Analysis

The same photos obtained for the two-dimensional analysis were used to investigate questions about elevation (Lilesand and Kiefer 2000). The two-dimensional analysis described above can offer insights into directional changes in the area and width of the beach. The two-dimensional analysis, however, cannot tell us about the topographic structure of the beach. Having topographic information is important because Sands Beach is backed by large sand dunes, which Western Snowy Plovers prefer be present at nesting and over-wintering sites (Page et al. 1995). Data on elevation in this area were not collected in the past, so stereo air photos are likely the only source of data on historic topography.

One way to measure three-dimensional information is to use scanned aerial photos in conjunction with an automated DEM extraction program like ERDAS IMAGINE’s OrthoBASE. Building a DEM from stereo aerial photos is an ideal way of investigating historic topography because automated DEM generation techniques are as accurate as manual methods but work more quickly (Baily et al. 2003). DEMs of the beach were built using stereo pairs, GCPs, and camera calibration reports to obtain elevation information from Sands Beach and compared to one another in order to identify areas of accumulation or erosion on the beach.

Using ERDAS IMAGINE’s OrthoBASE program, a DEM with 5x5 meter cells was built from each of the 1986, 1989, 1992, and 2001 stereo pairs, using UTM zone eleven north with NAD 1983 as the projection (Leica Geosystems 2003). Following identification of the basic image and camera model information, including focal length, principal points, and location of the fiducial marks found on the camera calibration report, the exterior orientation was created by recording GCPs and their coordinates, as well as marking tie points (i.e., points marking features visible in each photo of the pair). Tie points were positioned on the beach where stable GCPs could not be taken to reduce the error in this portion of the model. Tie points were also distributed throughout the stereo portion of the two images to reduce the overall error. Tie points were added until the root mean squared error was less than 1.0.

Once the image orientation information was set, I used default settings (Leica Geosystems 2003) to automatically generate the DEM. Jacobsen's simple model for additional parameters, an option in the program's settings for self calibration, was used in the extraction process because it reduces the effect of systematic errors in the DEM, like film distortions and scanner errors (Leica Geosystems 2003). The parts of the images that included the ocean and areas far from the measured GCPs created errors in the DEMs, such as mountains at the HWL, and were excluded from the final DEMs. The errors and cell sizes for each DEM are reported in Table 4. The resulting grids covered the area of the reserve and little else. Given more GCPs, more extensive DEMs could be created, if needed.

In addition to accuracy estimates provided by the software it was necessary to evaluate accuracy by other means (Lane et al. 2000). One way to test the accuracy of a DEM is by comparing the elevations predicted in the DEM at specific locations to measurements taken at those points. These control points must not be used in the

DEM creation process. This method is applied in many studies (Brown and Arbogast 1999; Baily et al. 2003; Lane et al. 2000), but was not possible for this study because the number of GCPs available was small. All the usable points taken at the site had to be used to build the DEM. Coal Oil Point Reserve has few areas where stable GCPs can be taken. Vegetation is short and ever-changing and the few road intersections are limited to the east side of the reserve. Further complicating matters is the slough in the center in which no GCPs can be taken (there is nothing to chart). Another option for measuring accuracy is to compare sections of the DEM with ground survey profiles (Hapke and Richmond 2000). This method also cannot be employed here because ground survey data is not available.

Since quantitative methods were not possible, I relied on qualitative methods to assess the DEMs' accuracy. I looked at the elevation values of the DEMs in areas where I could estimate what the elevations should be and compared my estimates to the elevations generated by the computer. Areas of particular concern were the beach near the HWL and the dunes behind the vegetation line. These areas should be of reasonable heights, about zero meters at HWL and less than five meters for the dunes. Beach elevations above -1.0 meters were considered reasonable. For the purposes of this study, more rigorous quantitative assessments were unnecessary.

OrthoBASE is capable of creating a grid relating the quality of each cell's prediction. Cells are rated from one, "excellent", to five, "suspicious", based on the correlation coefficient calculated during the extraction process (Leica Geosystems 2003). This grid was also used in the qualitative evaluation of the DEMs.

Results

2-Dimensional Analysis

Using referenced photos rather than orthorectified photos did not change the area measurement enough to warrant concern about introducing error. The percent difference between the measurements for all four years is less than 0.004% (Table 5). The difference in areas is not larger than what might be expected with minor discrepancies in digitizing high water line (HWL) or vegetation line.

Georeferenced photos provide sufficiently accurate measurements of beach width The differences between the average transect length measured on the four othrorectified photos and the corresponding georeferenced photos were minimal. The largest difference was 8.26% for the average vegetation transects measured on the 1992 photo. For all the other measurements, the difference was much smaller. The differences in the beach transect lengths were less than 0.5% for all the photos (Table 5), indicating that the relief distortion in the referenced photos was small. In general, the vegetation and water transects also exhibited little difference between the two types of photos. The exception to this is the 1992 photo, where the difference was about 10 meters. These results are consistent with the measured quality of the georeferenced photos. The 1992 photo had a higher RMSE than the other three photos examined here (Table 2). Overall the quality of the data obtained from the referenced photos was sufficient for this study.

The area did not appear to be related to the depth of precipitation recorded for the water year corresponding to the photo date (results not shown). The beach areas were compared to the precipitation data collected by Santa Barbara County. There was a positive but insignificant relationship between these variables (the slope of the relationship is 0.002 meters per year and the probability that the slope of the line was equal to zero is 0.095).

Table 6 shows the results of a series of linear regression analyses performed with the measurements taken of the beach area and transect length measured on the georeferenced photos versus time. Beach area, average beach transect length, and average vegetation transect length coinciding with Devereux Slough are the only measures significantly growing or declining over time. Despite the large number of eroding beaching in California, the area of Sands Beach appears to be increasing over time. Figure 7 shows a scatterplot of the area versus time and a linear regression line with a positive slope. This slope is significantly different from zero ($p = 0.001$). On average, the beach is gaining more than 300 m^2 per year.

Why is the beach area increasing? I examined two possible explanations– either the HWL is advancing south (i.e. the beach is accreting sand) or the vegetation line is retreating. The area of the beach is influenced heavily by the movement of Devereux Slough. Visual inspection of the photos revealed that the slough's movement north in 1992 carved out a large portion of the vegetated dunes that once flanked its channel. This assessment is supported by numerical evidence as well.

The possibility that the HWL is moving can be ruled out. The slope of the linear relationship between length of the water transects and the year is not significantly different from zero (the probability that the slope is equal to zero is 0.195; Table 6 and Figure 8). The water transects that corresponded with the slough (transects numbered 25 to 36) might be suspect for growth, in spite of the rest of the transects remaining fairly constant. The water transects not intersecting the slough area were not moving. The slope of the linear regression was -0.160 (Figure 9), but the relationship was insignificant ($p = 0.162$). The slope of the relationship between the length of water segments near the slough and time was also likely equal to zero (the slope is -0.125 and $p=0.309$, Figure 10), so it can be concluded that the HWL is not experiencing directional change.

The majority of the vegetation line is stable as well, except for the portion near the slough mouth. The average vegetation transect length was not changing (the slope is 0.239 and probability that the slope is zero is 0.025; Figure 11). The slope of the linear relationship between the year and the average vegetation transect length without the slough transects was not significantly different from zero (the slope is 0.239 and $p = 0.119$; Figure 12). The length of the vegetation segments intersecting the slough, however, decreased at a rate of 0.457 meters per year ($p = 0.002$; Figure 13). The gain in beach area over time is, therefore, more likely due to the slough's movement causing a retreat in the vegetation line than from sand accretion.

Three-Dimensional Analysis

The digital elevation models (DEMs) built from the four stereopairs with calibration reports were not of sufficient accuracy to determine historic elevations. The elevations calculated on the beach varied wildly and are often large negative numbers (Figures 14 through 17). While low negative numbers might be expected near the HWL (indicating that the ocean level was low in the area), the values such as negative five meters are not reasonable.

The 2001 DEM overall had the best quality; the majority of the beach areas had values greater than -1.0 meters, but some areas (for example northwest and a larger area south of the slough mouth) were still suspect. The beach area in the 1992 DEM was almost entirely less than -1.0 meters in elevation. Much of it is less than -5.0 meters, elevations that are certainly not plausible. The 1989 DEM also had a fairly large area of low values, but they were not as low as the 1992 grid. Excluding the swash zone from the DEMs removed some of the beach area in the automatic extraction process. Unfortunately, most of the beach area was missing from the 1986 DEM. The remaining beach pixels had reasonable values, but not enough remain to draw any conclusions.

The quality grids for all the DEMs showed a high amount of error in the beach area. The 1989 grid has the most “suspicious” cells, with the majority of the beach considered low quality (Figure 15). The other grids had better results, but areas of lower quality on the beach were larger than the upland sections of the DEMs.

While specific elevation values were generally poor, the relative elevations within the photos seemed to be fairly accurate. For example, within a DEM for a particular year, we can see that one location was of lower elevation than another, but the absolute elevations were not necessarily correct. So in the 1992 and 2001 DEMs we can see that the dunes on the northwest side of the slough mouth have been leveled. This information is valuable because elevations and relief cannot be easily determined in the photos. We can only see that the dune vegetation is gone. From the DEM we can determine that the dunes themselves have actually been removed.

Discussion and Conclusions

Current photogrammetric methods of investigating coastal geomorphology with aerial photographs have mixed results when applied to an assessment of shorebird habitat. These methods can successfully be used to measure movement of important beach features and to investigate the effects of water bodies coincident with the habitat. To investigate topographic changes current methods require more development and ground data than were available.

Working in undeveloped coastal areas in California can be challenging for remote sensing techniques. For this study, the available photos and ground control points (GCPs) could not be used to build accurate digital elevation models (DEMs) for the purpose of investigating historic beach topography. However, building DEMs for coastal areas is not impossible. Unfortunately, the limitations of measuring quality GCPs at this site limited the accuracy of the DEMs to such an extent that the results were poor. Topographic changes might have explained why the beach has changed in size and why the mouth of Devereux Slough shifted to the north.

While having orthorectified photos is ideal for monitoring shorebird habitat, they were not entirely necessary. If photos can be referenced with minimal error, it is possible to obtain high quality area and width measurements from georeferenced photos. This is important for long-term and historical studies because the information necessary for orthorectifying photos may be unavailable for older photos. Also, occasionally photos cannot be acquired in stereo or funding limitations prevent buying photos in pairs.

Measuring the width of the habitat at regular intervals makes it possible to assess how width has changed as well as analyze the movement of important beach features. It has the advantage of being able to answer questions not only about how beach features are moving, but if certain regions of the beach are more affected than others by isolating and testing dynamic portions of the habitat. In addition, it provides more detailed information than measuring the area of the habitat alone.

Using these methods, Sands Beach was found to be increasing in size. The growth in the beach area is due to the movement of the vegetation line, rather than a seaward movement of high water line (HWL); i.e. the area is not increasing due to accretion of sand. Using a transect analysis to measure beach width and the movement of beach features, it is clear that the HWL is neither advancing nor retreating. The additional beach area is actually added only by the movement of the vegetation line near the mouth of Devereux Slough. The retreat of the vegetation line is entirely facilitated by the movement of Devereux Slough. Had a factor besides the slough movement been causing the vegetation retreat, the movement would have been evident in the shortening of transects not near the slough as well.

Sands beach falls into the small category of stable California beaches. Monitoring should continue to assess whether this remains the case. The results indicating a lack of relationship between rainfall and beach area as well as the general positive trend in beach area are surprising as is the stability of the HWL. With erosion suspected to be a problem on so many beaches it is unexpected to find that this beach is stable. The linear regression model of beach growth should not be taken as a projection of continued increase in beach area. If the slough position stabilizes, the area of open sand and Plover nesting area will begin to decrease as the vegetation (and presumably the dunes) begin to grown in areas vacated by the slough.

The lack of relationship between the amount of rainfall and the beach area was surprising, but not altogether unexplainable. The initial loss of sand during storm events may be followed by a higher than normal amount of sediment transported through nearby water courses. This is not to say that large storms do not cause damage, but overall, after several months of time to rebuild, Sands Beach's area is not significantly affected by large or small rain events. It is also possible that other factors besides depth of rainfall determine the affect of a particular storm on the beach.

The accuracy of the DEMs was lower than expected. Areas near GCPs were often of incorrect elevation. My lack of confidence in the elevations calculated near known locations leads me to be skeptical of the beach elevations so they were not used to make calculations.

Unedited, automatically-generated DEMs of coastal areas often have high error because beaches are usually low in contrast and have areas of high interference, like the swash zone (the area of beach where waves regularly wash up and retreat; Hapke and Richmond 2000). Post-generation editing to include breaklines at the HWL and matching misinterpreted areas to the ground could improve the qulity of the DEMs (Hapke and Richmond 2000). In this case, editing is not practical because the accuracy is low everywhere.

Air photos of 1:12000 or smaller scale may not be sufficient for a detailed analysis such as this but another cause may be at the root of the problem. The parent images for the 2001 DEM are of larger scale than those of the other DEMs – 1:12000 compared with 1:24000 of the other three sets of images – but the accuracy was still too low. The small number of GCPs is probably the cause of the low quality of all the DEMs. GCPs could not be measured on the beach because the elevation of the sand is expected to change over time. Tie points also could not be placed on the beach portion of the image for most of the photos due to a lack of visible features to mark. These problems are exaggerated by the fact that neither tie points nor GCPs could be placed in the ocean. Extrapolating outside the range of GCPs resulted in a low quality DEM.

In the georeferencing process described earlier for the two-dimensional analysis, the 1992 photo had the second highest RMSE of all the photos, and of the years that were used to build DEMs, it had the highest. The fact that this year's images created the DEM with the lowest accuracy and a georeferenced image with the second highest error may be indicative of image distortions created either by the camera or in the scanning process.

In general, this method of investigating elevations has promise for identifying differences in the structure of shorebird habitat. Care should be taken to find a number of GCPs at a site that are visible in all the photos used in a study. Given a larger quantity of quality GCPs as well as the necessary photos and camera calibration reports, comparisons between formerly used and currently used nesting cites could be made.

Figures

Figure 1: Western Snowy Plovers, a small threatened shorebird dependent on high quality beach habitat at Coal Oil Point Reserve (Coal Oil Point Reserve 2005).

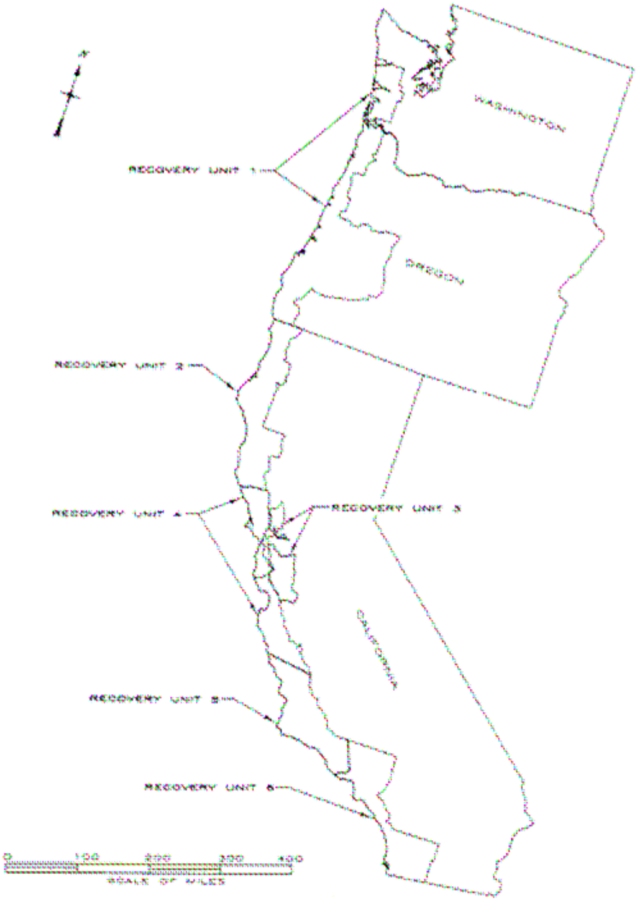

Figure 2: Habitat range of Western Snowy Plovers in the United States. Their range extends south to Bajia Magdalena, on the west coast of Mexico. The recovery units depicted above are defined by the U.S. Fish and Wildlife Service. Coal Oil Point falls in recovery unit 9, east of Point Conception (image from U.S. Fish and Wildlife Service 2001, Appendix A, p. A-2).

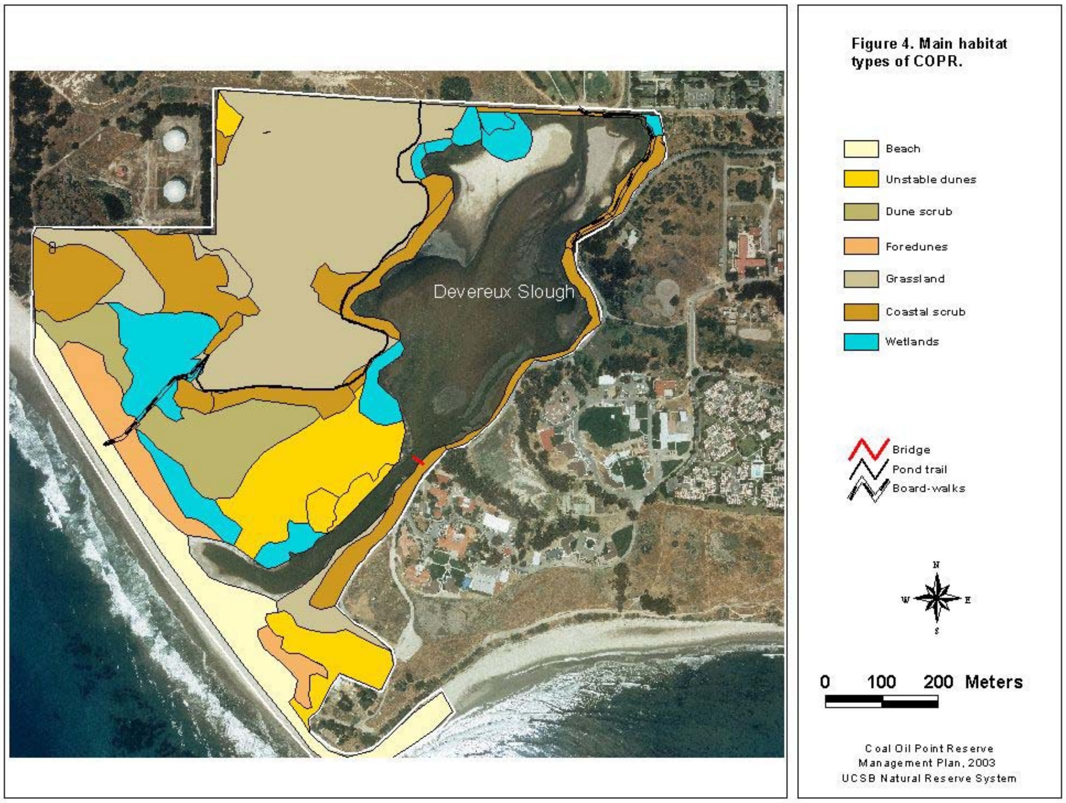

Figure 3: Coal Oil Point Reserve habitat types (Coal Oil Point Reserve 2005)

Figure 4: Location of ground control points shown on a georeferenced photo from 1997.

Figure 5: High water line is visible in the above image (a portion of the georeferenced 2001 photo) as the change in color from the bright white sand to the yellow colored sand. The grey sand shows the current wave swash area. By adjusting the brightness and contrast of the images, these features can be clarified.

Figure 6: Transects overlaying the beach area polygon and referenced photo for 2001. For clarity, the transect pieces are named for the features they overlay. Transects 1 and 45 mark the northwest and southeast boundary used to digitize the perimeter of the beach.

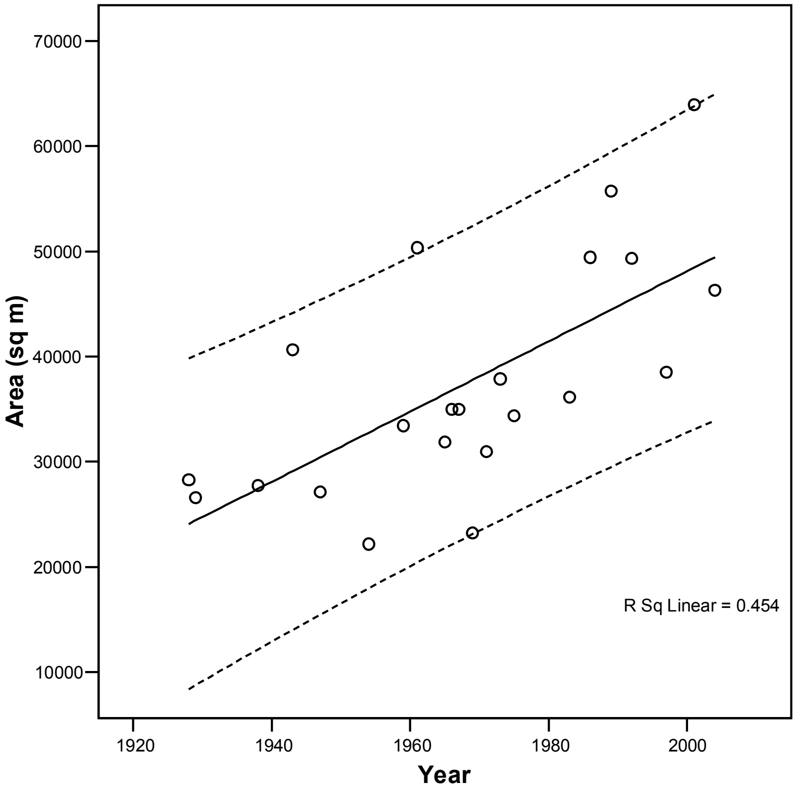

Figure 7: Linear regression of beach area and year (represented above by a solid line). The slope of the line is 333.906 m^2 per year. The dashed line represents the 95% confidence interval.

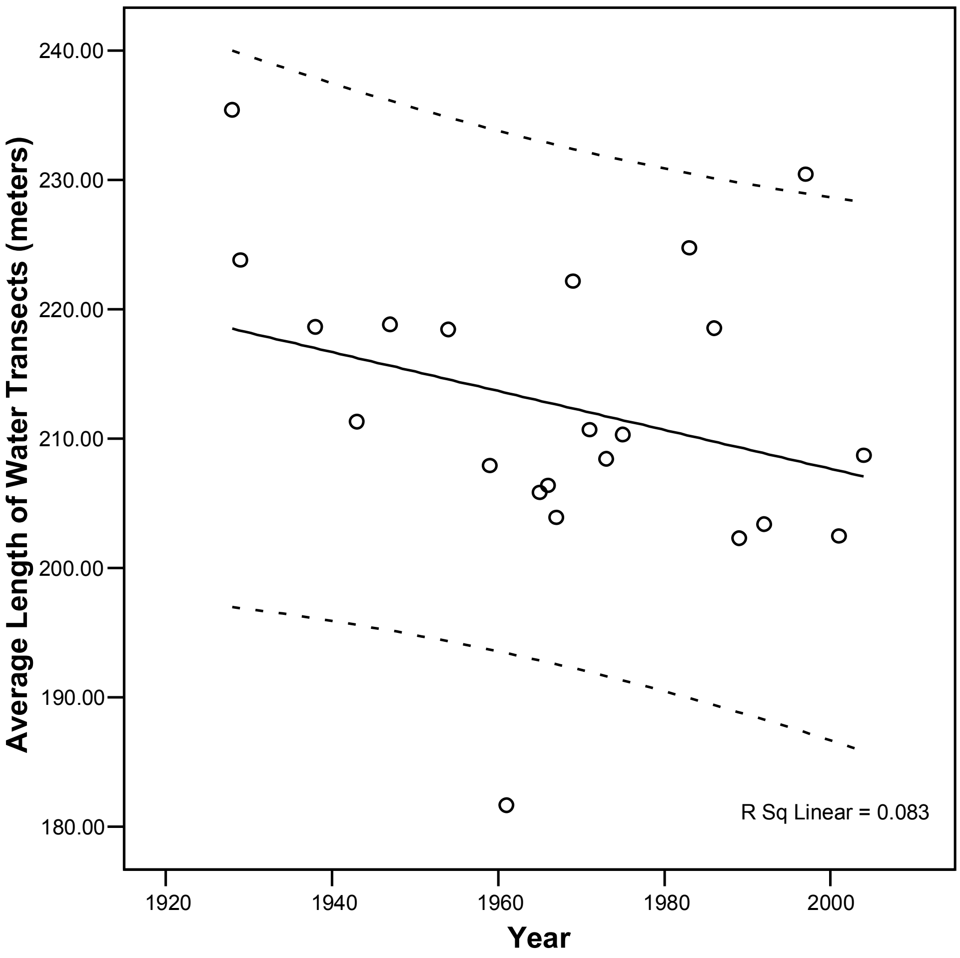

Figure 8: Linear regression of water transects and year (represented above by a solid line). The slope of the line is -0.150 m^2 per year. The dashed line represents the 95% confidence interval.

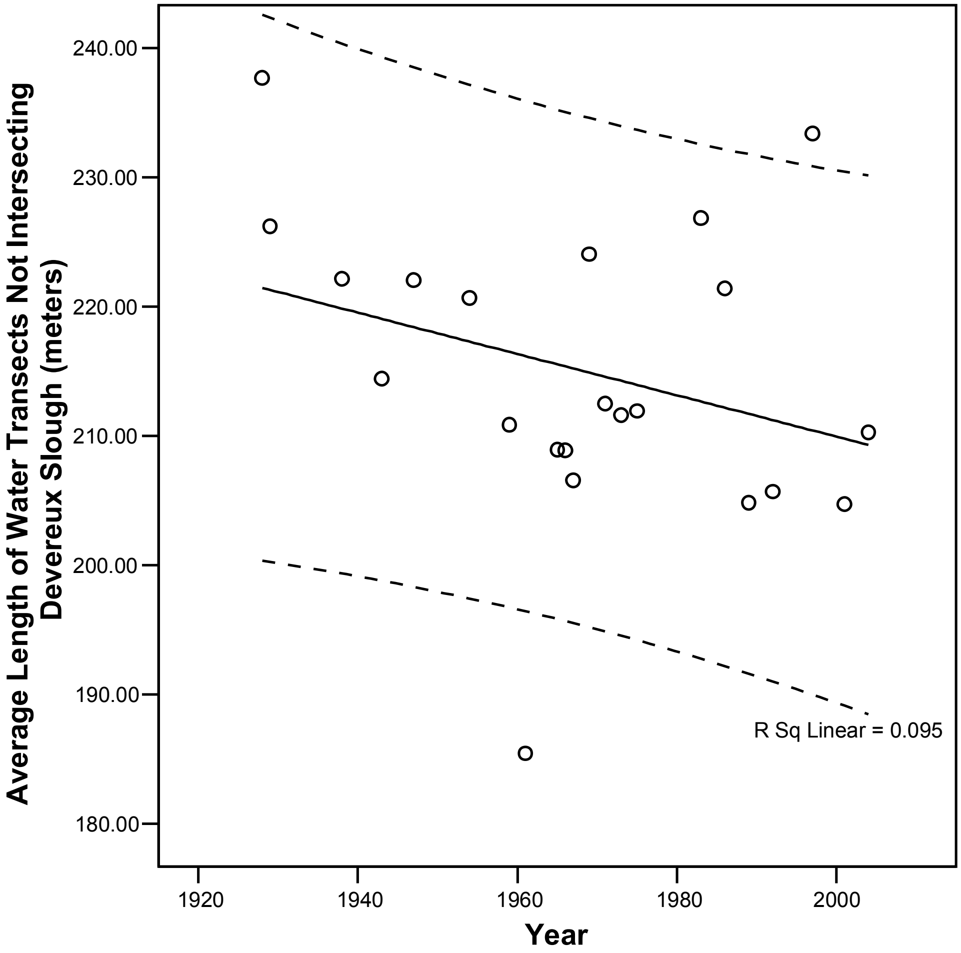

Figure 9: Linear regression of water transects not intersecting Devereux Slough and year (represented above by a solid line). The slope of the line is -0.160 m^2 per year. The dashed line represents the 95% confidence interval.

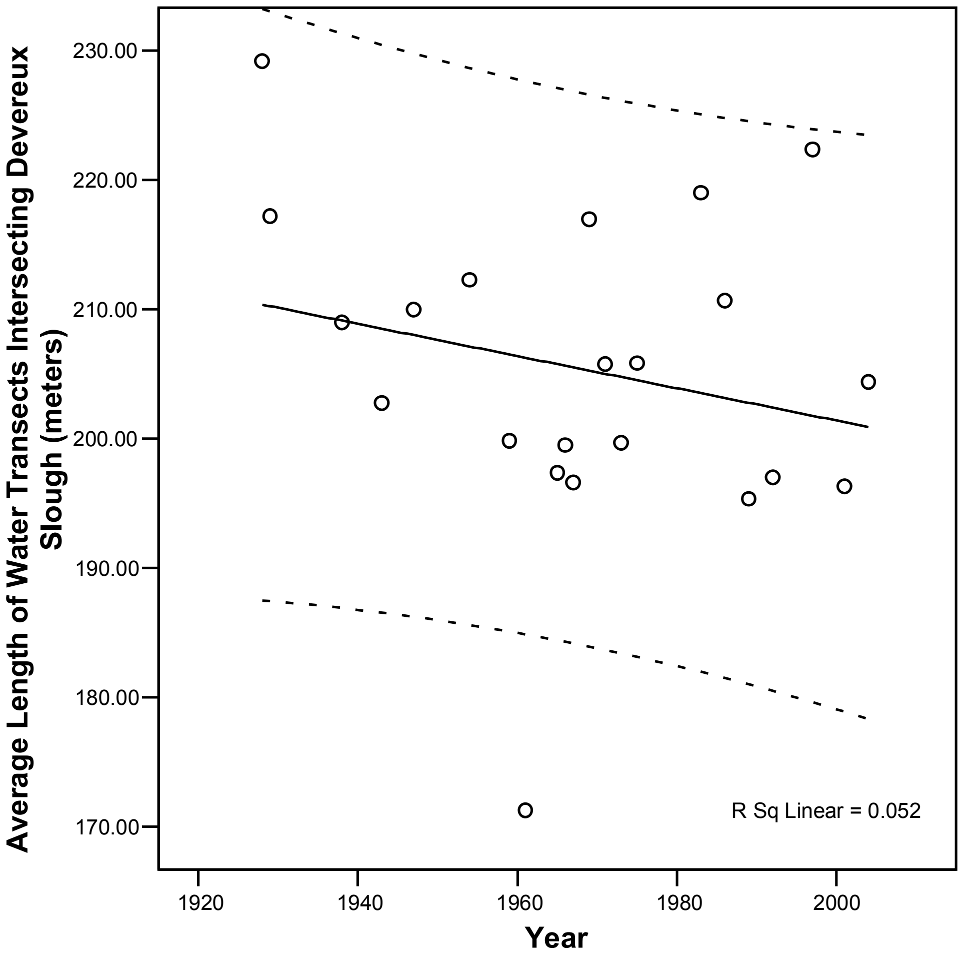

Figure 10: Linear regression of water transects that intersect Devereux Slough and year (represented above by a solid line). The slope of the line is -0.150 m^2 per year. The dashed line represents the 95% confidence interval.

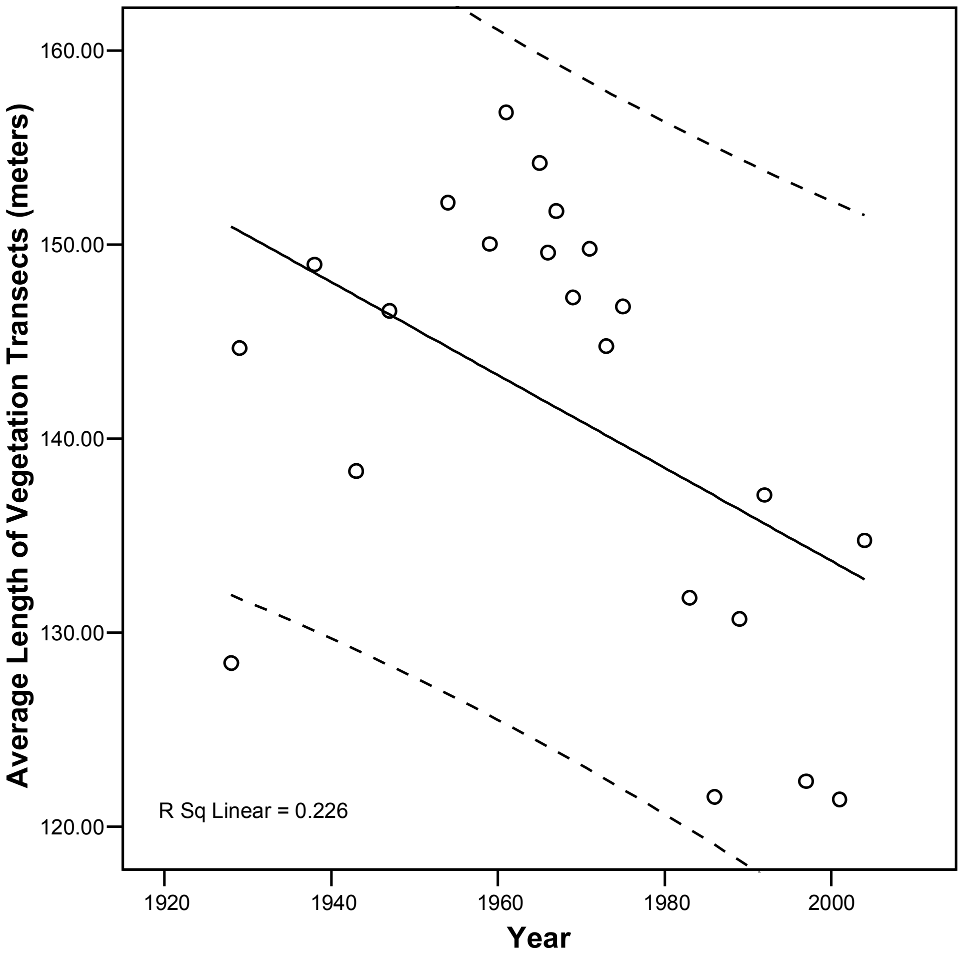

Figure 11: Linear regression of vegetation transects and year (represented above by a solid line). The slope of the line is 0.239 m^2 per year. The dashed line represents the 95% confidence interval.

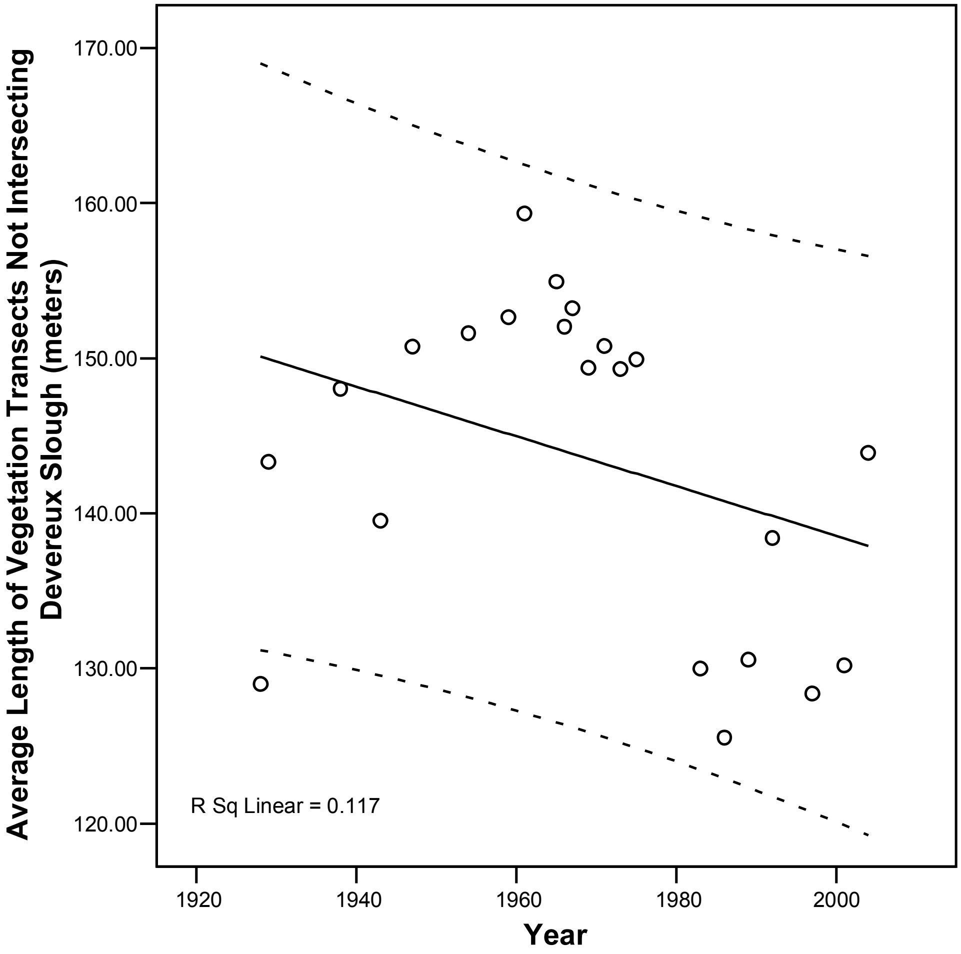

Figure 12: Linear regression of vegetation transects not intersecting Devereux Slough and year (represented above by a solid line). The slope of the line is -0.160 m^2 per year. The dashed line represents the 95% confidence interval.

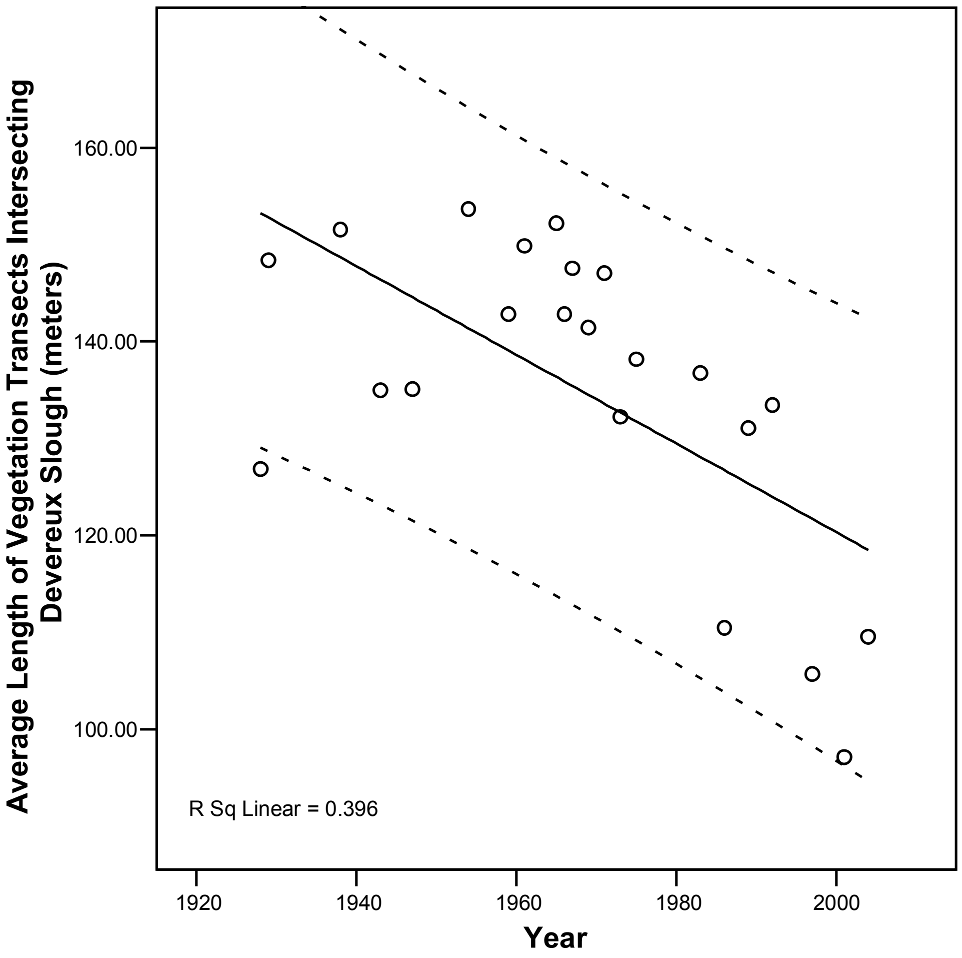

Figure 13: Linear regression of vegetation transects intersecting Devereux Slough and year (represented above by a solid line). The slope of the line is -0.457 m^2 per year. The dashed line represents the 95% confidence interval.

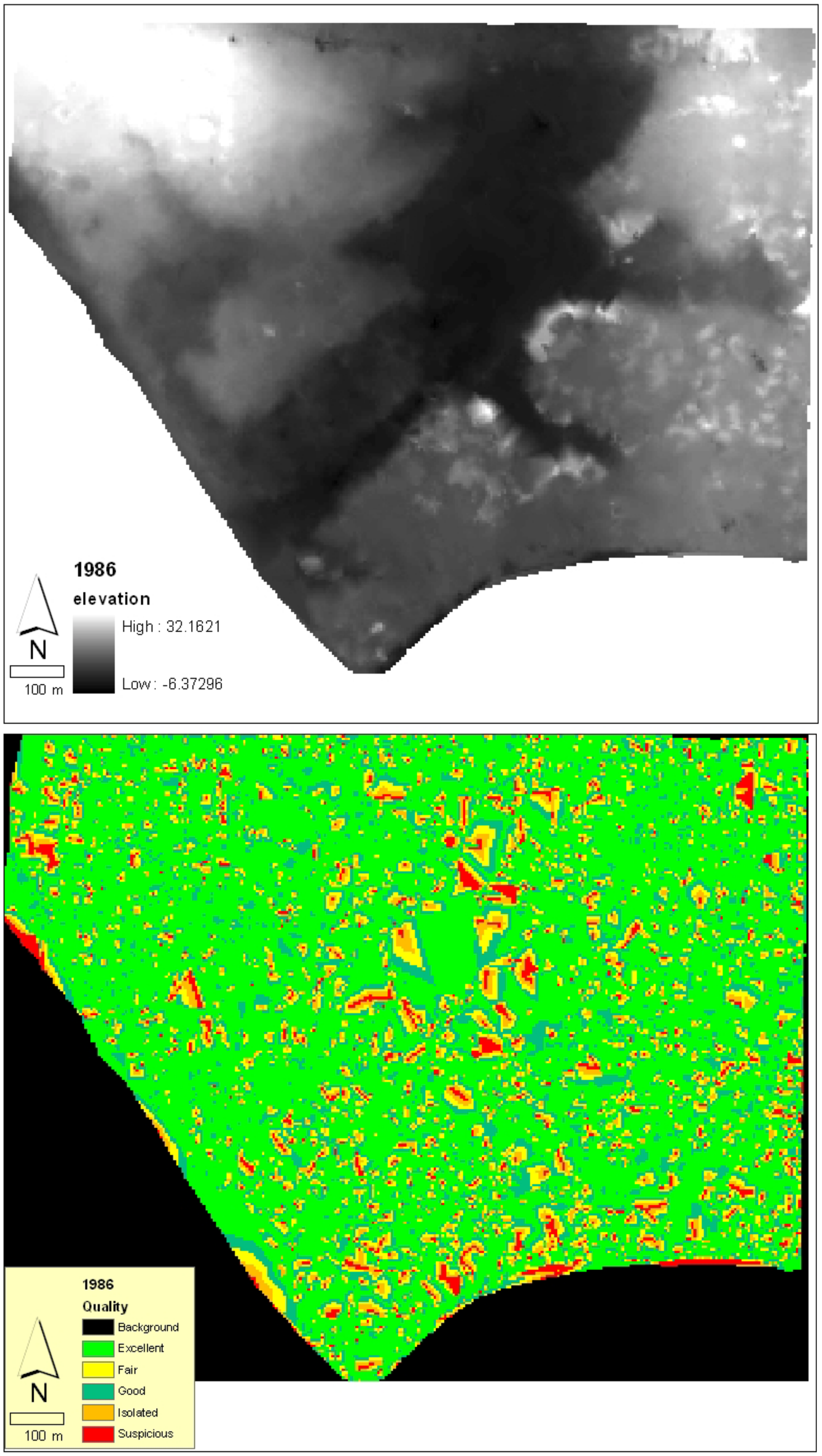

Figure 14: 1986 DEM (top) and quality grid (bottom).

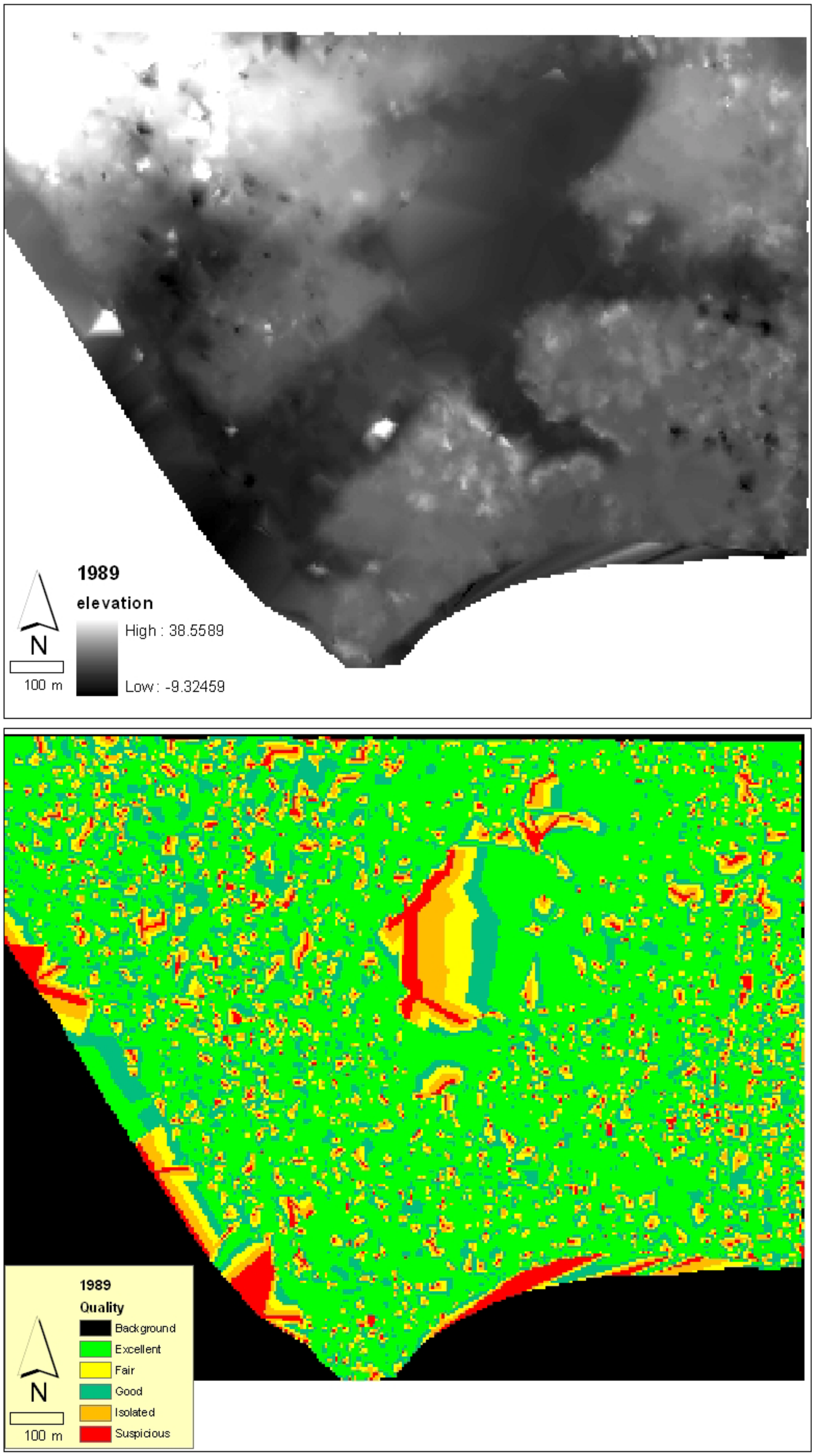

Figure 15: 1989 DEM (top) and quality grid (bottom).

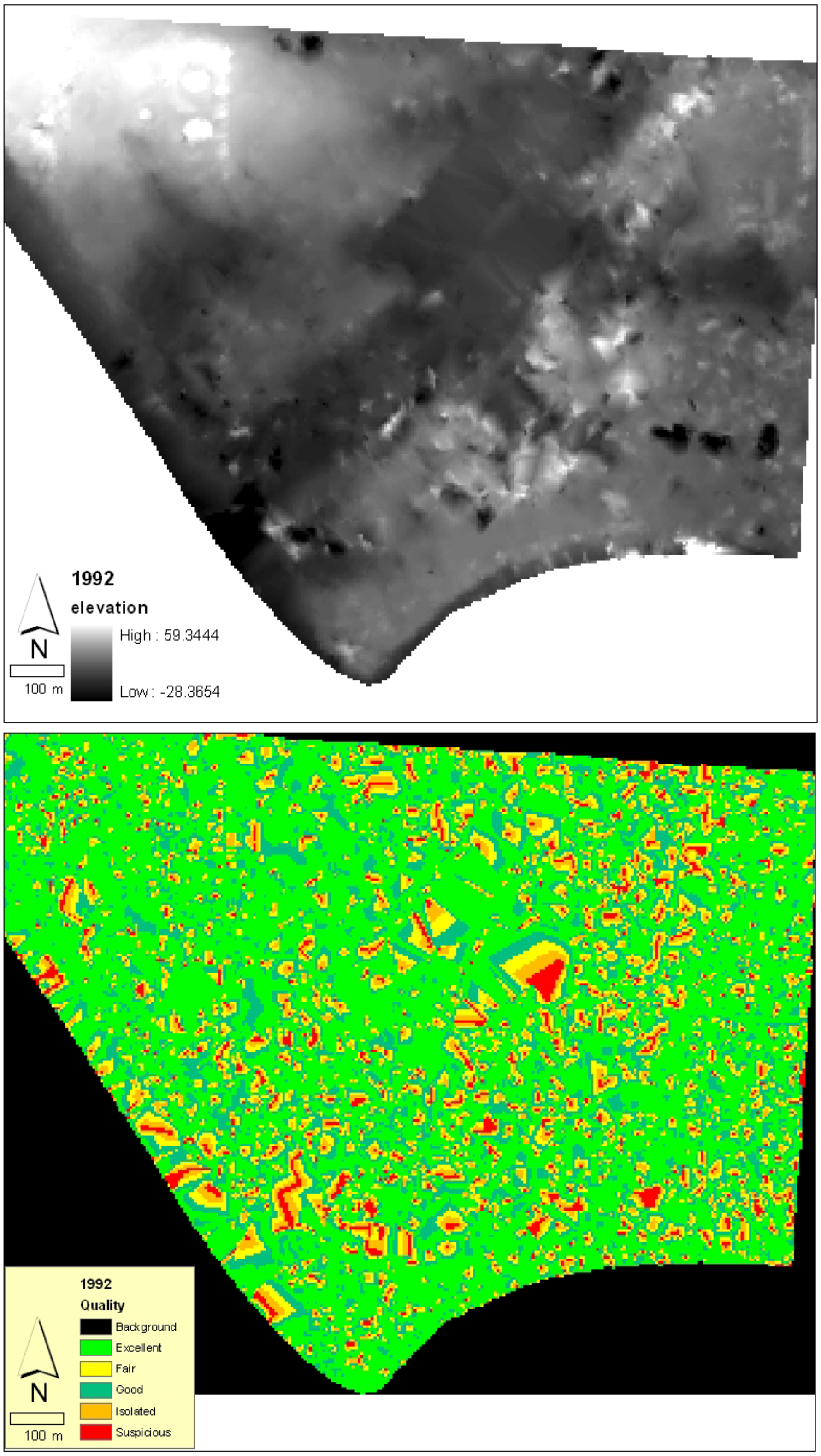

Figure 16: 1992 DEM (top) and quality grid (bottom).

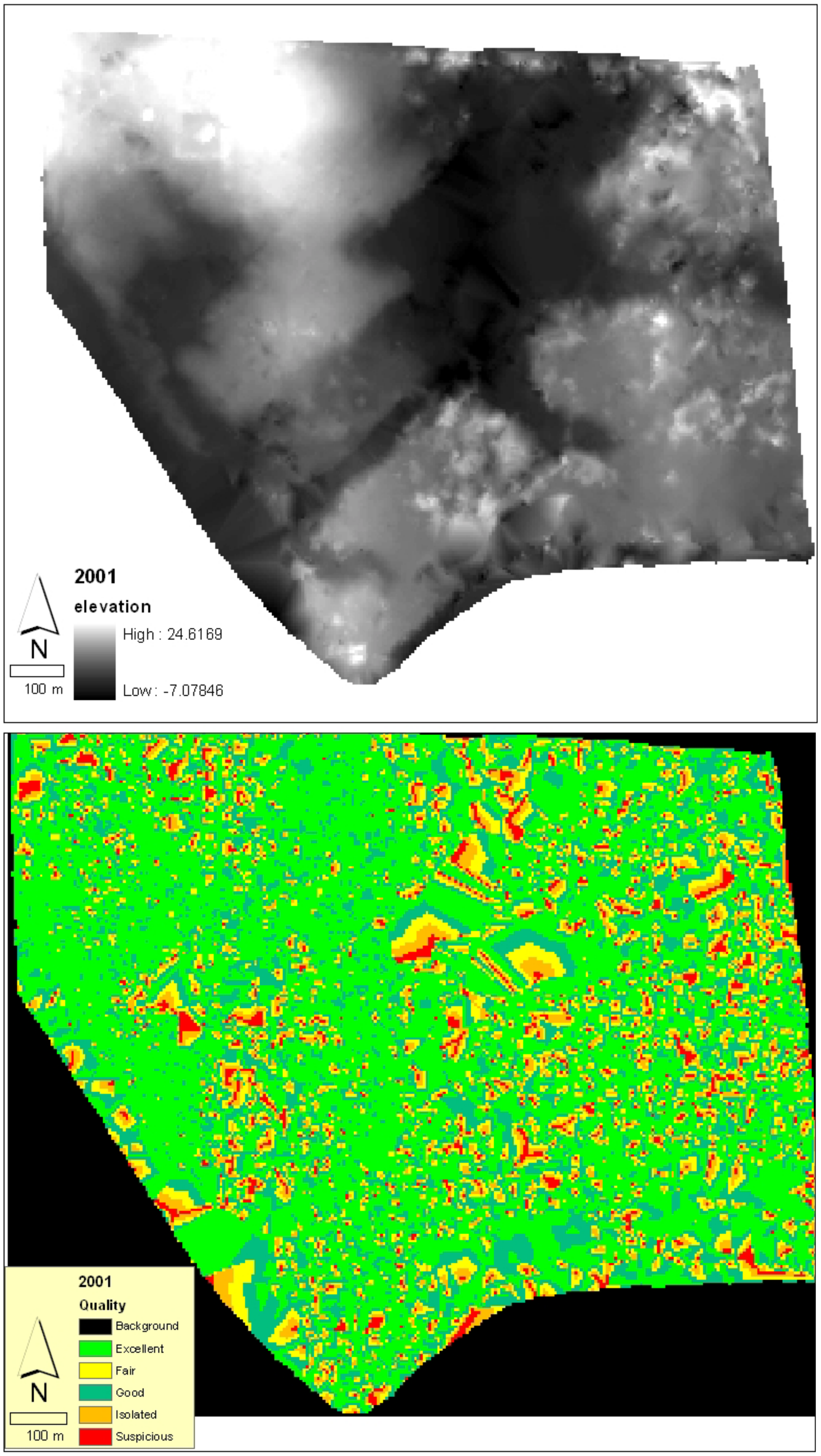

Figure 17: 2001 DEM (top) and quality grid (bottom).

Tables

Table 1: Aerial photograph film and flight information.

Flight Date	Flight Name	Frame	Scale	Film	Photo Selected
1928	c-307a	72	1:18000	black & white	•
1928	c-307a	73	1:18000	black & white	
1929	c-430	A4	1:24000	black & white	•
1938	c-4950 SE	186	1:24000	black & white	
1938	c-4950 SE	187	1:24000	black & white	•
9/22/1943	BTM-1943	5B-02	1:20000	black & white	
9/22/1943	BTM-1943	5B-03	1:20000	black & white	•
8/16/1947	GS-EM	3-68	1:24000	black & white	
8/16/1947	GS-EM	3-69	1:24000	black & white	•
5/4/1954	CM	1-76	1:14400	black & white	
5/4/1954	CM	1-77	1:14400	black & white	•
8/21/1959	HA-FN	5	1:12000	black & white	
8/21/1959	HA-FN	6	1:12000	black & white	•
7/5/1961	BTM-1961	7BB-81	1:20000	black & white	•
7/5/1961	BTM-1961	7BB-82	1:20000	black & white	
6/9/1965	hb-dr	84	1:24000	black & white	
6/9/1965	hb-dr	85	1:24000	black & white	•
9/23/1966	hb-iu	134	1:12000	black & white	•
9/23/1966	hb-iu	135	1:12000	black & white	
5/14/1967	btm-1967	1HH-28	1:20000	black & white	•
5/14/1967	btm-1968	1HH-28	1:20000	black & white	
9/2/1969	an-am	31	1:24000	black & white	
9/2/1969	an-am	32	1:24000	black & white	•
6/1/1971	hb-sj	20	1:12000	black & white	•
6/1/1971	hb-sj	21	1:12000	black & white	
6/1/1971	hb-sj	22	1:12000	black & white	
8/23/1973	hb-wl	48	1:12000	black & white	
8/23/1973	hb-wl	49	1:12000	black & white	•
7/29/1975	TG-7500C	36-5	1:24000	black & white	
7/29/1975	TG-7500C	36-6	1:24000	black & white	•
10/26/1983	pw-sb-5	6	1:24000	color	
10/26/1983	pw-sb-5	7	1:24000	color	•
10/31/1986	pw-sb-6	8	1:24000	color	
10/31/1986	pw-sb-6	9	1:24000	color	•
5/22/1989	pw-sb-7	12	1:24000	color	
5/22/1989	pw-sb-7	13	1:24000	color	•
6/14/1992	pw-sb-8	10	1:24000	color	•
6/14/1992	pw-sb-8	9	1:24000	color	
6/6/1997	pw-sb-10	13	1:24000	color	•
6/6/1997	pw-sb-10	14	1:24000	color	
9/25/2001	ccc-bqk-c	72 - 15	1:12000	color	
9/25/2001	ccc-bqk-c	72 - 16	1:12000	color	•
9/1/2004	Airphoto USA	-	-	color	•

Table 2: Error and referencing information for georeferenced photos.

Year	Referenced To	Control Point Error			Cell Size (m^2)
		X	Y	Total	
1928	1983 photo	0.0252	0.0252	0.0316	0.9589
1929	1983 photo	0.0145	0.0127	0.0192	1.0000
1938	1983 photo	0.0054	0.0060	0.0081	1.0000
1943	1983 photo	0.0063	0.0079	0.0101	1.0000
1947	1983 photo	0.0060	0.0110	0.0125	1.0000
1954	1983 photo	0.0081	0.0157	0.0177	0.6296
1959	1983 photo	0.0135	0.0150	0.0202	0.5458
1961	1983 photo	0.0084	0.0120	0.0146	0.8922
1965	1983 photo	0.0026	0.0044	0.0052	1.0000
1966	1983 photo	0.0065	0.0086	0.0108	0.5401
1967	1983 photo	0.0048	0.0048	0.0067	0.9814
1969	1983 photo	0.0047	0.0047	0.0060	1.0000
1971	1983 photo	0.0137	0.0087	0.0162	0.5292
1973	1983 photo	0.0046	0.0068	0.0082	0.5542
1975	1983 photo	0.0054	0.0039	0.0066	1.0000
1983	GCPs	0.0046	0.0063	0.0078	1.0000
1986	GCPs	0.0040	0.0053	0.0066	1.0000
1989	GCPs	0.0024	0.0055	0.0060	1.0000
1992	GCPs	0.0178	0.0158	0.0238	1.0000
1997	GCPs	0.0035	0.0033	0.0048	1.0000
2001	GCPs	0.0129	0.0095	0.0160	0.5564
2004	GCPs	0.1746	0.2621	0.3150	0.3065

Table 3: Error and cell size for orthorectified photos.

Year	Flight	Frame	Output Cell Size	RMSE
1986	pw-sb-6	9	1.0	0.9569
1989	pw-sb-7	12	1.0	0.5639
1992	pw-sb-8	10	1.0	0.7347
2001	ccc-bqk-c	72-16	0.6	0.7234

Table 4: Error for digital elevation models.

Year	Output Cell Size	RMSE
1986	1.0	0.9569
1989	1.0	0.5639
1992	1.0	0.7347
2001	0.6	0.7234

Table 5: Area and width measured on orthorectified images, non-orthorectified referenced images, and the percent difference between the two measurements. The measured difference was calculated by subtracting the measurement made on the referenced image from the measurement made on the orthorectified image.

Transect Type	Year	Orthorectified Image Measurement (meters)	Referenced Image Measurement (meters)	Measurement Difference (meters)	% Difference
Water					
	1986	222.08	218.54	-3.54	-1.59%
	1989	201.12	202.30	1.18	0.59%
	1992	214.01	203.37	-10.64	-4.97%
	2001	205.65	202.47	-3.18	-1.55%
Beach					
	1986	55.91	55.78	-0.13	-0.24%
	1989	63.14	62.86	-0.28	-0.44%
	1992	55.21	55.39	0.18	0.32%
	2001	71.81	71.99	0.18	0.25%
Vegetation					
	1986	117.86	121.53	3.67	3.12%
	1989	131.59	130.69	-0.90	-0.69%
	1992	126.63	137.09	10.46	8.26%
	2001	118.38	121.39	3.01	2.54%
Area	1986	49351.53	49440.40	88.87	0.0018
	1989	55920.14	55739.65	-180.49	-0.0032
	1992	49138.56	49325.57	187.00	0.0038
	2001	63815.53	63962.71	147.18	0.0023

Table 6: Gain per year in area and width. These were determined with a linear regression with the year. Slough transects are numbered 25 to 36 (see Figure 6 for locations and numbers).

	Gain per Year	R	R^2	Probability the Gain per Year is Zero
Area	33.906 m^2	0.674	0.454	0.001
Beach Transects				
all	0.390 m	0.683	0.467	0.00
Water Transects				
all	-0.150 m	-0.287	0.083	0.195
without slough	-0.160 m	-0.309	0.095	0.162
only slough	-0.125 m	-0.227	0.052	0.309
Vegetation Transects				
all	0.239 m	0.475	0.226	0.025
without slough	-0.160 m	-0.342	0.117	0.119
only slough	-0.457 m	-0.630	0.396	0.002

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