



Assessing Long-term Variations in Vegetation and Land Mass within Coastal Areas on Cape Cod

2009 Report

Natural Resource Report NPS/NER/NRR—2015/899



ON THE COVER

Hatches Harbor, Cape Cod National Seashore
Photograph by: Robin Baranowski

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January 2015

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Johnson, S., P. Godfrey. 2015. Assessing long-term variations in vegetation and land mass within coastal areas on Cape Cod: 2009 report. Natural Resource Report NPS/NER/NRR—2015/899. National Park Service, Fort Collins, Colorado.

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Abstract

We present analyses of vegetation and land mass change at selected coastal areas on Cape Cod over a 70-yr period. The purpose of these analyses is to assess the effectiveness of management recommendations made 30 years ago for beaches within the Cape Cod National Seashore by Dr. Paul Godfrey of the National Park Service Cooperative Research Unit. We focused on Coast Guard Beach, Race Point Beach, and Hatches Harbor. These three sites were among the most heavily used beach areas during previous field studies conducted in the 1970's and 1980's evaluating the impacts of visitor use on the natural resources at the National Seashore. We visually assessed and quantified changes in vegetation and land mass using GIS software and aerial photographs. Archived photographs from the original study were also compared with photographs taken again at each site in 2007. Our analyses suggest that recommendations made to the National Park Service to allow these areas to recover by minimizing anthropogenic disturbance and stopping traditional anti-erosion practices were highly successful. These coastal areas appear to be able to overcome degradation naturally and without assistance from natural resource management in a relatively short period of time.

Introduction

Project Background

In 1974, the National Park Service Cooperative Research Unit (NPS-CRU) led by Dr. Paul Godfrey, began ecological studies at the Cape Cod National Seashore, and at other NPS locations along the Eastern seaboard. The focus of their research was to evaluate the effects of visitor use on coastal ecosystems. They collected data on the impacts of off-road vehicles (ORV's) and other human activities, recorded observations regarding natural changes to dune and marsh vegetation, and created extensive photo documentation of site conditions during the study period. Based on his research, Dr. Godfrey and his team provided suggestions to the National Park Service regarding management practices to aid in the recovery of dune and marsh vegetation at several of these sites. Essentially, his advice was to reduce human impacts and allow the vegetation to recover naturally, without attempting to control erosion at the sites.

In 2004, Dr. Godfrey proposed revisiting research sites that were considered to be the most heavily used coastal areas at the time of the original study to assess the effectiveness of the management decisions that had been based largely on his study, three of which are located on Cape Cod - Coast Guard Beach, Race Point Beach, and Hatches Harbor (Fig. 1). NPS provided the funding for this work in 2005; however, due to illness Dr. Godfrey was unable to lead this project, and I was asked to take over as the principal investigator in 2007.

Dr. Godfrey originally planned to revisit each site to collect data on the current state of vegetation and to re-create photographs taken earlier to make comparisons and assess changes in vegetation. In addition, he hoped to properly archive his photographic slides and prints. After I sorted and organized all of Paul's photographs and field notes, I spoke with Ivan Valiela of the Boston University Marine Program and we came to the conclusion that using historic aerial photographs and Geographic Information Systems (GIS) software would be more effective for achieving the goals of the study as it would provide easily quantifiable data on vegetation cover that can then be used to show trends and changes over time. Because these photographic records extend back 30 years or more prior to the NPS-CRU studies, we also hoped to examine long term recovery patterns and reactions of vegetation communities to both natural and anthropogenic impacts. Therefore, I incorporated GIS analyses into this project to complement the limited amount of information that could be obtained from historical photographs and field data for assessing long-term changes at these sites.

Barrier beaches are dynamic and important ecological systems that are naturally disturbed by overwash events. The purpose of this study was to examine how anthropogenic disturbance and resource management techniques influence their natural cycles. The questions that we attempt to answer with this study are: 1) How has the vegetation at barrier beaches responded to human impacts?, 2) How have recovery rates of land mass and vegetation been affected by human impacts?, and 3) What can be concluded from any observed trends regarding management suggestions made by Dr. Godfrey?

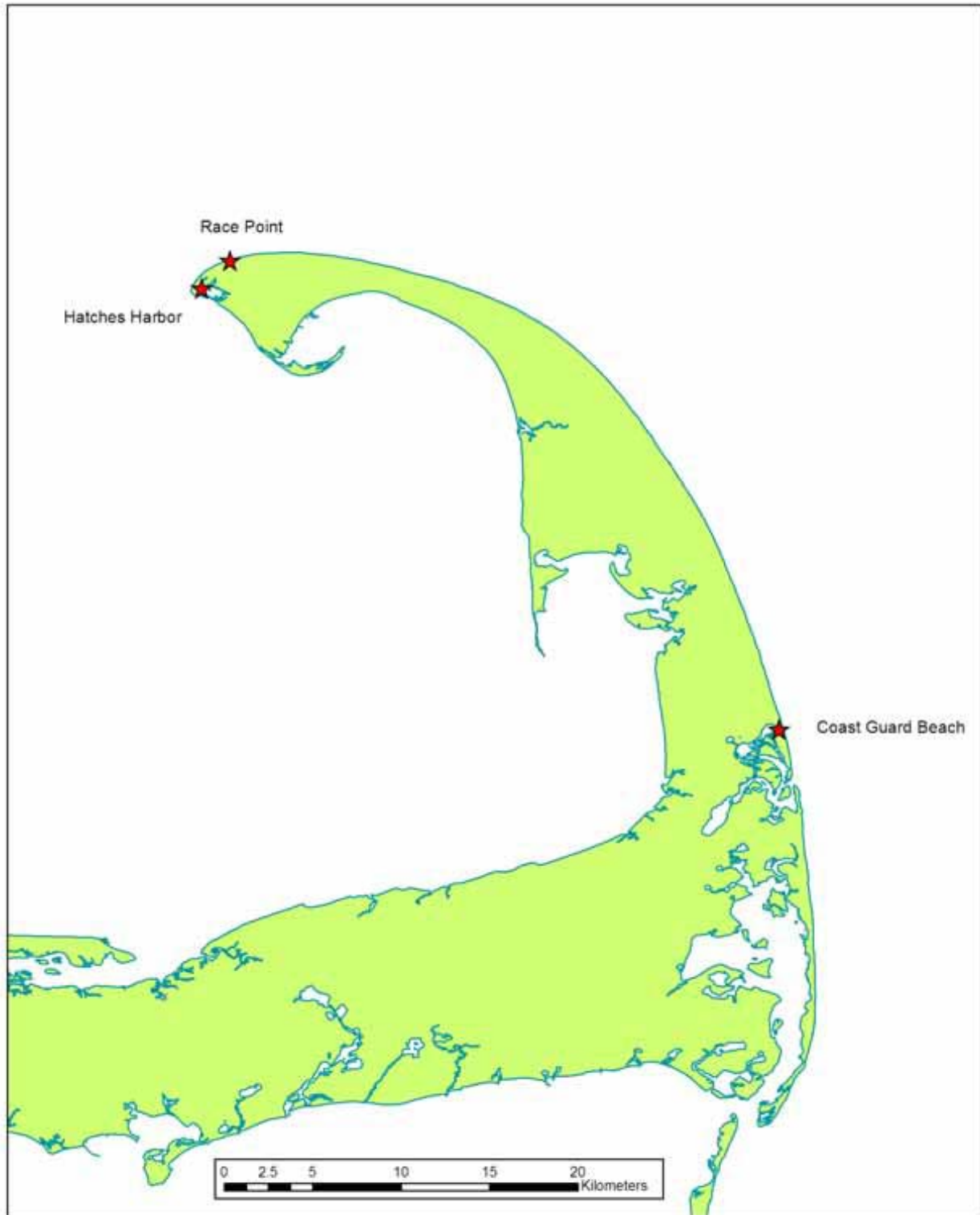


Figure 1. The locations of the three sites on Cape Cod included in this study – Coast Guard Beach, Race Point, and Hatches Harbor.

Geological Processes of Barrier Beaches

The three study sites – Coast Guard Beach, Race Point, and Hatches Harbor - are classified as barrier beaches because they contain structures called “coastal barriers”. Coastal barriers are made of sand, gravel, cobbles, and other sedimentary materials eroded from glacial deposits by ocean waves, storm-driven overwash, tidal currents, sea level rise, and prevailing winds. Coastal barriers are important to coastal areas because they protect bays and marshes from the direct onslaught of the ocean. Cape Cod’s present day coastal barriers were derived from glacial sediments laid down during the last stage of the Pleistocene (the Wisconsin period) around 15,000 years ago; glaciers laid down sediments in the form of moraines and outwash plains. Since that time (thousands of years of the Holocene epoch) the sediments have eroded and been moved around by oceanic forces, continually reforming these barriers. There are three main mechanisms involved with the formation of coastal barriers - erosion due to wave and wind action, deposition due to littoral drift, and deposition due to storm overwashes.

Coastal barriers can take the form of bay barriers, tombolos, spits, hooks, or islands. Coast Guard Beach is a good example of a barrier spit. It is an elongated finger-like extension made of sand and gravel eroded into the sea from the glacial deposits to the north in Eastham and Wellfleet, and moved south by wind-driven wave currents, called littoral drift.

Littoral drift, or long-shore transport, is created when waves strike the beach, and flow back into the sea bringing sand and gravel with them. Each successive wave moves sediment further down the beach. Most waves that approach Cape Cod come from the northeast, especially in the fall, winter, and spring; therefore the sand flow is southward. Waves approaching during the summer, particularly during tropical storms and hurricanes, come from the southeast. These waves move sand northward. Because of these patterns, there are two main areas of sediment deposition occurring from littoral drift on Cape Cod, at the outermost point (Provincetown) and at the elbow (Orleans to Monomoy Island) (Fig. 2).

The second form of deposition comes from overwash events typically associated with storm surges from large storm events. Storm surges can either remove sediment from or deposit sediment along a barrier beach. On Cape Cod, many significant overwash events appear to occur during northeasters. Overwash can be an important source of sediment providing structure for coastal barriers (Kochel and Dolan 1986, Matias et. al. 2009). In addition, overwash is beneficial to coastal ecosystems because fresh sand provides nutrients for dune vegetation. Overall, erosion and deposition are natural, ongoing processes related to coastal barriers and they play important roles in the ecology of these ecosystems.

During the study period there were two major storm events that created significant overwashes at the study sites – the Great Blizzard of 1978 and a second northeaster in 1994. The impacts of these storms are illustrated in our results and discussion of our analyses.

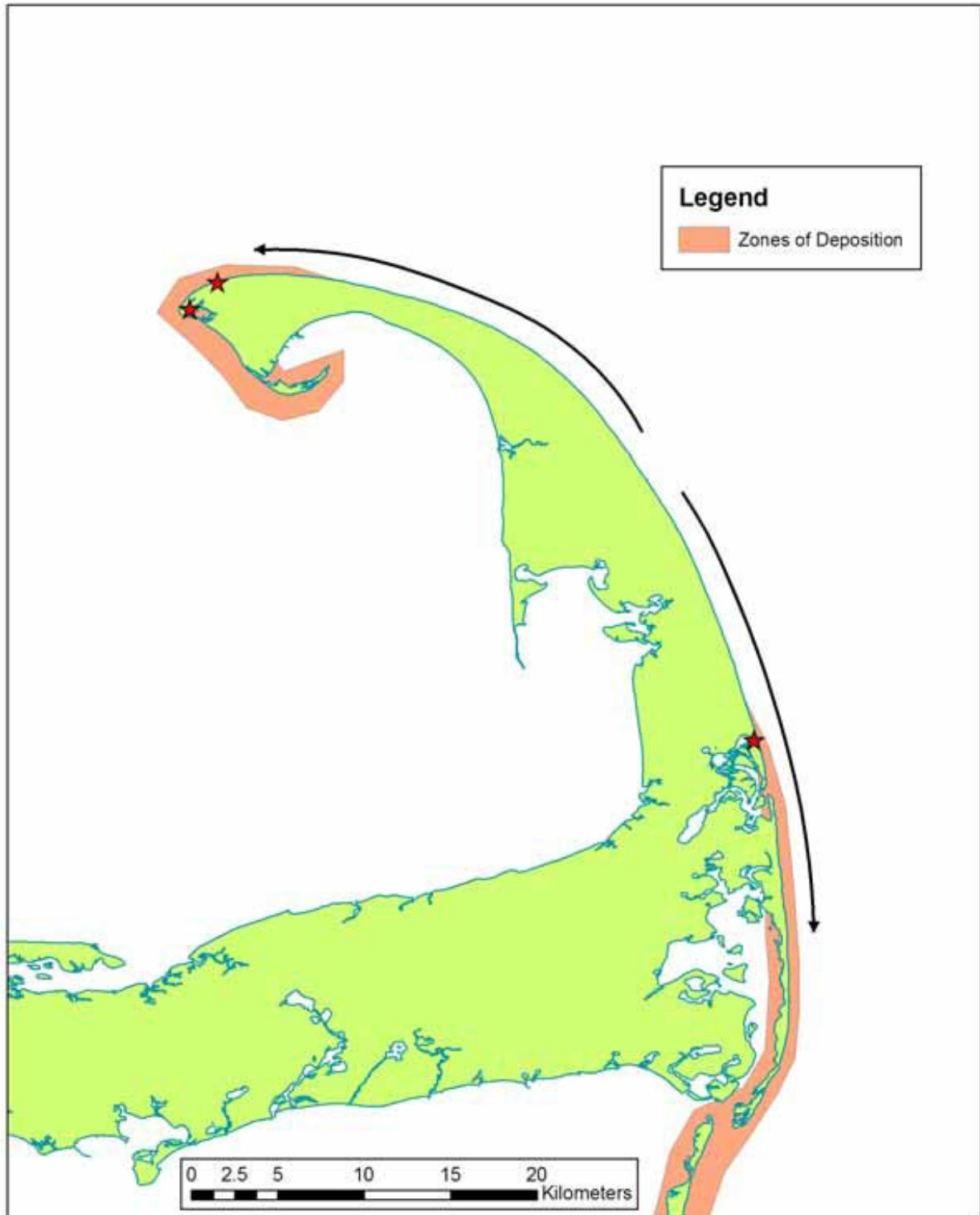


Figure 2. Patterns of littoral drift on Cape Cod resulting in two concentrations of sediment deposition, at the outermost point (Provincetown) and at the elbow (Orleans to Monomoy Island).

Study Areas

Coast Guard Beach

Coast Guard Beach is a very popular beach and recreational area (Fig. 3). During the original NPS-CPU study, visitors in ORVs had easy access to beaches on the entire eastern side of the Seashore for fishing and other activities and to reach private cottages in the dune zone, among them Henry Beston's famous "Outermost House" located near Coast Guard Beach. In addition to beach access, there were ORV trails along the back side of the dunes and over salt marsh edges. These human impacts can be readily seen as linear gaps in the vegetation behind and within the dune zone (Figs. 4-15). Many tracks led directly to overwash passes, and thus made interior areas more prone to storm surges. The installation of a large, paved parking lot on the heavily-used low dunes directly adjacent to the salt marsh edge, also contributed to the vulnerability of this area to surges (Fig. 7).

The obvious impact of these trails and the parking lot led to the selection of this area as a major research site by NPS-CRU in 1974. However, the Great Blizzard of 1978 opened a whole new topic of research – recovery from major overwashes on what had then become a natural beach system. After this storm, Dr. Godfrey recommended that NPS restrict human traffic, both in the form of ORV use and hiking, within the dune vegetation community. All plans by NPS to restore the previous facilities and ORV use were therefore cancelled.



Figure 3. The study area at Coast Guard Beach delineated and marked with red lines over the 2005 Mass GIS orthophoto.

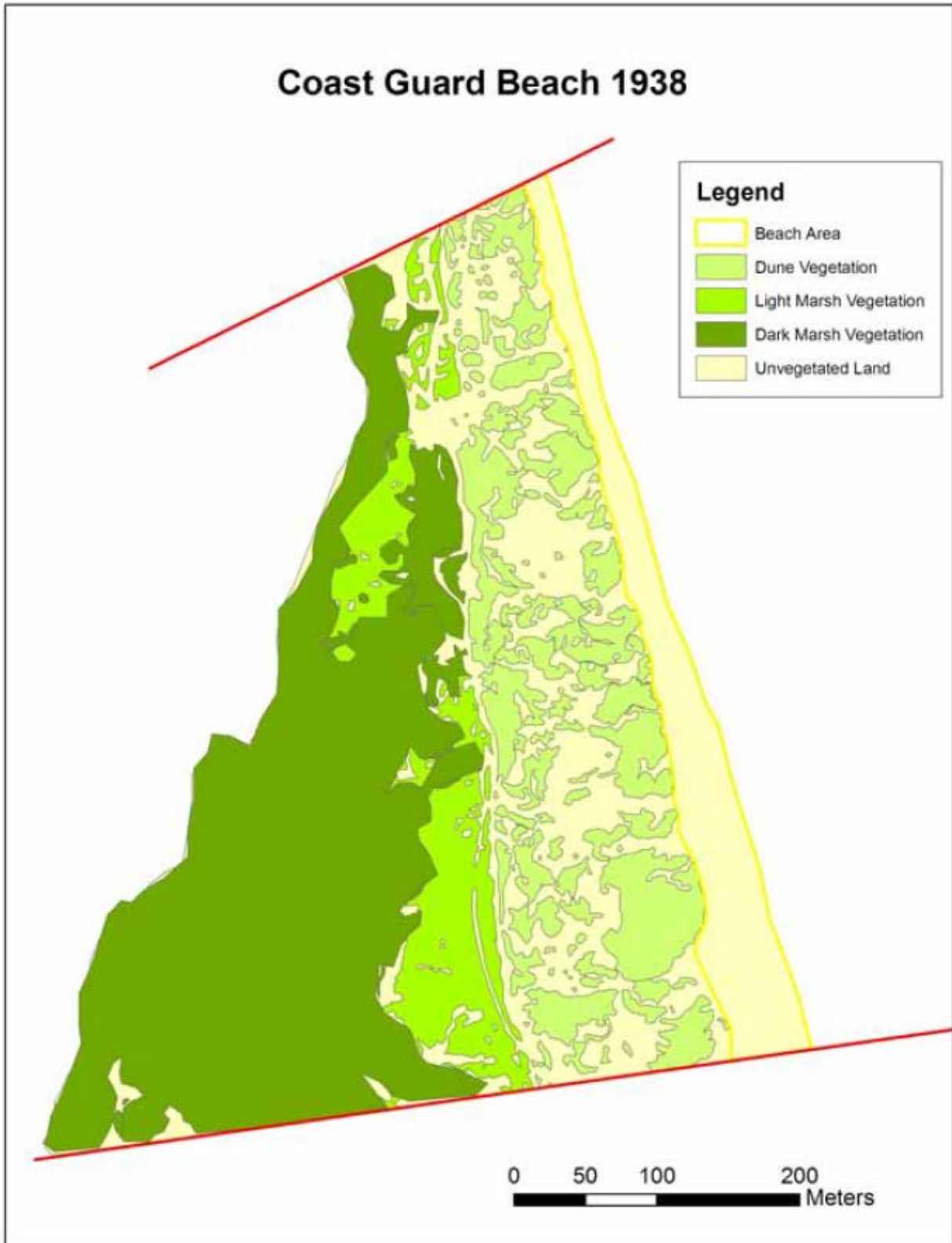


Figure 4. Polygons representing beach area, vegetation cover, and unvegetated land at CoastGuard Beach in 1938.

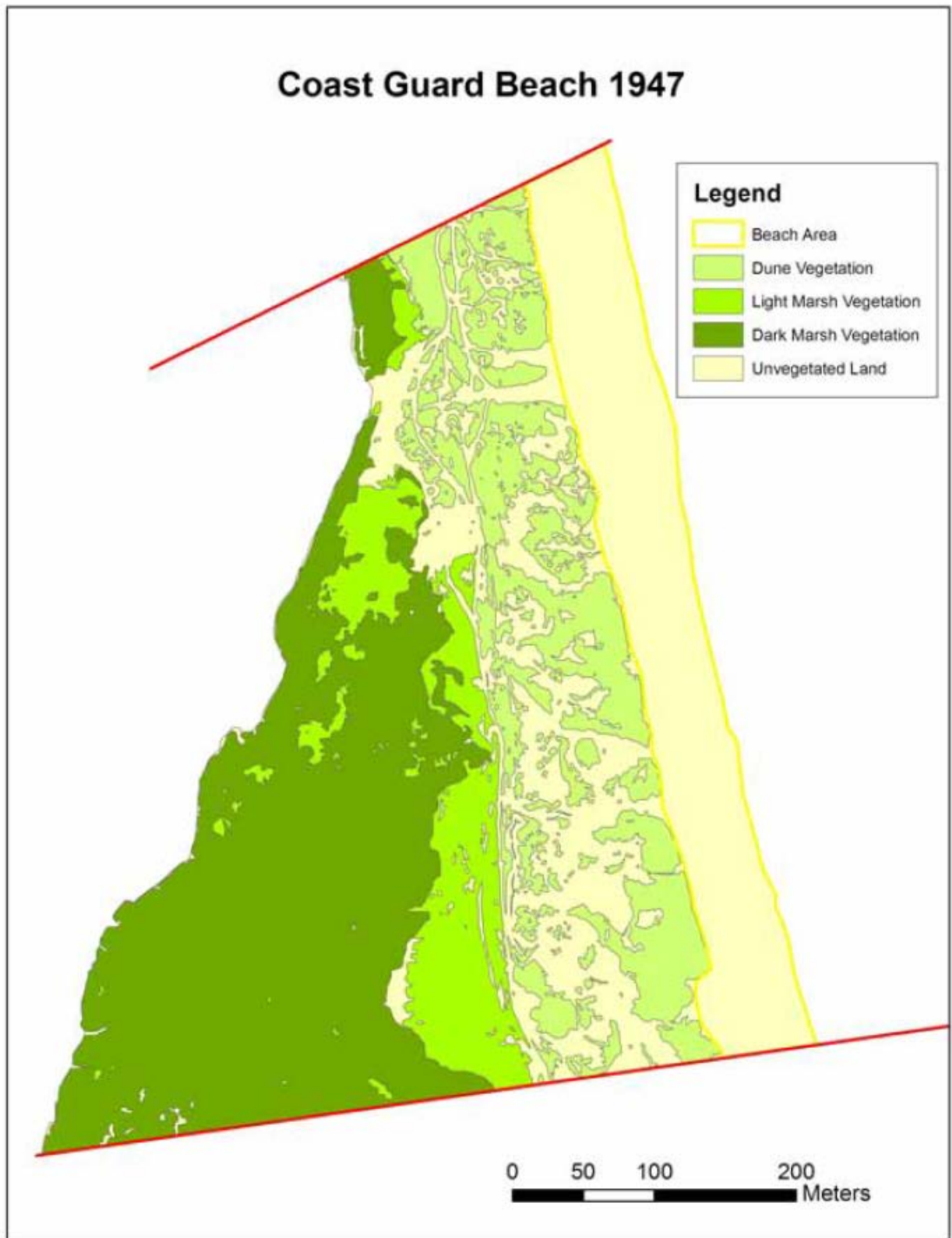


Figure 5. Polygons representing beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 1947.

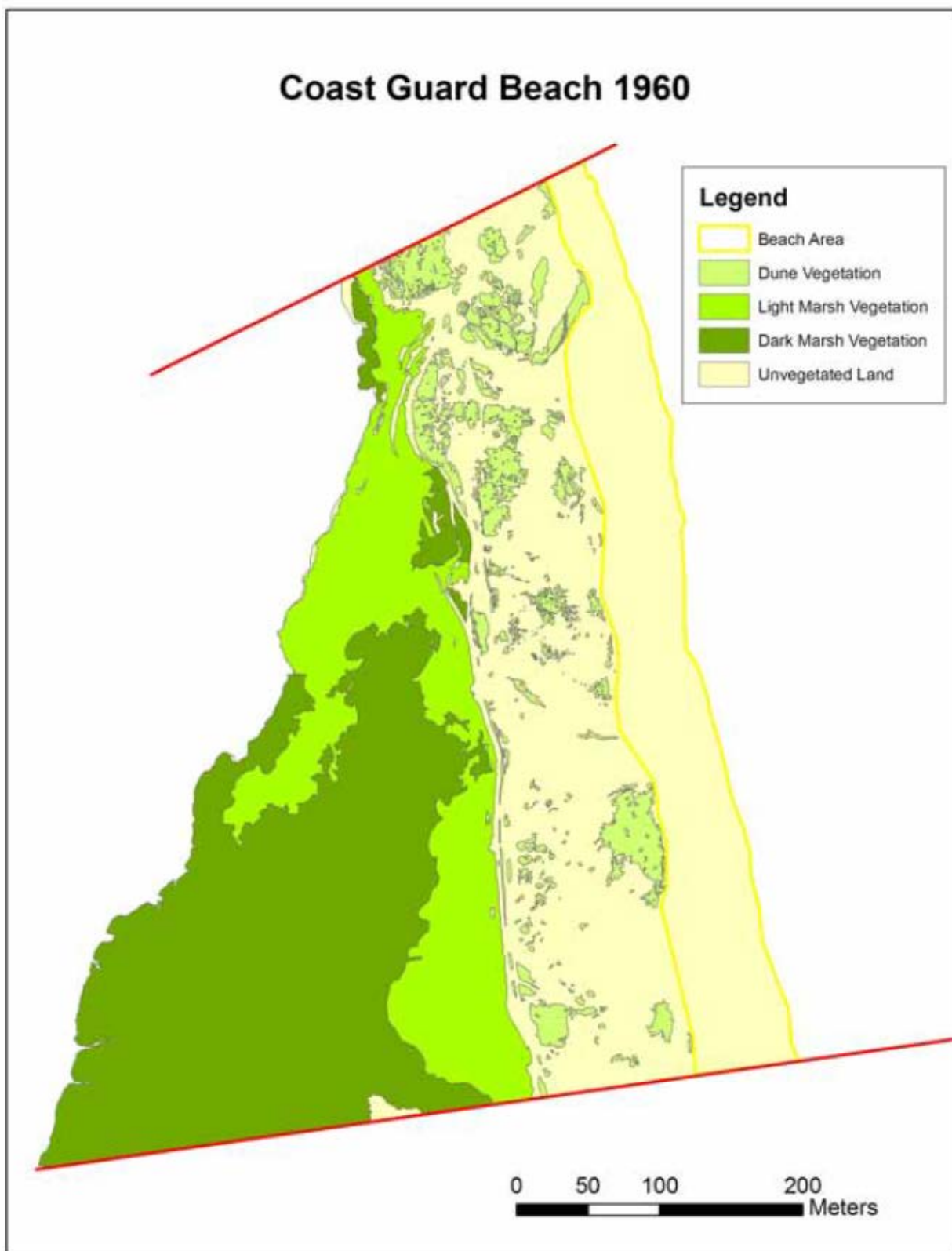


Figure 6. Polygons representing beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 1960.

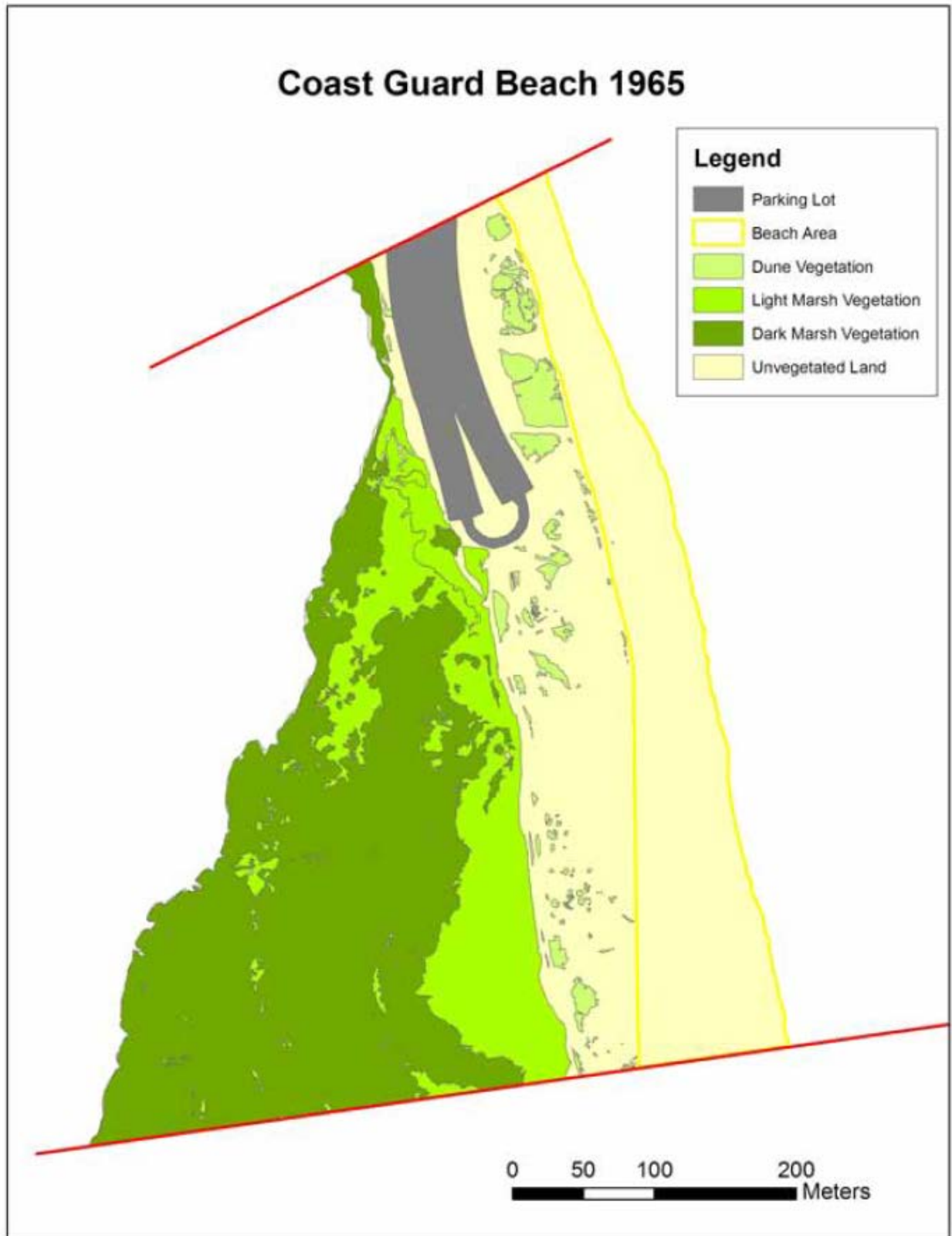


Figure 7. Polygons representing the parking lot, beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 1965.

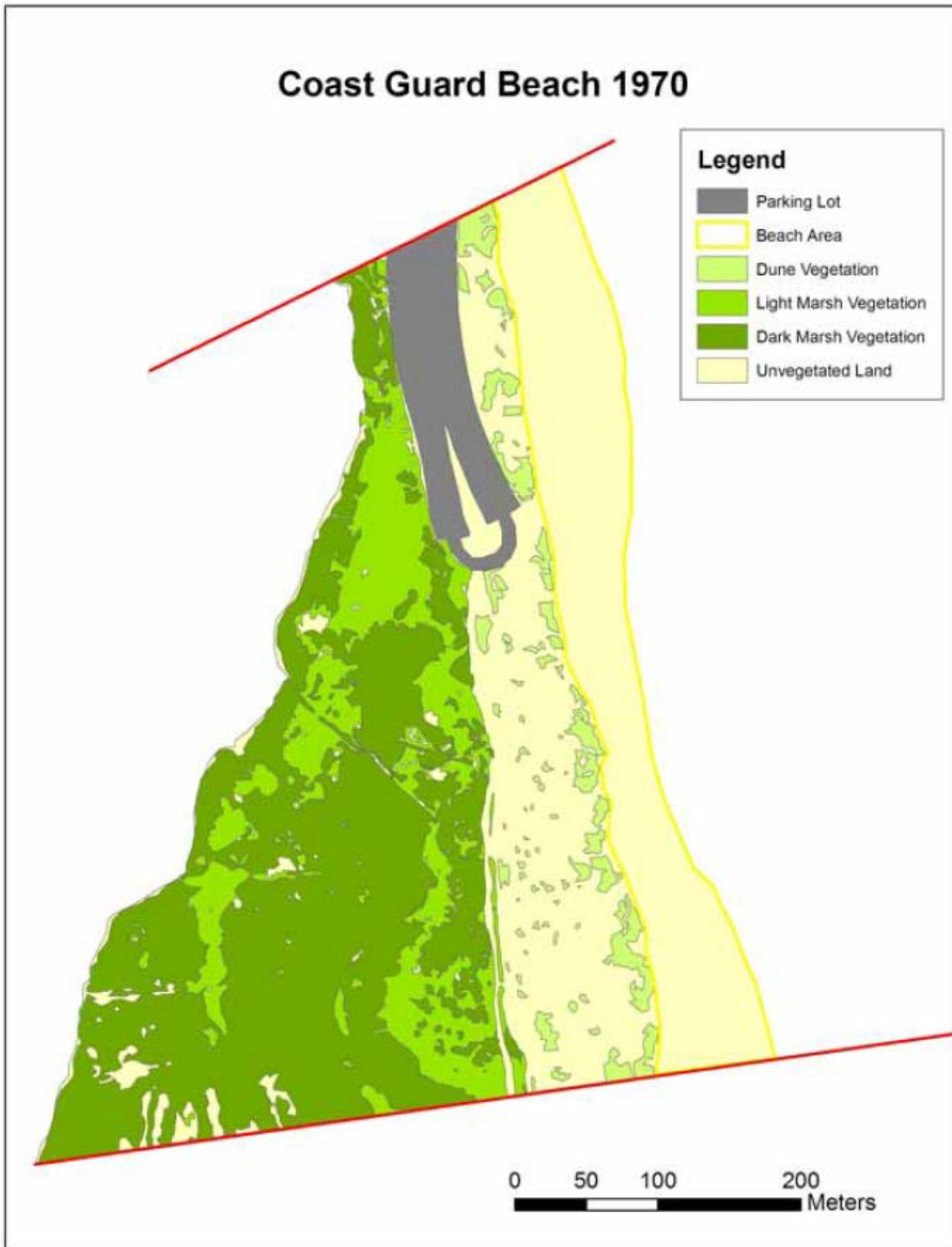


Figure 8. Polygons representing the parking lot, beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 1970.



Figure 9. Polygons representing the parking lot, beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 1974.

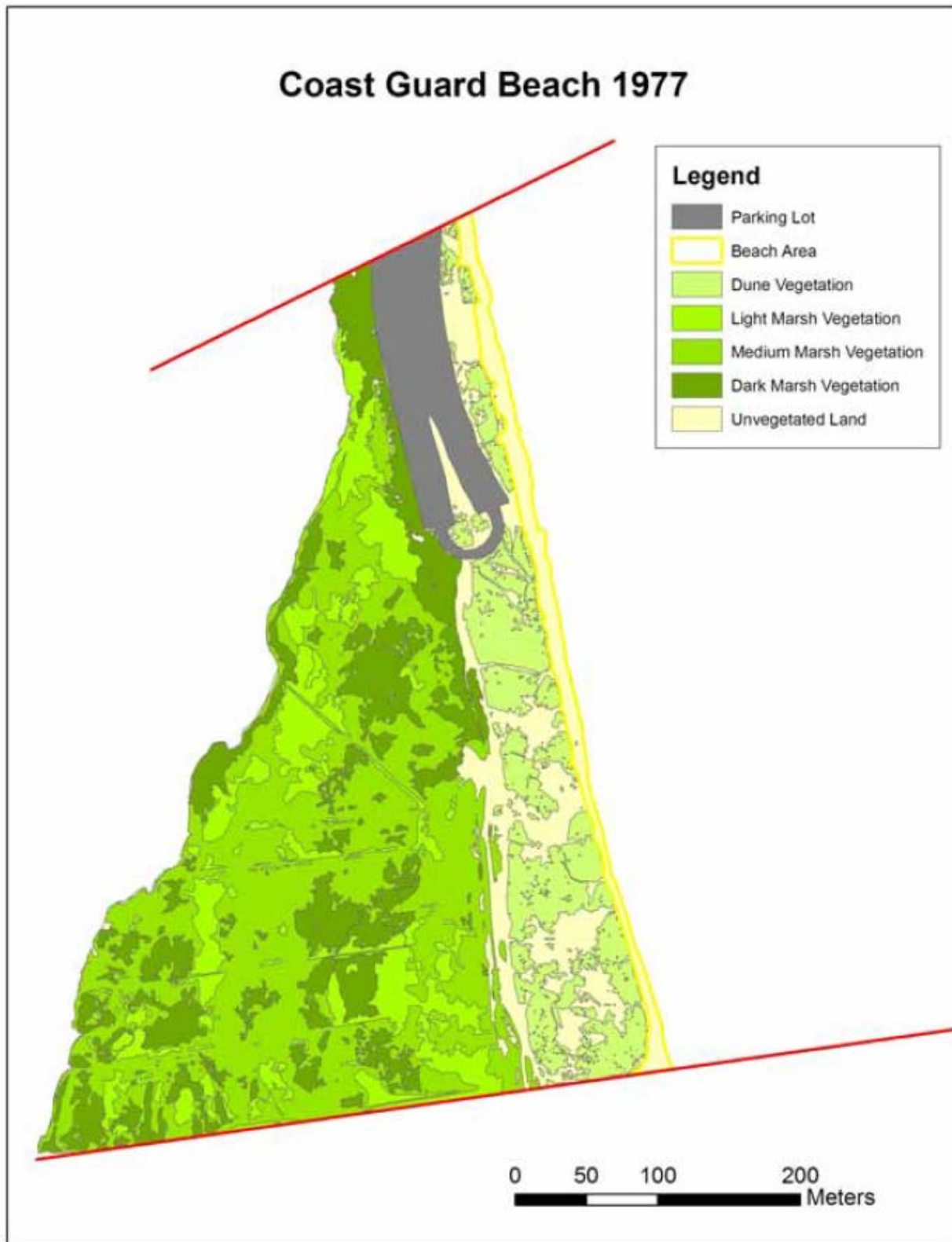


Figure 10. Polygons representing the parking lot, beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 1977.

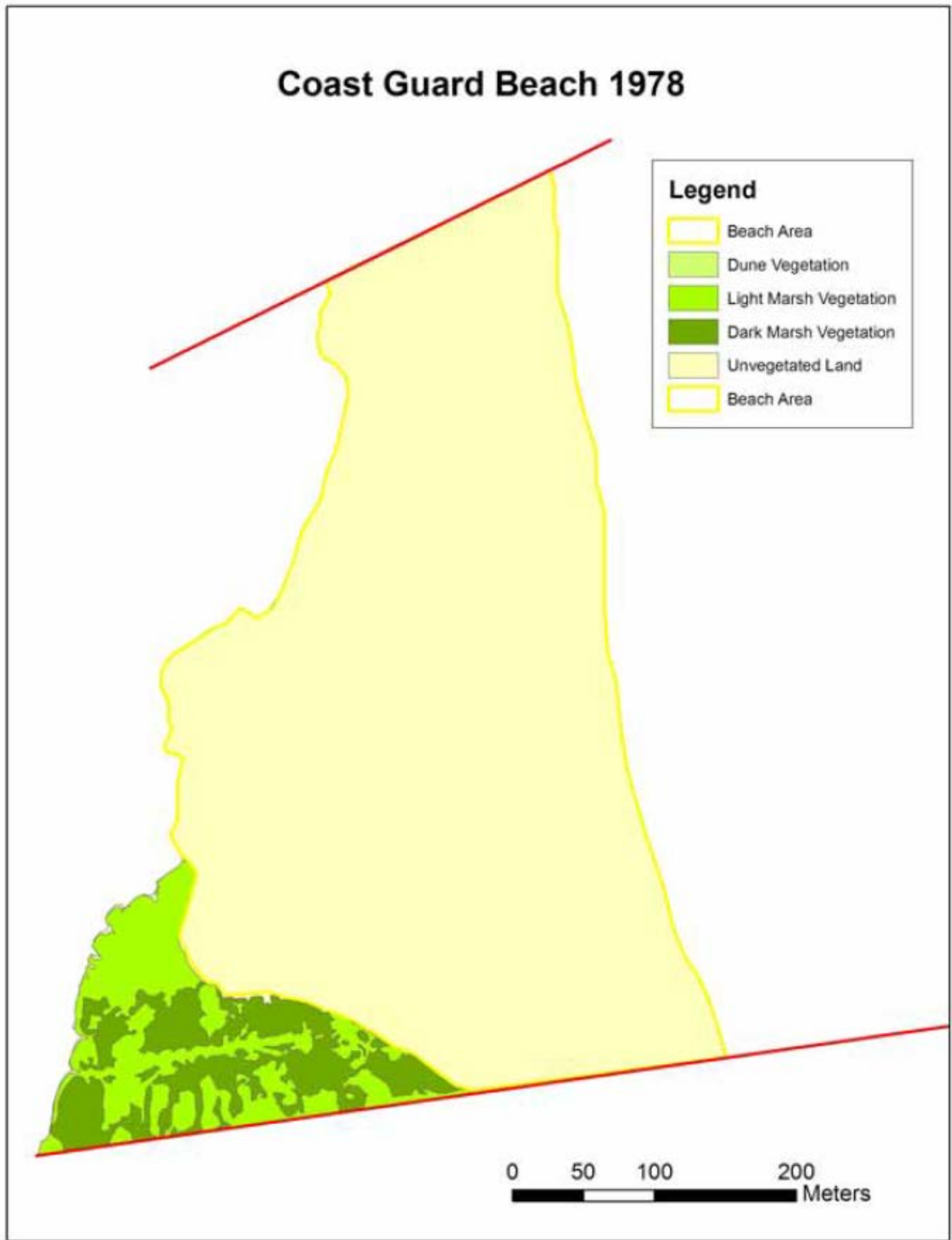


Figure 11. Polygons representing beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 1978.

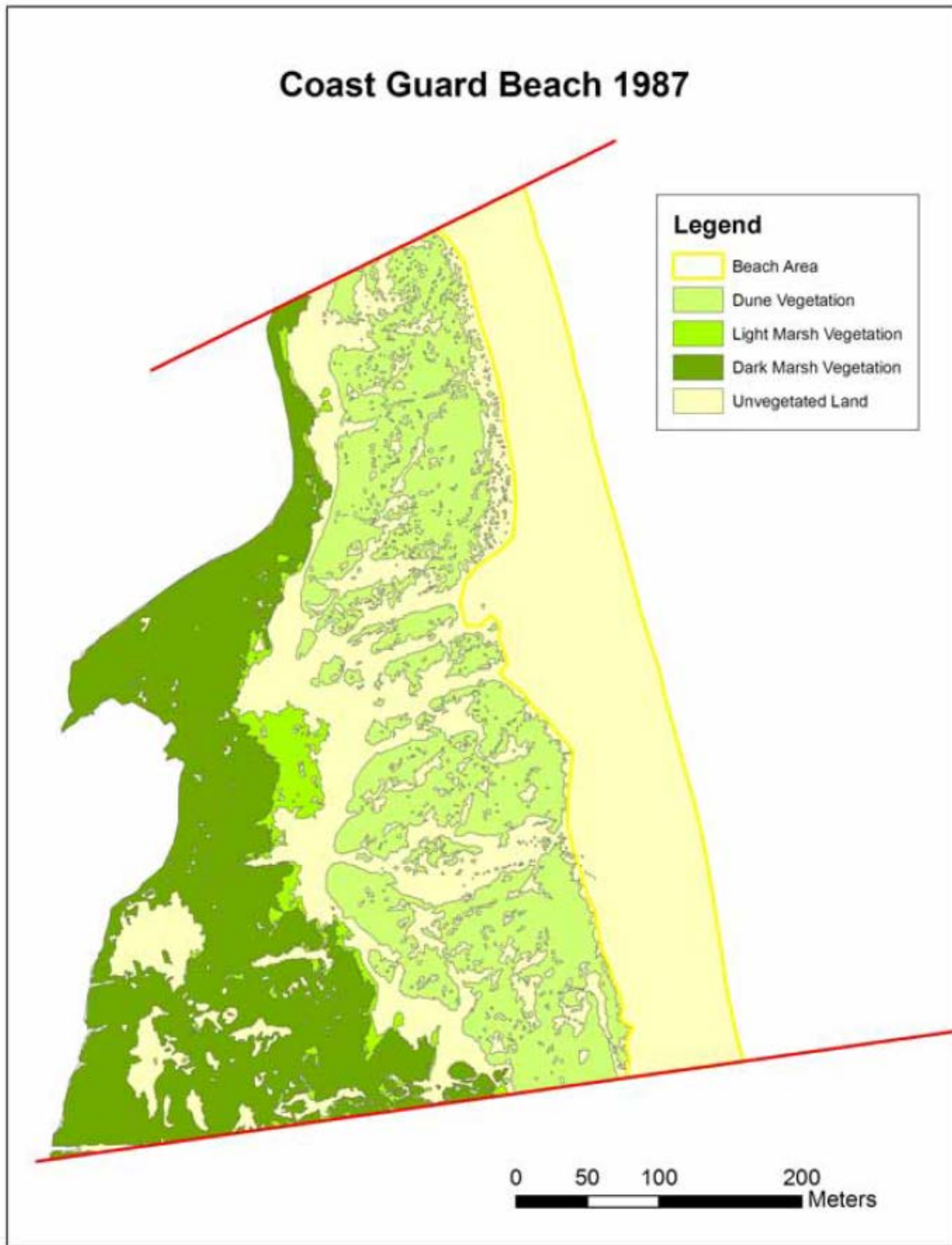


Figure 12. Polygons representing beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 1987.

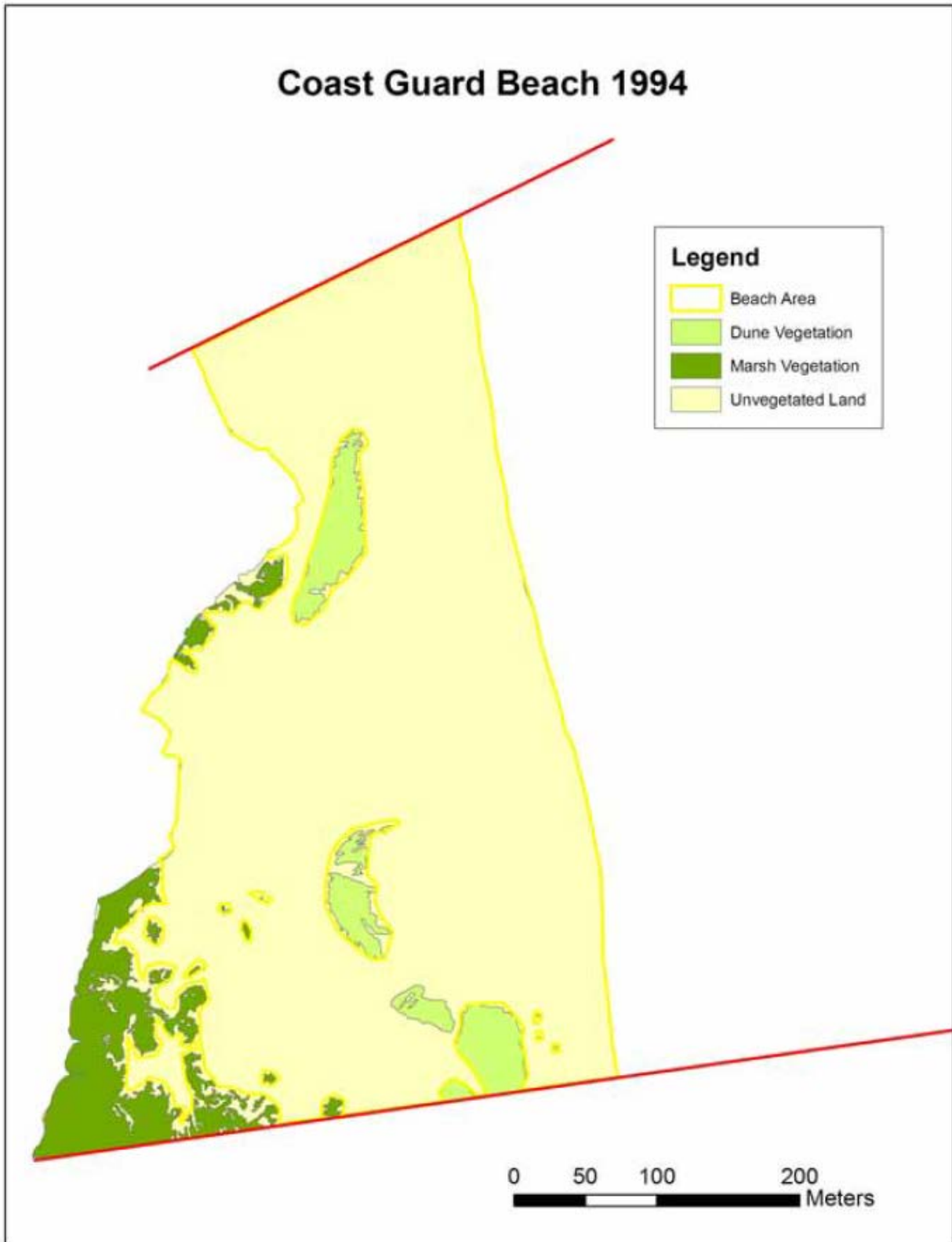


Figure 13. Polygons representing beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 1994.

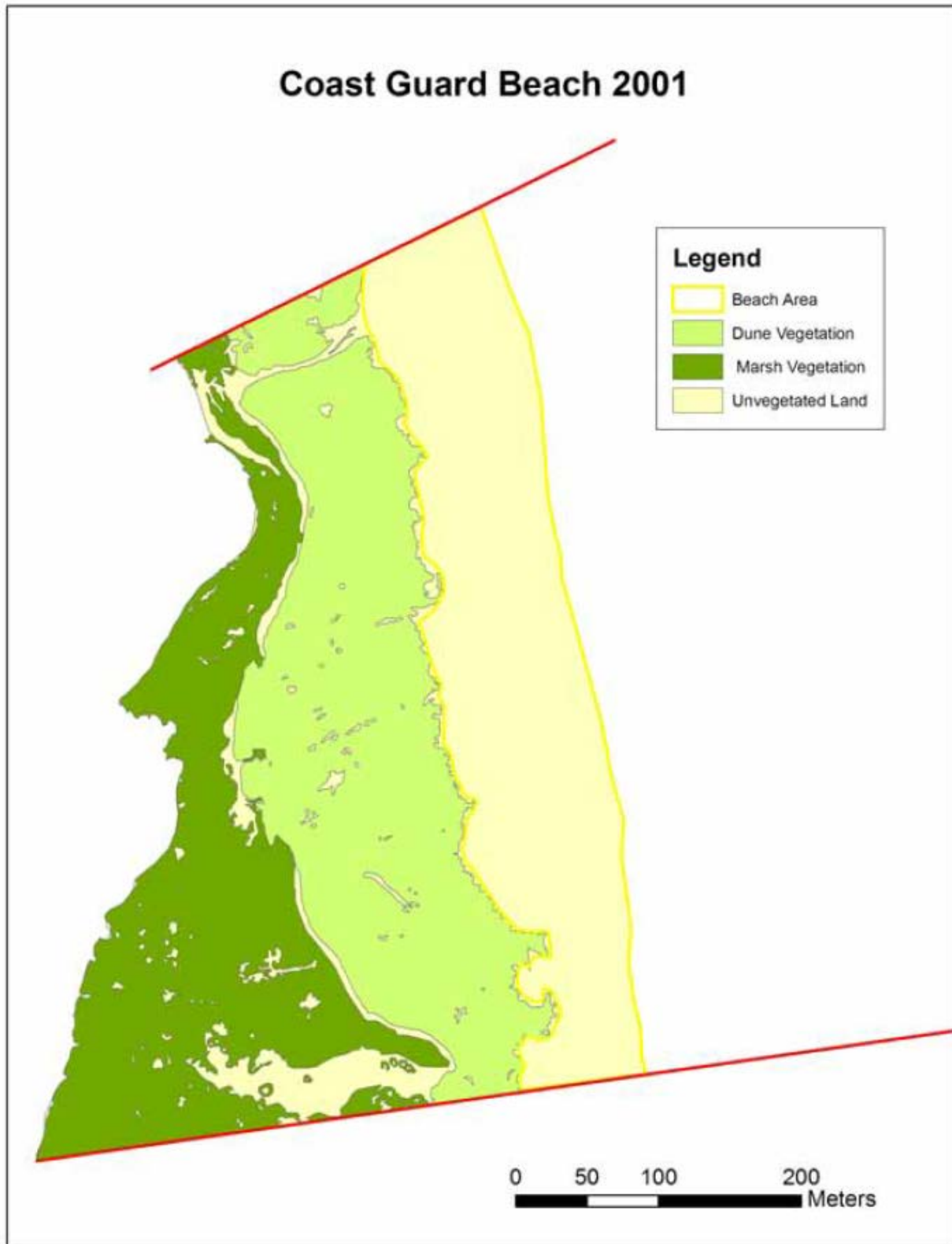


Figure 14. Polygons representing beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 2001.

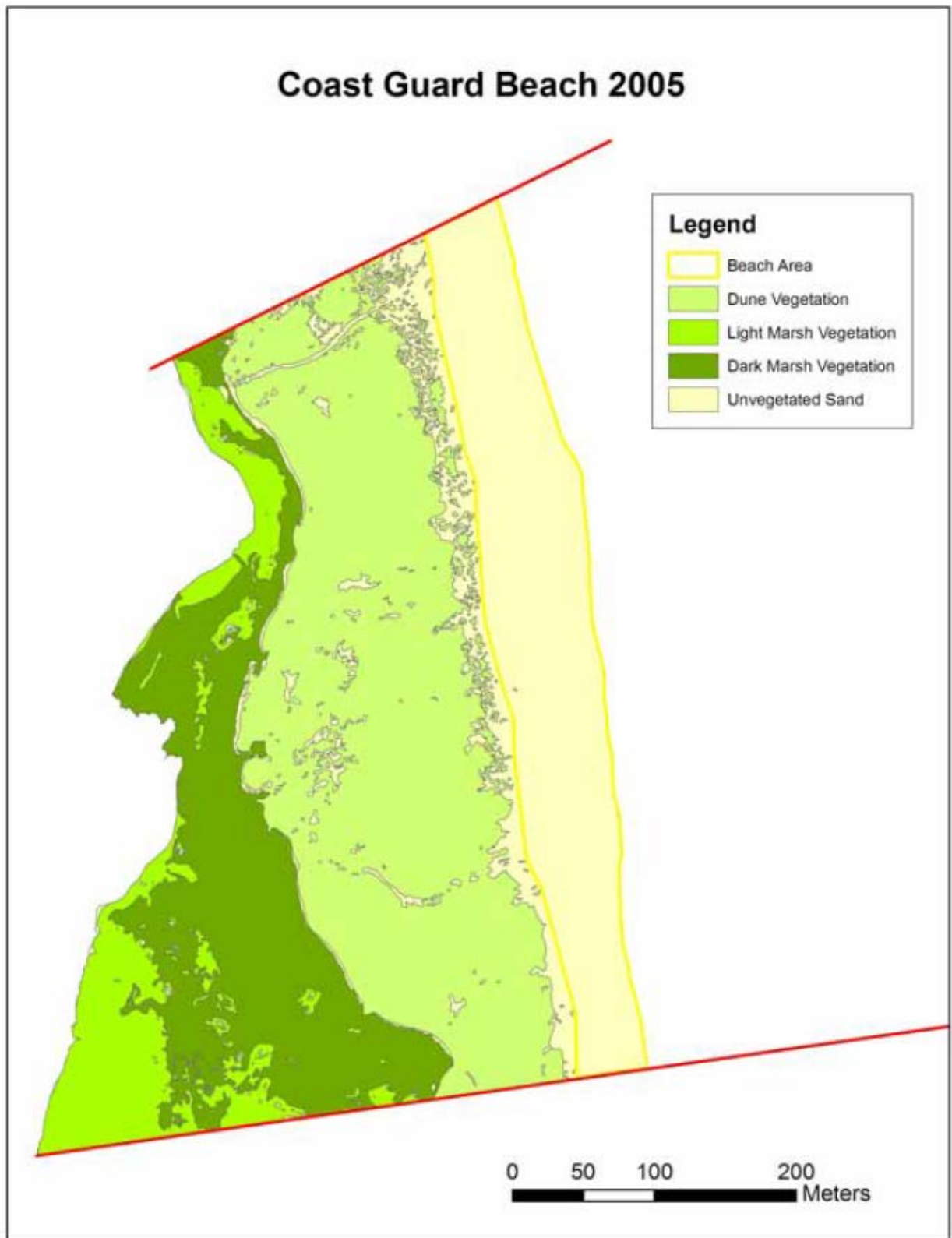


Figure 15. Polygons representing beach area, vegetation cover, and unvegetated land at Coast Guard Beach in 2005.

Race Point Beach

This beach has been used for centuries as a fishing and swimming area on the northern coast of the Province Lands, and served as an entryway to the dune zone west to Race Point, as well as east within the Province Lands (Fig. 16). Prior to NPS-CRU research, ORVs also had access to the interior dunes along numerous trails that led to the Race Point Lighthouse. Recreational “dune driving” had great impacts on dune vegetation and structure, especially in the latter part of the 20th century with the increasing availability of four-wheel drive vehicles. Polygons representing dune vegetation and unvegetated land at Race Point can be seen in Figs. 17-24.

As with Coast Guard Beach, the many parallel vehicle tracks and cross-overs on the vegetated dunes can be seen in historic images of Race Point (Fig. 17). An additional impact that is not evident in the aerial photographs is that of ORV traffic within larger patches of unvegetated sand within the dune vegetation. In many cases, these patches were probably created by ORV traffic and then expanded by wind erosion. In 1960, the entire area was covered by new sand blown in during a major storm (Fig. 18), but by 1977 dune vegetation had grown through the new layers of sand and recolonized the main dune ridge (Fig. 19).

Because of the heavy ORV use of this beach area, NPS-CRU established a research area at Race Point in 1974 that included the beach, active dune zones along the shore, and interior stabilized dunes. The 1977 image provides evidence of this as a research site; the figure-8 ORV impact test is visible within the dune vegetation (Fig. 19). The results of these studies led to highly regulated ORV access (for the first time in a National Seashore) to reach specific areas of Hatches Harbor beach used for fishing. All ORV use on the back area of the beach, where new dunes form, was banned. Likewise, all travel to the interior dunes was prohibited except along a specifically marked trail to Race Point. Finally, all sites used by nesting, state-listed shorebirds were closed and eventually educational programs were implemented to instruct fishermen, when they apply for a permit, to stay within designated areas.

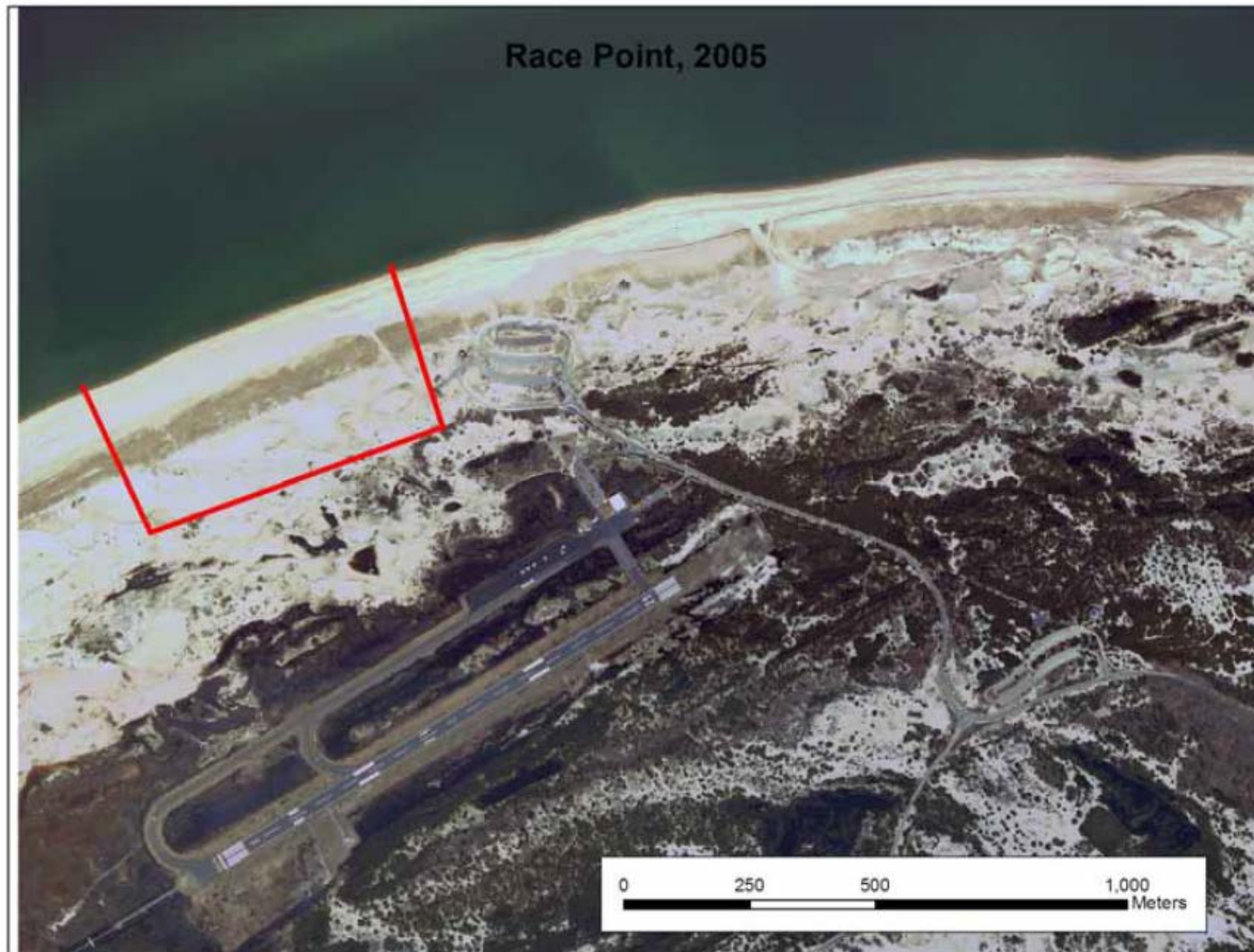


Figure 16. The study area at Race Point delineated on 2005 Mass GIS orthophotos..

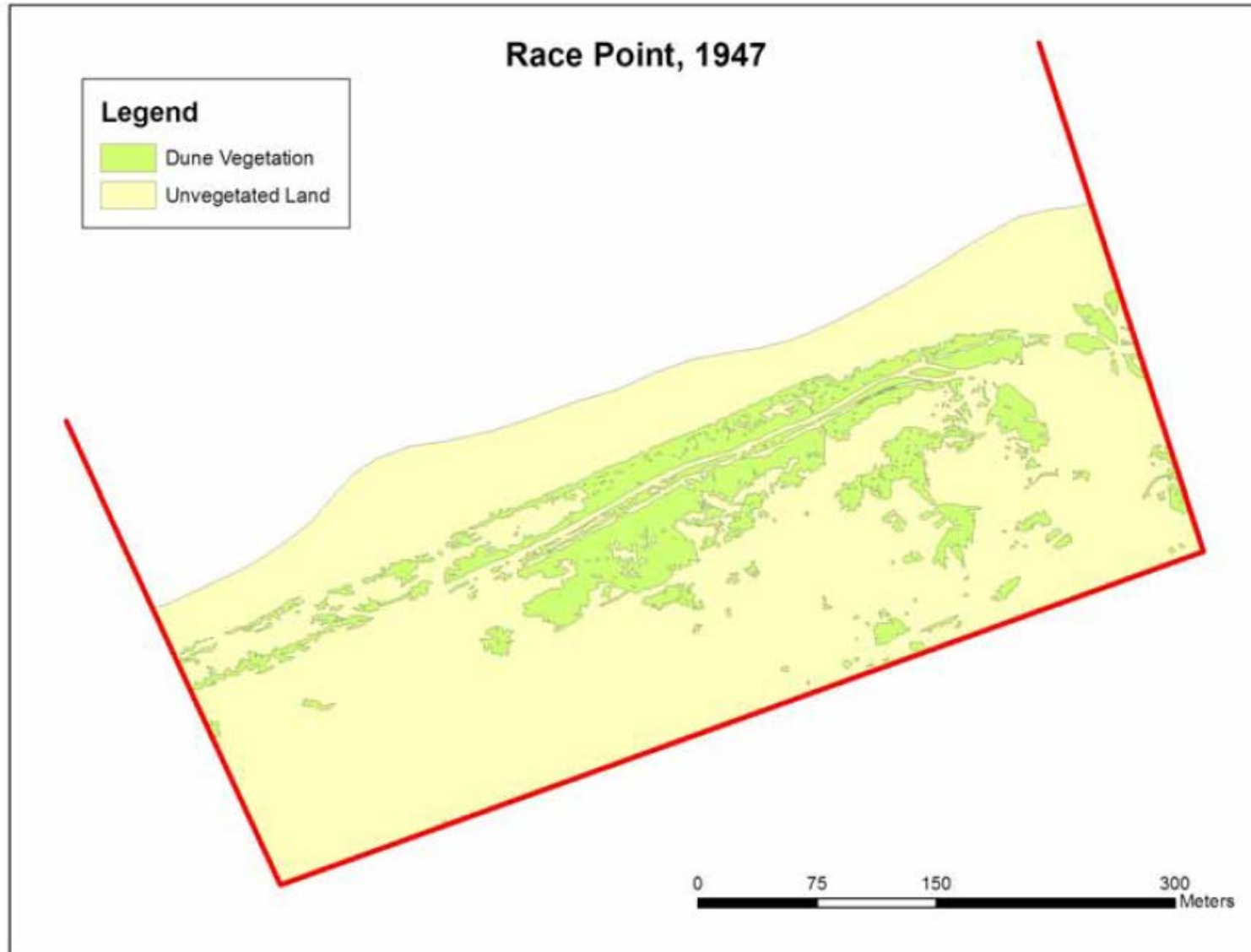


Figure 17. Polygons representing dune vegetation and unvegetated land at Race Point in 1947.

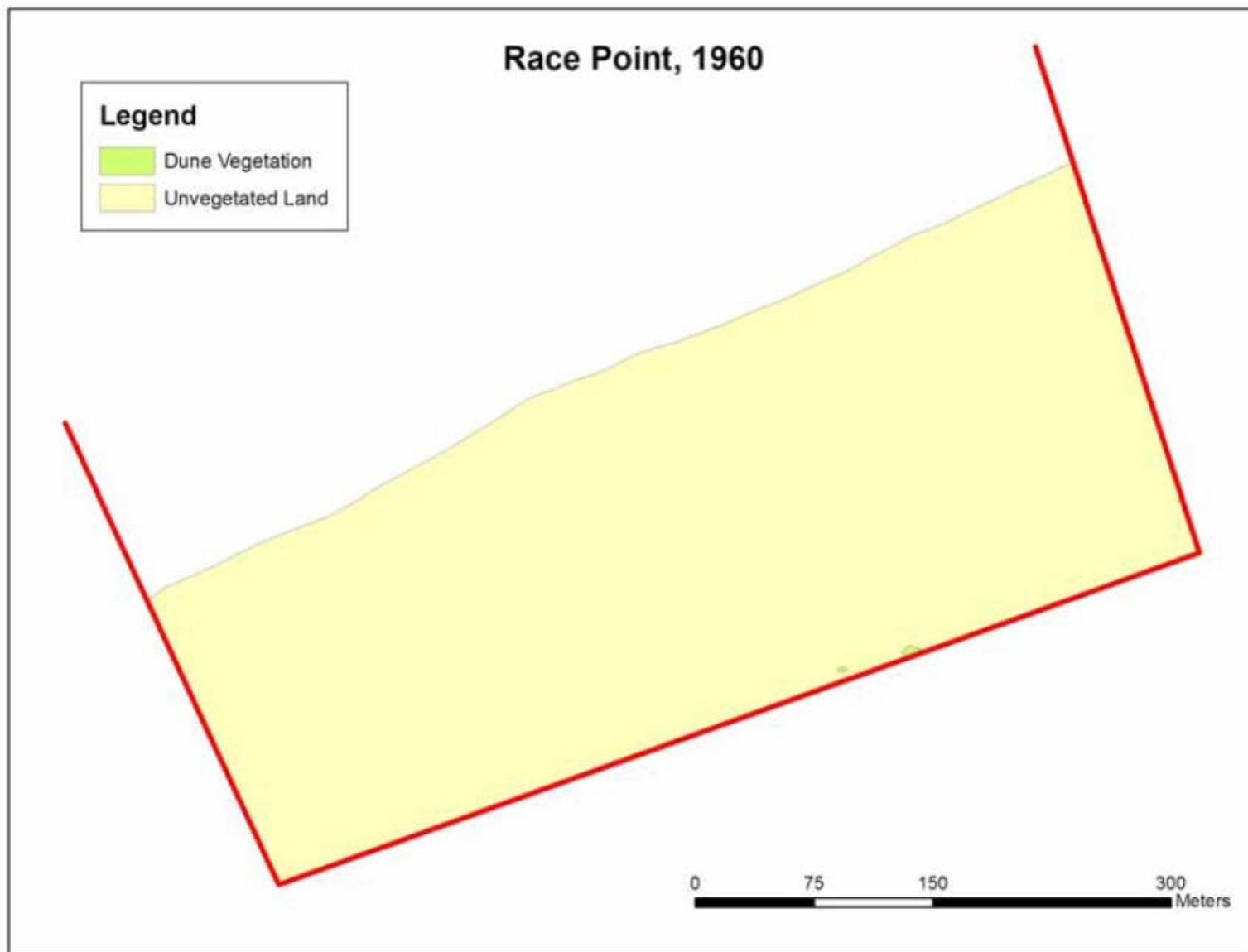


Figure 18. Polygons representing dune vegetation and unvegetated land at Race Point in 1960.

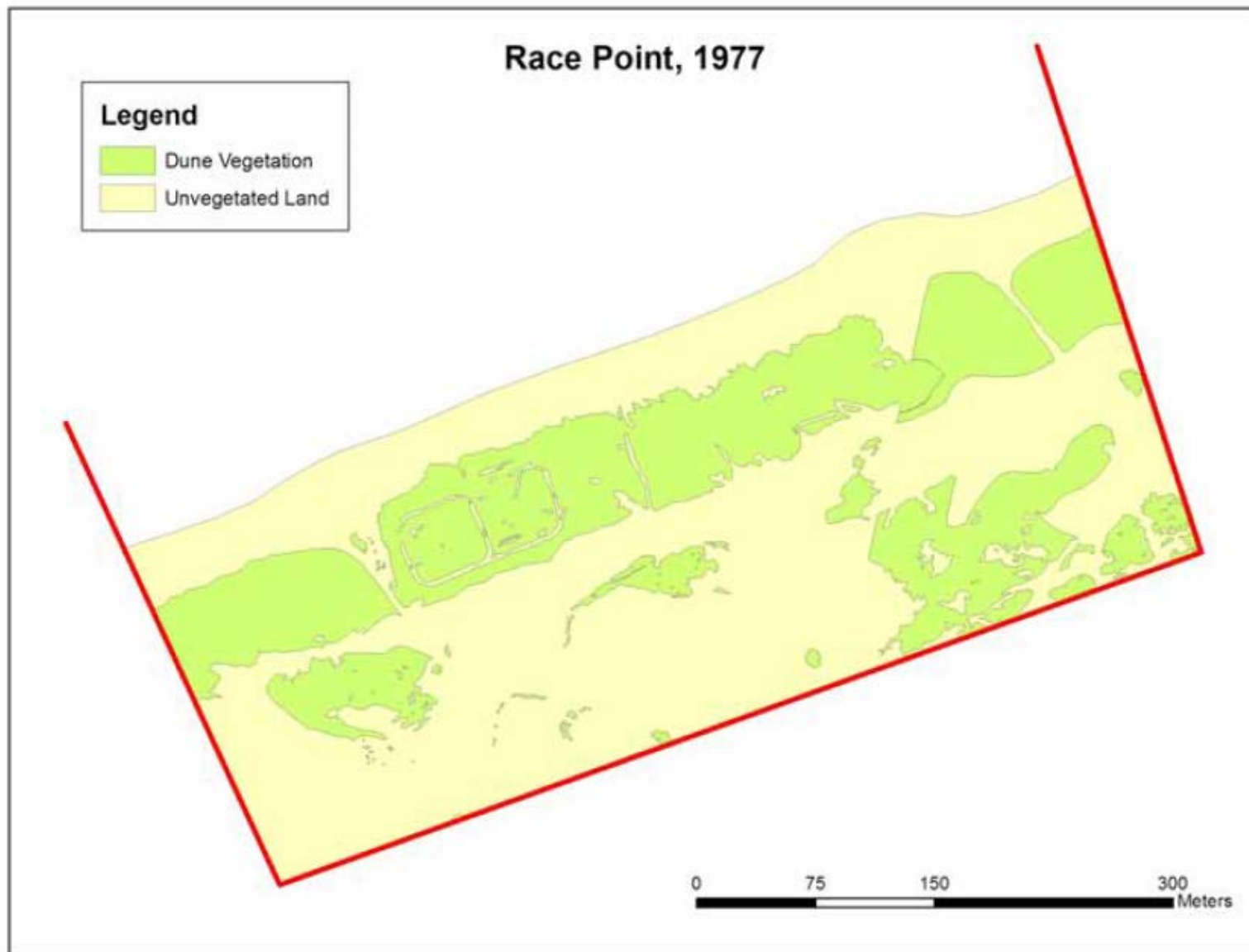


Figure 19. Polygons representing dune vegetation and unvegetated land at Race Point in 1977.

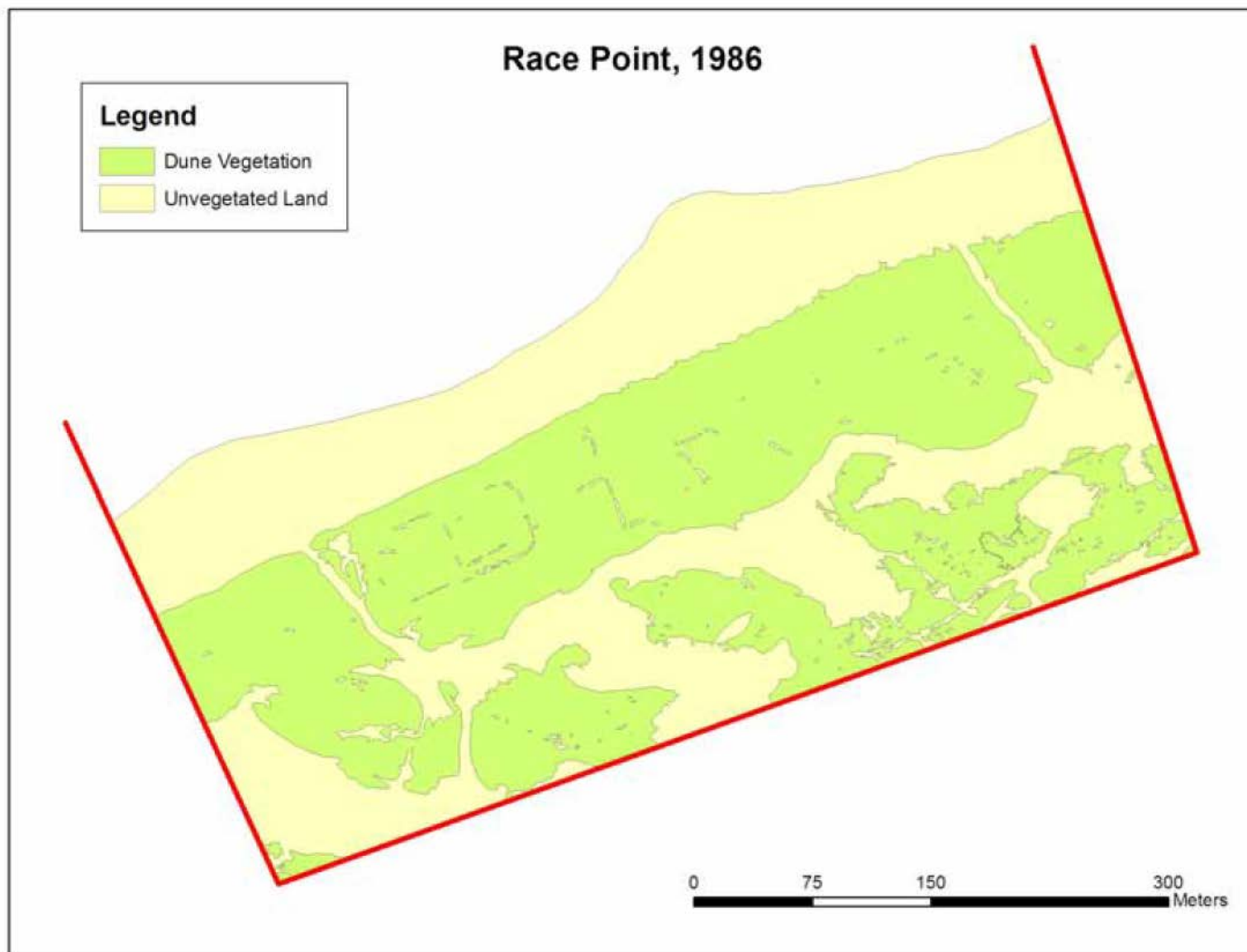


Figure 20. Polygons depicting land mass and beach grass cover within the Race Point study area in 1986.

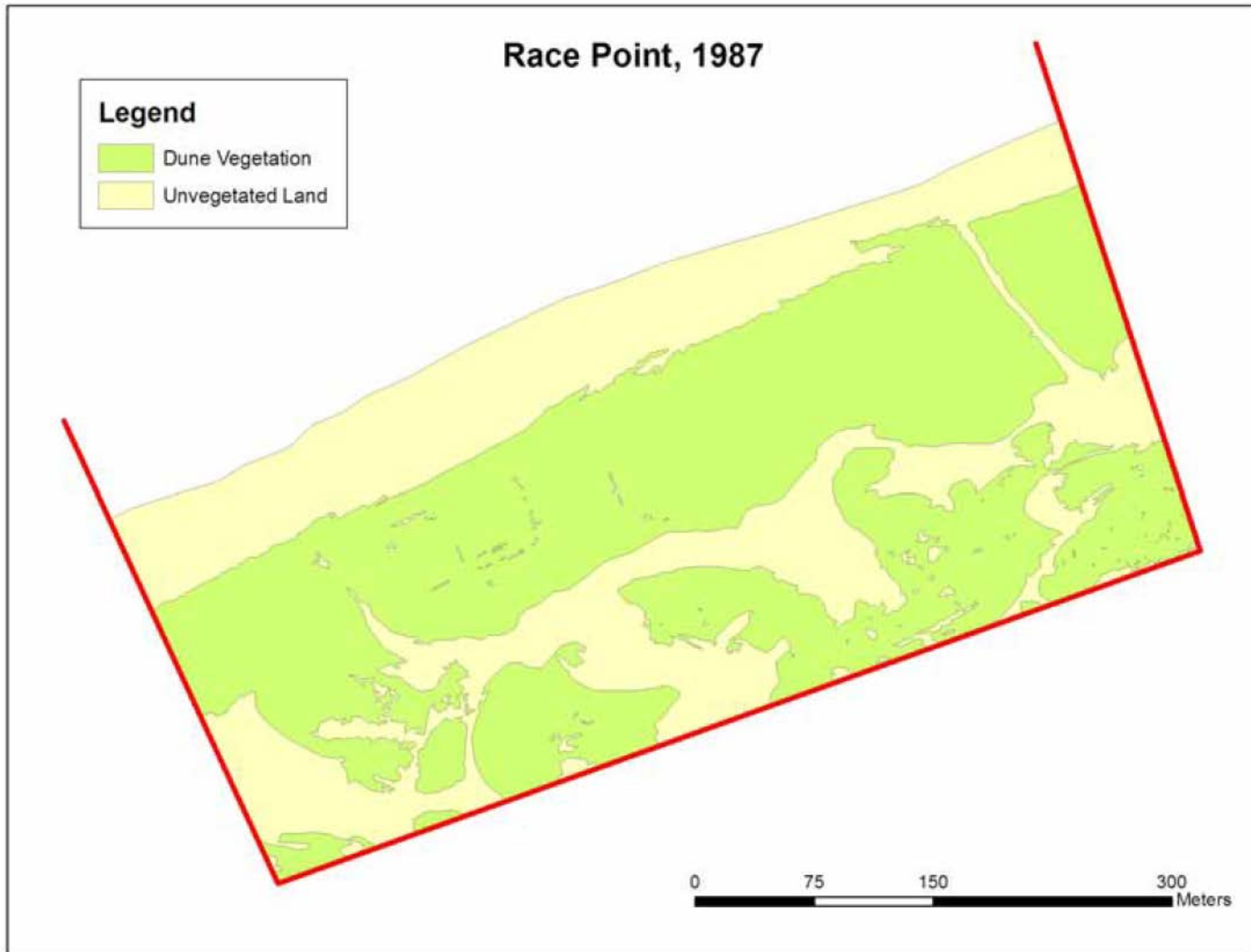


Figure 21. Polygons representing dune vegetation and unvegetated land at Race Point in 1987.

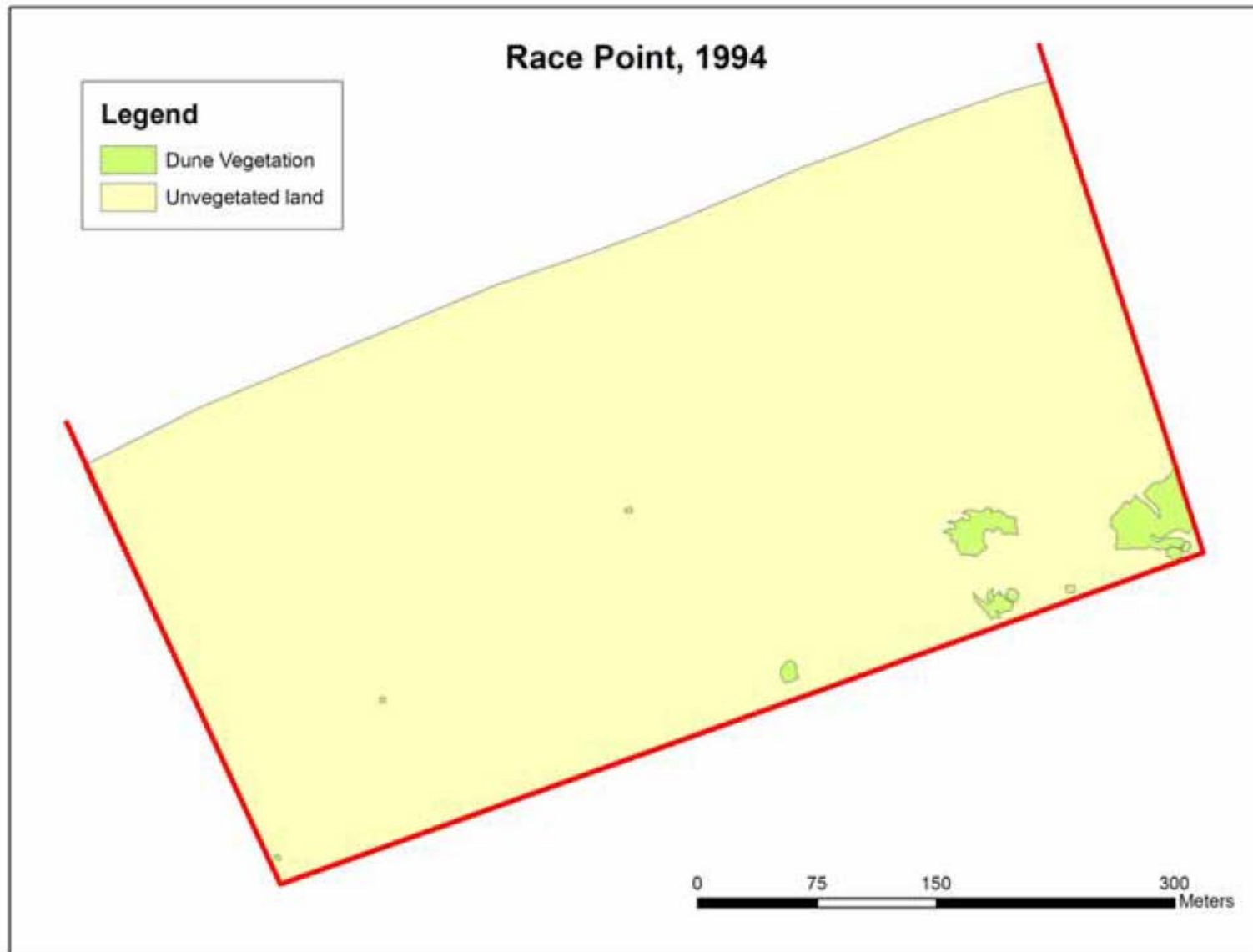


Figure 22. Polygons representing dune vegetation and unvegetated land at Race Point in 1994.

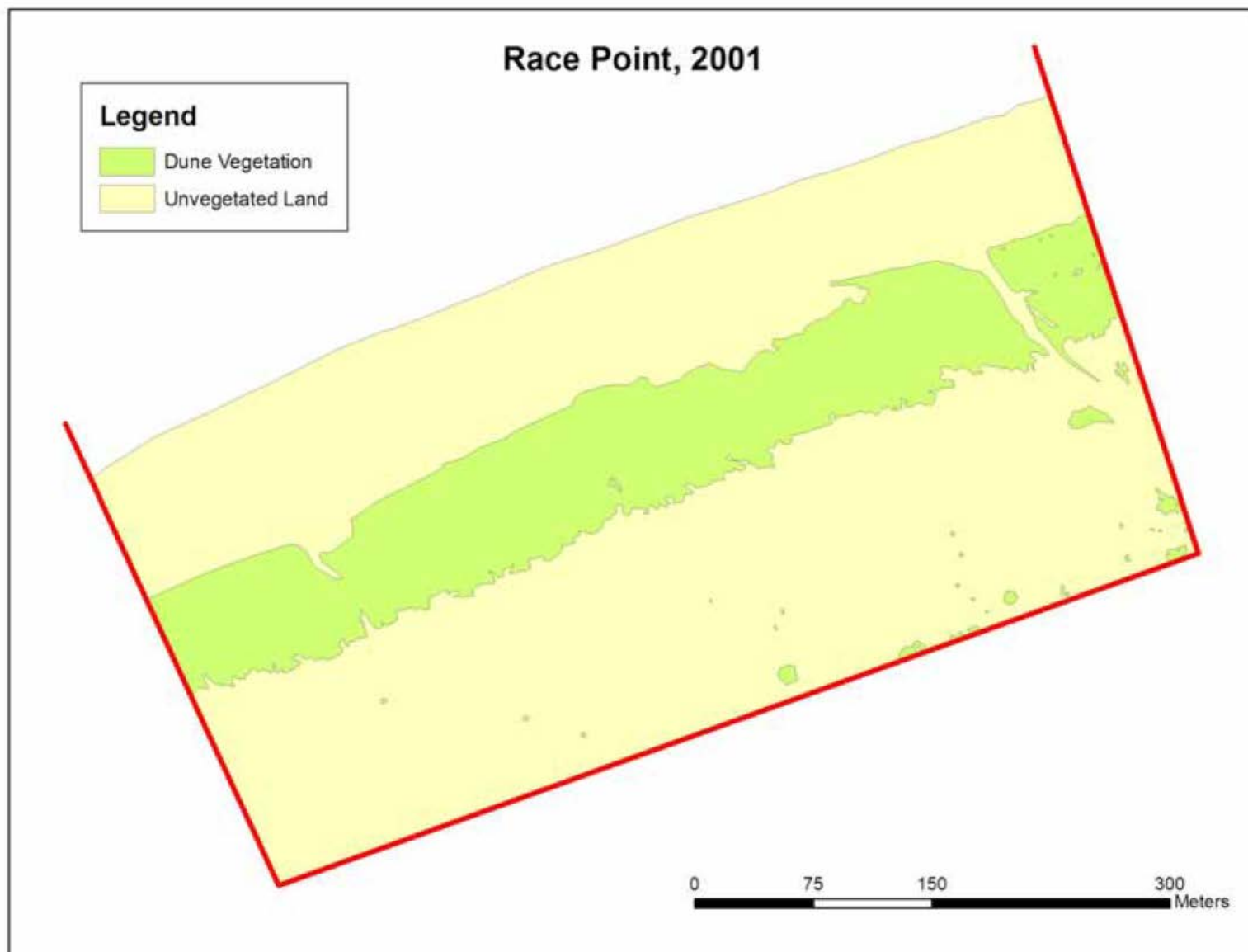


Figure 23. Polygons representing dune vegetation and unvegetated land at Race Point in 2001.

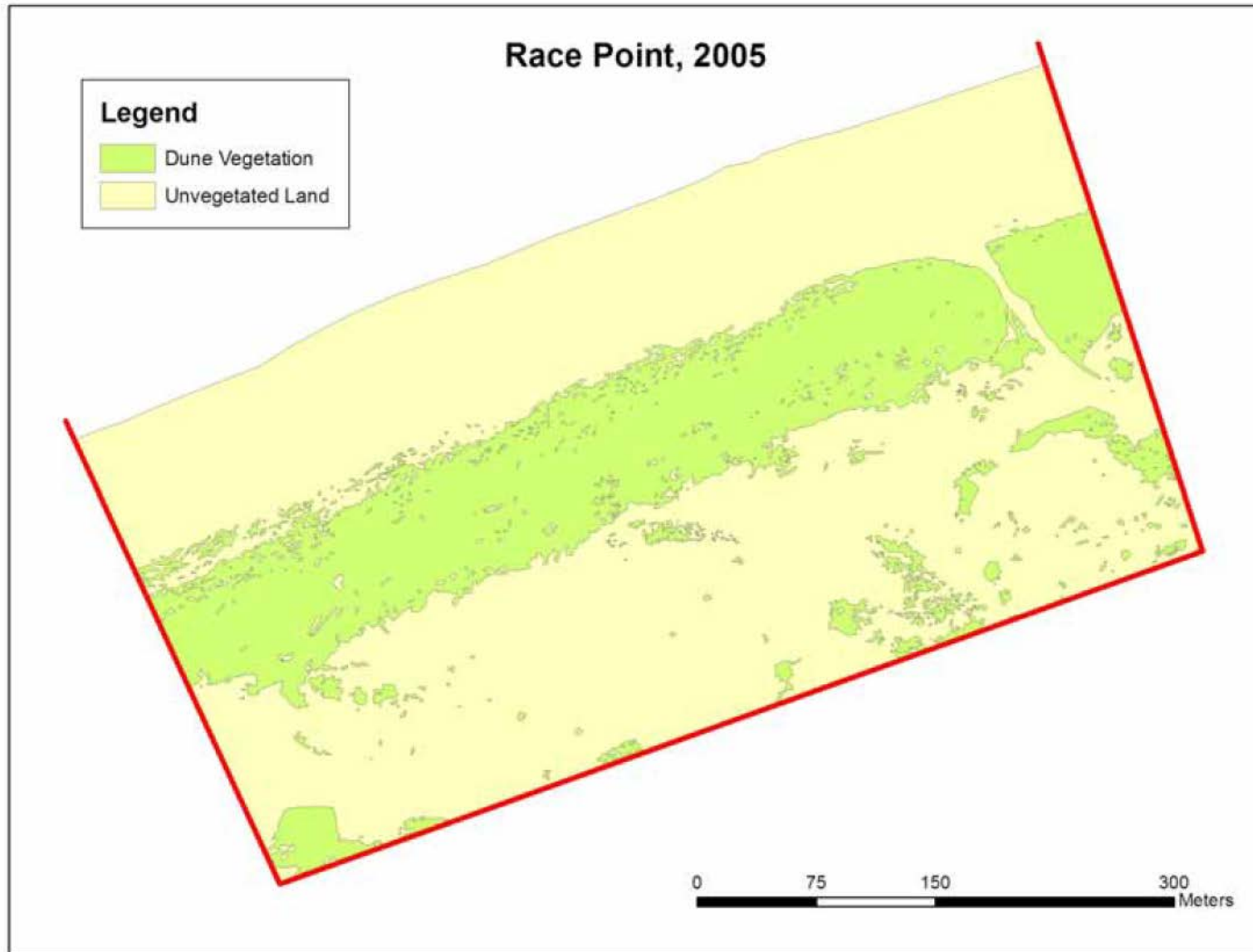


Figure 24. Polygons representing dune vegetation and unvegetated land at Race Point in 2005.

Hatches Harbor

Hatches Harbor is an intertidal salt marsh and sand/mud flat system formed during the early 1800s as the growing Race Point hook closed off a portion of the ocean at the western tip of the Province Lands (Zeigler et al. 1965) (Fig. 25). A quiet embayment, protected by dunes along its northern side, became a major habitat for marine life in developing salt marshes and tidal flats behind the hook. At one time open water extended well inland to what is now the Province Lands Airport.

Over time, the harbor completely silted in, and was finally diked to prevent tide water from reaching the airport site. The region was an important source of shellfish, waterfowl, fish and other marine resources. Prior to the NPS-CRU research, ORVs also had access to the interior dunes along numerous trails that led to Hatches Harbor, a popular site for harvesting soft-shelled clams (*Mya arenaria*). Increasingly heavy traffic on the tidal flats and marshes led to virtual extinction of the soft-shelled clam by the 1970s. As a result, NPS-CRU established experimental research sites in this important wildlife habitat. Polygons representing dune vegetation, marsh vegetation, and unvegetated land at Hatches Harbor can be seen in Figs. 26-31.

By 1960, nearly all the intertidal sand/mud flats were barren (Fig. 26). Uncontrolled traffic resulted in compaction of the wet sand and mud surface into a hard, impenetrable layer. Clams could not survive under such conditions because their siphons could not penetrate the compacted layer to obtain food and oxygen from the water, nor release waste products. Also, any plants that began to grow here were crushed by the vehicles, but in any case could not have penetrated the surface and established root systems. The only organisms that could survive were Cyanobacteria (a.k.a. blue-green algae). Vehicles were driven along the edges of the dunes, causing severe water erosion of the dune borders and preventing marsh vegetation from growing in the upper-intertidal zone. Many tracks actually cut through salt marshes and quickly destroyed the stabilizing plants (*Spartina* spp.) leading to more water erosion and deepening channels. Experimental test sites were established in the salt marsh areas and vehicle trails. The results showed that less than 100 passes of a jeep totally destroyed the salt marsh grass and left deep ruts in the marsh peat that lasted for many years thereafter (Brodhead and Godfrey, 1977; Godfrey & Godfrey, 1980).

Following presentation of NPS-CRU findings that ORV use severely damaged all of the intertidal habitats and their biota, NPS closed Hatches Harbor completely to vehicles. The only access allowed was by foot from Race Point, or along the dike which is now opened to tidal flow.



Figure 25. The study area at Hatches Harbor delineated on 2005 MassGIS orthophotos.

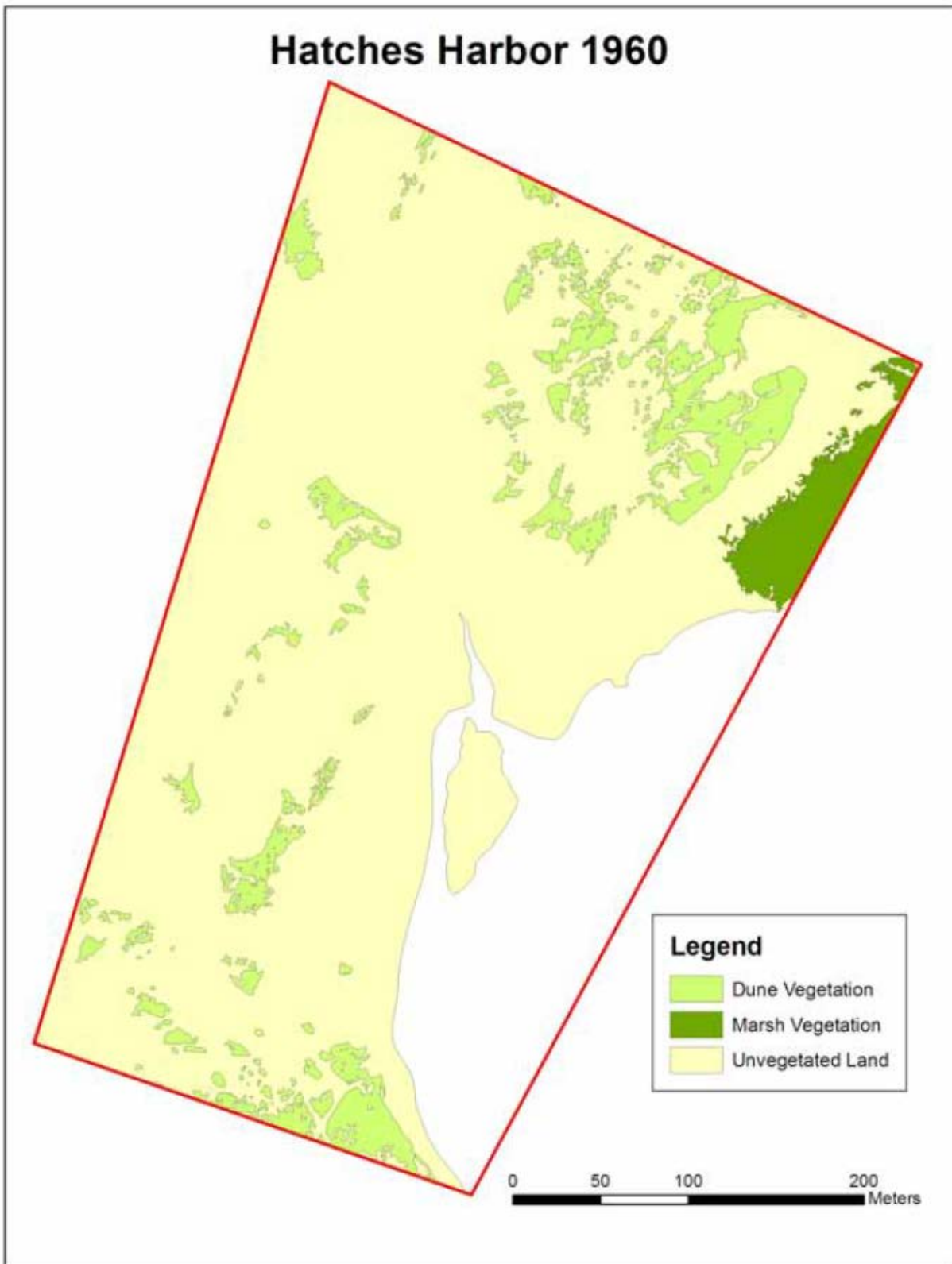


Figure 26. Polygons representing dune vegetation, marsh vegetation, and unvegetated land at Hatches Harbor in 1960.

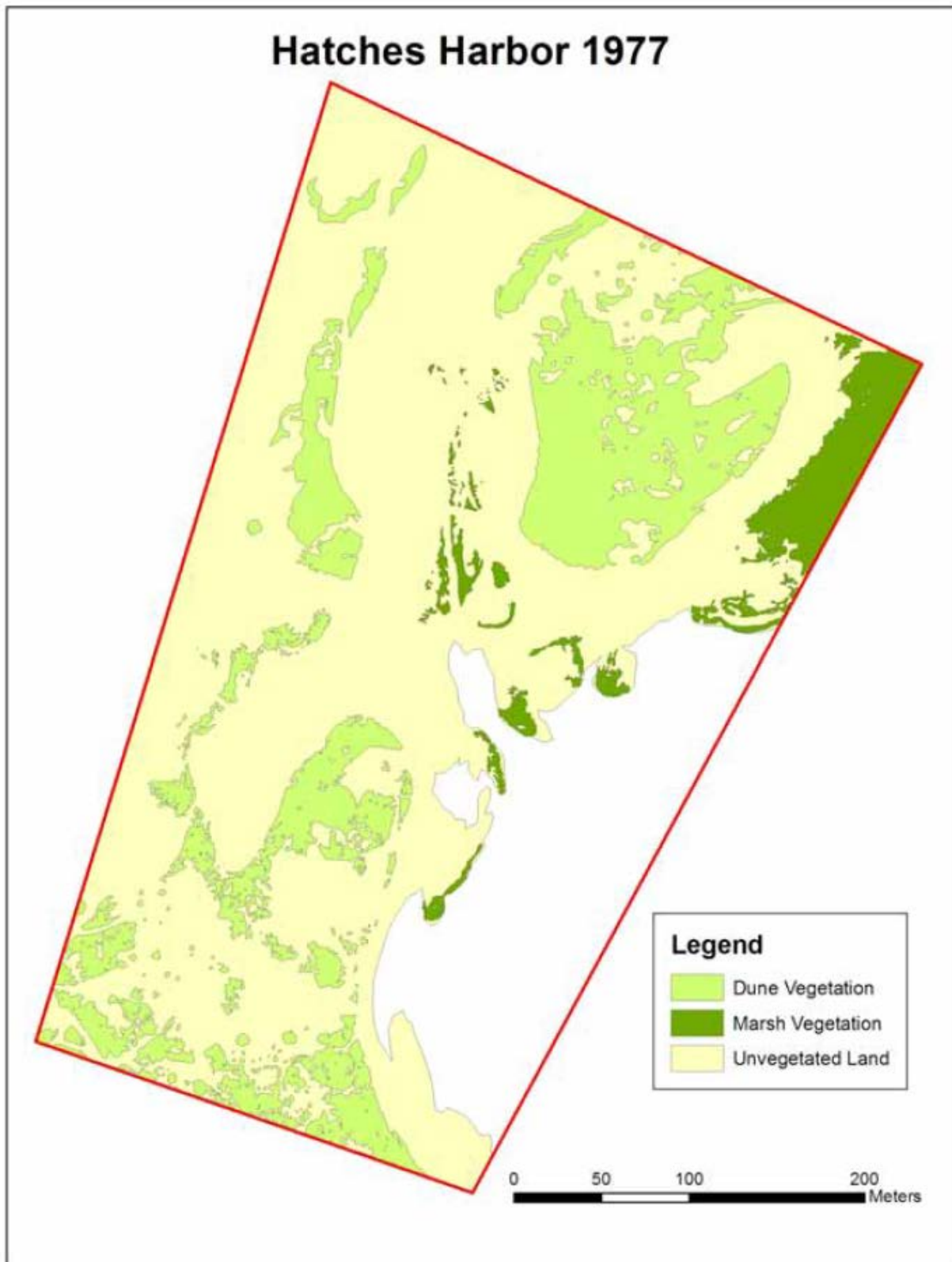


Figure 27. Polygons representing dune vegetation, marsh vegetation, and unvegetated land at Hatches Harbor in 1977.

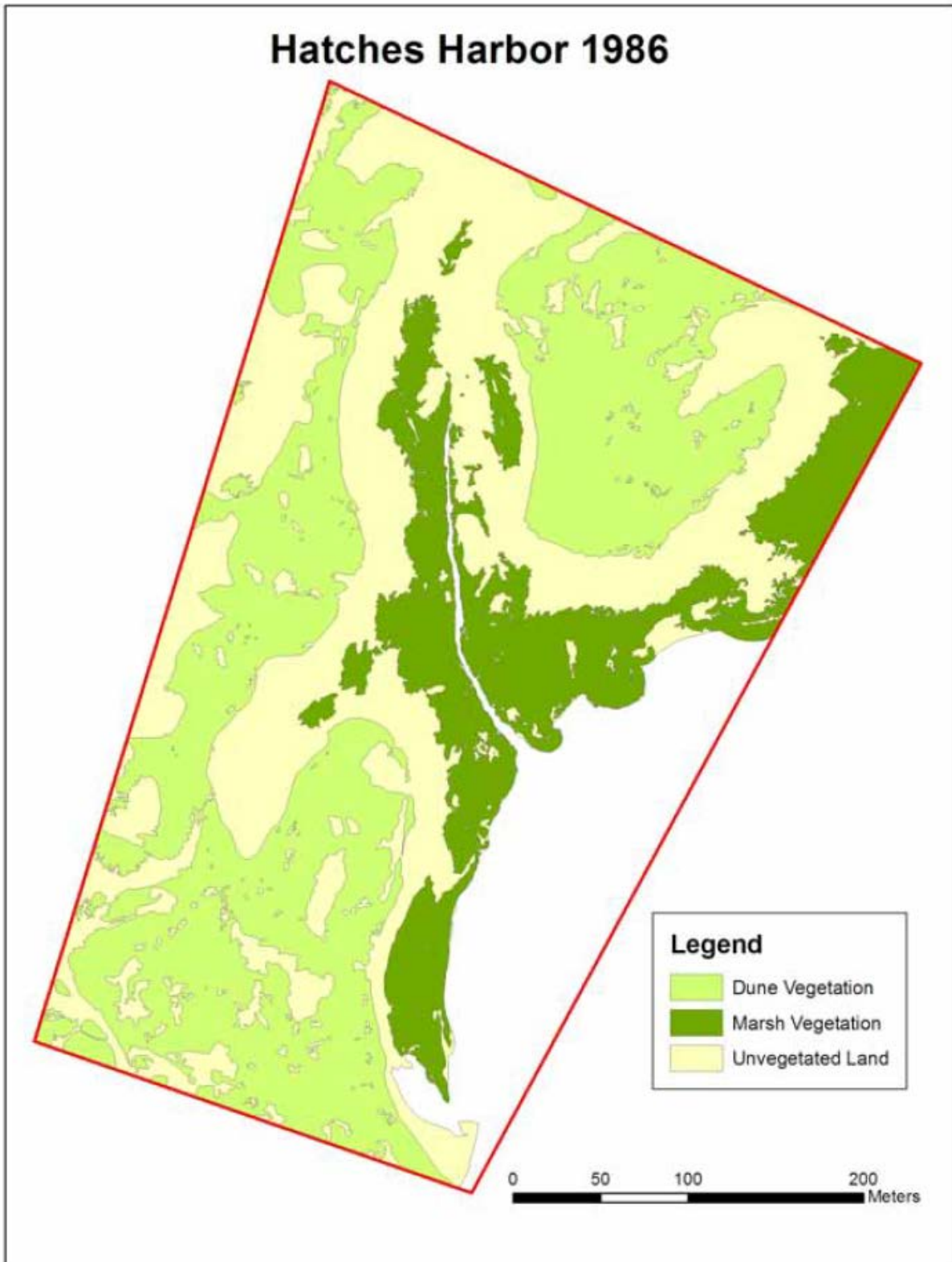


Figure 28. Polygons representing dune vegetation, marsh vegetation, and unvegetated land at Hatches Harbor in 1986.

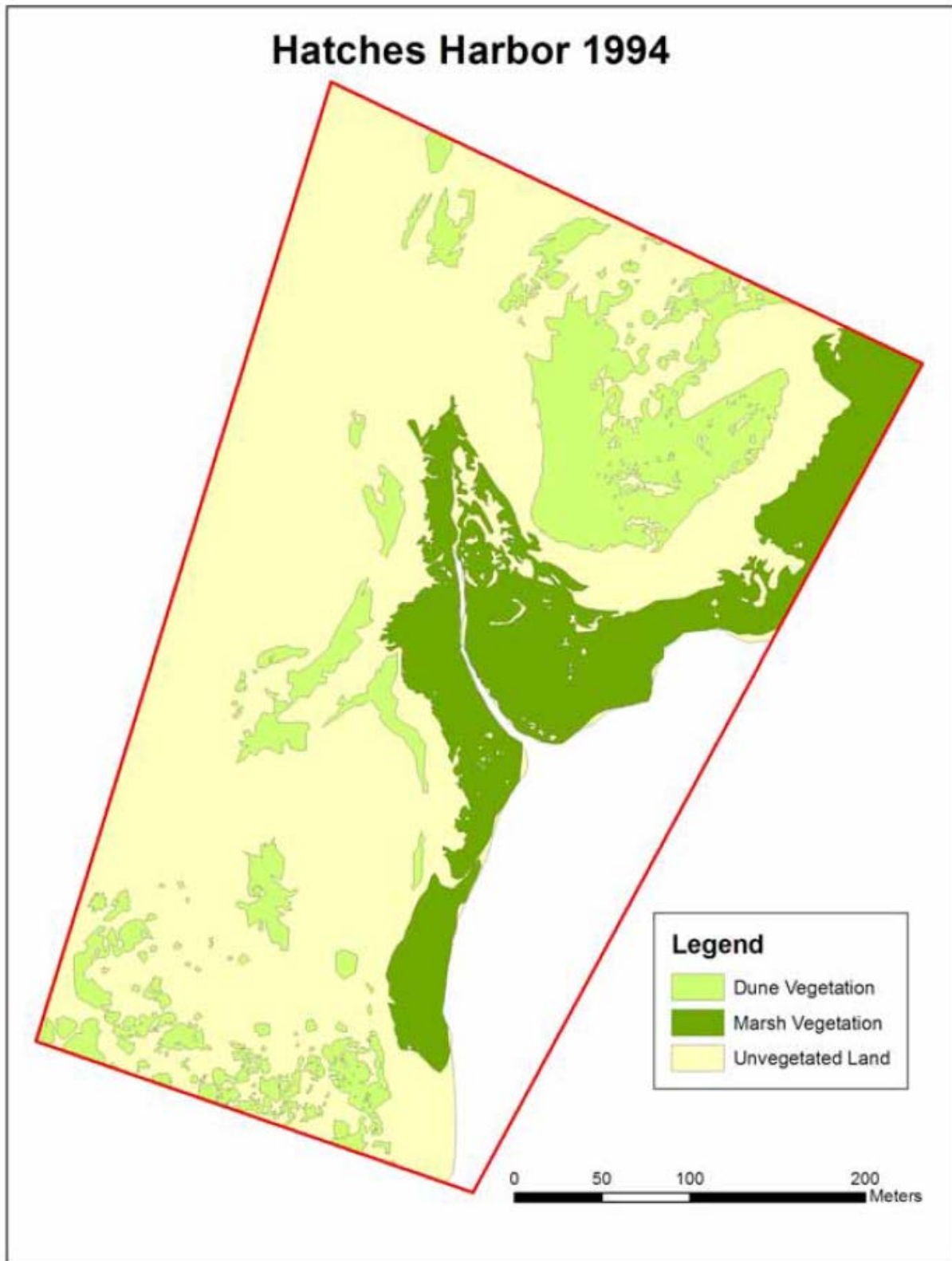


Figure 29. Polygons representing dune vegetation, marsh vegetation, and unvegetated land at Hatches Harbor in 1994.

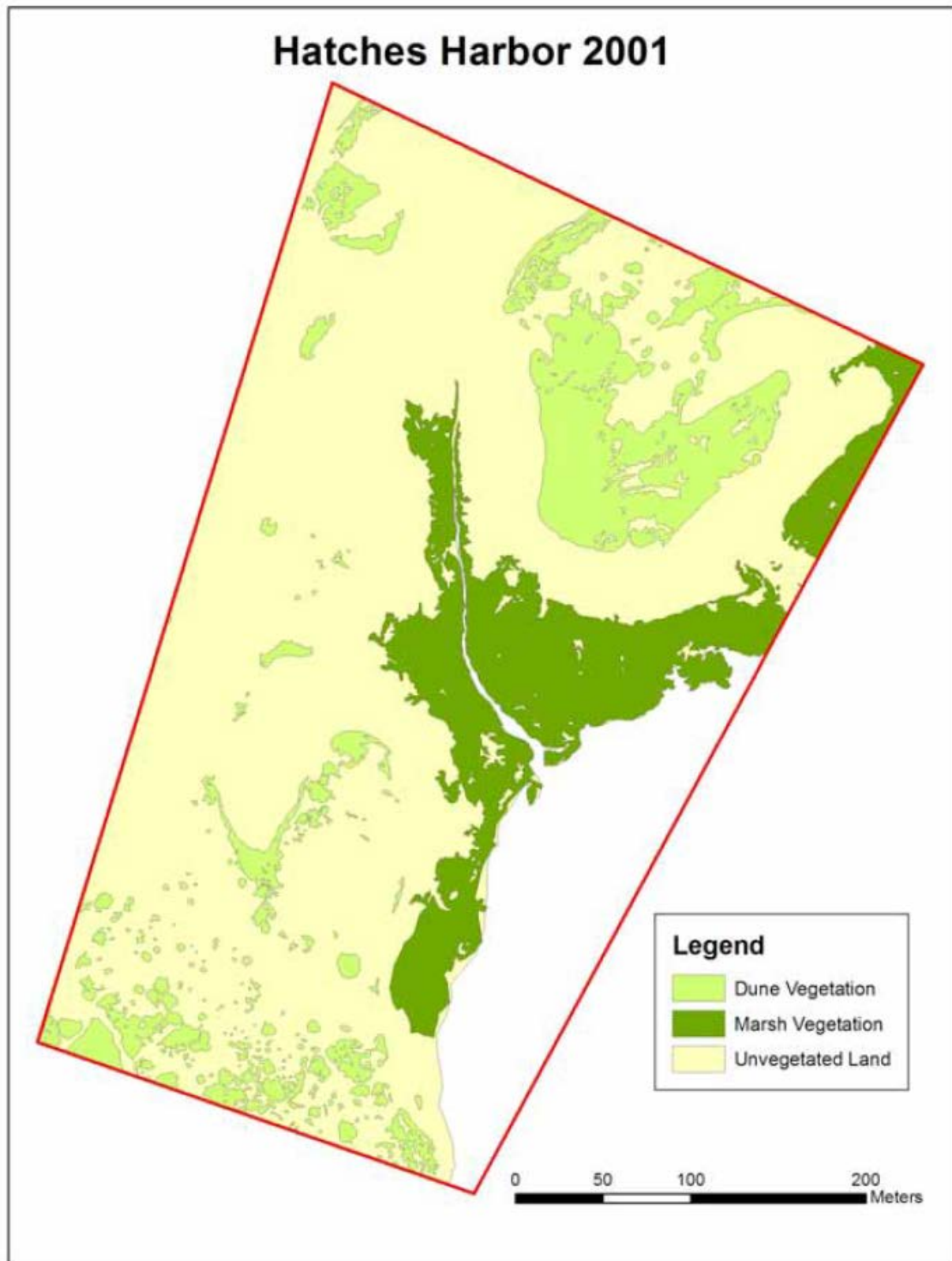


Figure 30. Polygons representing dune vegetation, marsh vegetation, and unvegetated land at Hatches Harbor in 2001.

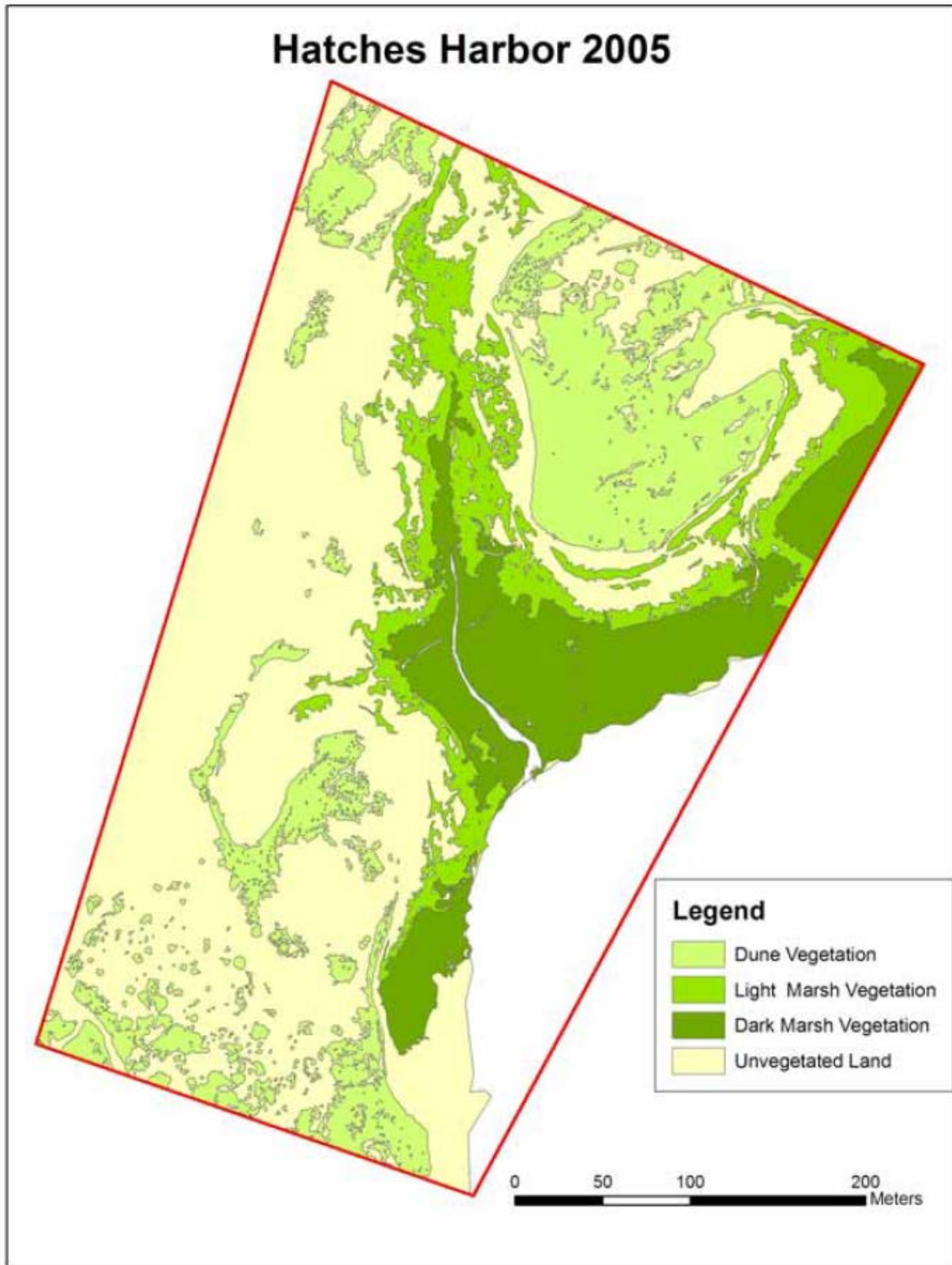


Figure 31. Polygons representing dune vegetation, marsh vegetation, and unvegetated land at Hatches Harbor in 2005.

Methods

Photographs and Field Notes

I searched through many boxes found in storage and organized Dr. Godfrey's photographs, slides, and field notes by location and year. I then created digital images of representative photographs from slides for the three study areas. I used a Nikon Coolscan V EP Scanner set at the maximum resolution of 600 dpi, adjusting color and contrast to create the best images possible. In total, I scanned 683 photographic slides from Dr. Godfrey's collection, creating digital images of Cape Cod spanning four decades (1957 through 1997). These included photographs Dr. Godfrey took while revisiting the sites in the 1980's and 1990's, as well as photos he collected that had been taken prior to the original study period. We visited Coast Guard Beach, Race Point, and Hatches Harbor in August of 2007. At each site we noted current conditions and vegetation cover types, and took photographs at locations where Dr. Godfrey had taken photographs during site visits in the 1970's, 80's, and 90's where possible. In total, we took 462 digital photographs during the 2007 site visits. I used the photographs from Dr. Godfrey's collection, as well as those we took during our 2007 site visit, to interpret the aerial photographs I used in the GIS analyses, determining vegetative community types and plant species within these community types.

GIS Analyses

I obtained aerial photographs from Mark Adams at the NPS National Seashore dating between 1938 and 1987 for the three study areas. I also downloaded orthophotographs from 1994, 2001, and 2005 from MassGIS for all three study areas. For Coast Guard Beach, I analyzed 12 images from 1938 to 2005, for Race Point I analyzed eight images from 1947 to 2005, and for Hatches Harbor I analyzed seven images from 1960 and 2005. I georeferenced aerial photographs from 1937-1987 to the 2005 orthophotographs (spatially-accurate aerial photographs) using ArcMap 9.2 (ESRI, 1999-2006). This technique involves pairing distinct landmarks that appear in both the aerial photographs and the orthophotographs and adjusting the aerial photographs so that all the images were uniform regarding spatial reference and were lacking in distortion. I followed this procedure for each aerial photograph, creating a montage of overlying images representing a series of years for each of the study sites. To quantify vegetation and land mass at each site for each available year, I began by delineating the study areas. I selected a reasonable extent for each site and marked this on each image with red lines (Fig. 3). The extent of each study area remained consistent across years. For each image, I digitized polygons representing total land mass, vegetation cover types (dune and marsh), and unvegetated land (Fig.32). For Coast Guard Beach, I also created polygons representing beach area, defined as the unvegetated zone between the dune vegetation and the ocean. I classified two main types of vegetation cover - dune vegetation and marsh vegetation. In some images there appeared to be two to three distinct types of marsh vegetation communities, indicated by differences in the degree of shading or color intensity within those areas. Therefore, I created multiple categories for marsh vegetation - light, medium and dark (Fig.33).

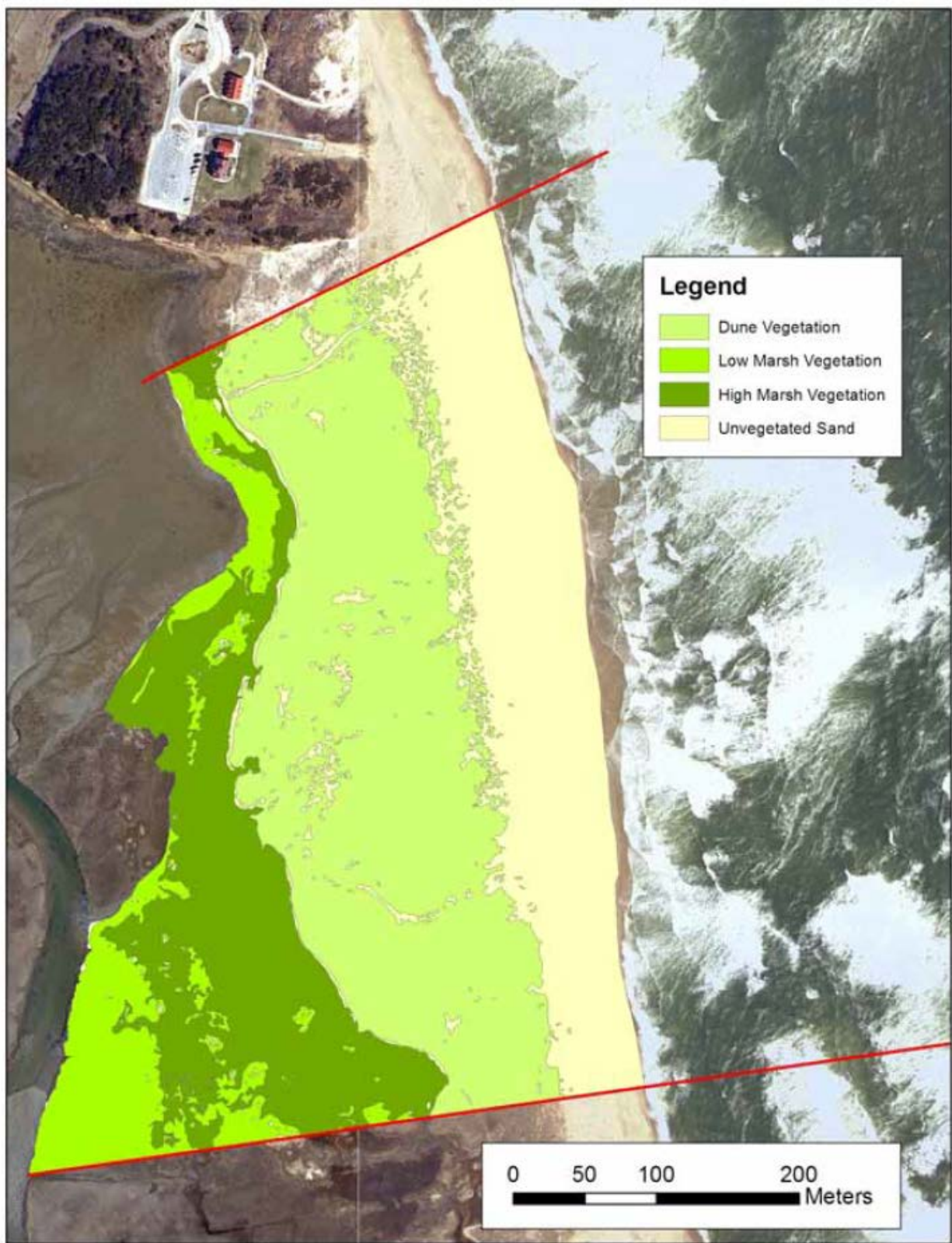


Figure 32. Polygons depicting land mass and vegetation cover types.

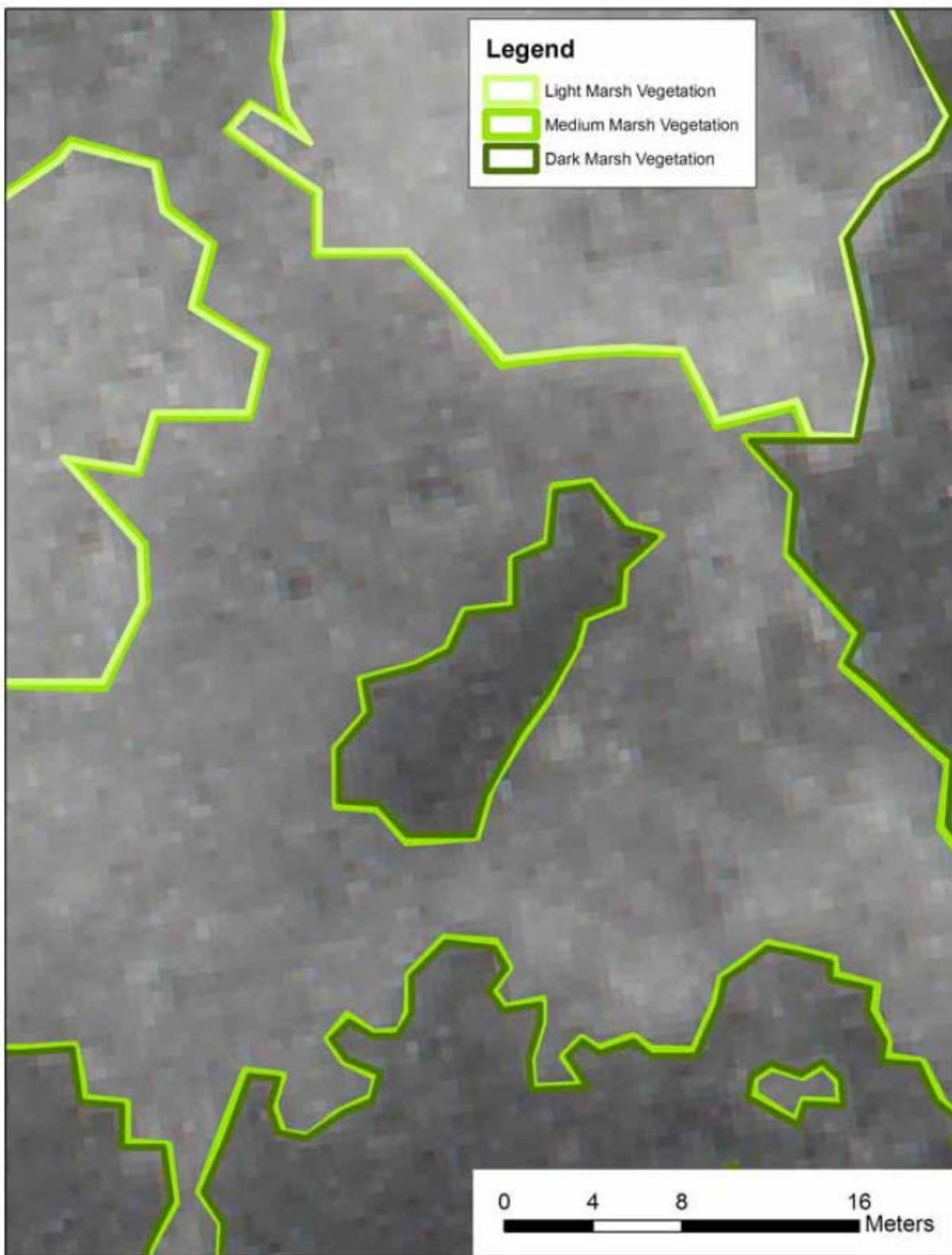


Figure 33. Close-up example of how marsh vegetation was delineated into three zones, based on degree of shading.

The visible differences in vegetation are likely the result of different plant communities arising from slight variations in elevation. Elevation determines the salinity and degree of inundation for a given site in coastal ecosystems. These in turn determine what species of marsh plants are most likely to thrive there. For instance, the lowest areas of salt marsh in New England are typically dominated by salt marsh cordgrass (*Spartina alterniflora*), because it is the species best suited for areas with high inundation. However, as elevation increases species that are well suited for less inundation, but that cannot survive in lower areas, outcompete lower marsh species, thus limiting those species to the lowest areas within a marsh. This pattern of physical constraints at the lower end of a zone, and competition at the upper end is repeated throughout the salt marsh. I chose to delineate these different zones within the salt marshes when they were apparent in the aerial photographs, hoping to examine how these changed over time. It became apparent that this was beyond the scope of this project; however, delineating these zones makes it possible for future, more detailed analyses changes within the marsh over time.

Creating polygons to represent the relevant features of these beaches provided us with highly accurate information about the amount of area covered by vegetation for each available year. In many cases, the resolution was fine enough to discern objects no more than one meter long, allowing me to make very detailed representations of the vegetation cover. I created from several to hundreds of polygons for each category of vegetation present in a single image. Within ArcMap, I was also able to calculate area for each polygon that I created. By dividing the area of vegetation types by the total land mass of a given study area, I calculated the percent cover for each cover type. Percent cover, rather than raw area, is more comparable between sites and years. I graphed this data to look for trends in the changes in vegetation over time for each site, and also compared the data of all three sites to look for overall trends. A potential source of error in my analysis of changes in vegetative cover over time is the interpretation of the aerial photographs, particularly the black and white images. Shadowing in these images could easily be mistaken for vegetation when photo resolution is low. Also, I did not take plant density fully into account when I created the polygons. Whenever possible, I created polygons that followed gaps in the vegetation, but thinly vegetated areas in general were treated the same as densely vegetated areas.

Results and Discussion

Coast Guard Beach

Total land mass fluctuated substantially over the 67-year period, ranging from a low of 14.8 to a high of 20.9 ha in 1977 and 1947, respectively (Table 1 and Fig. 34). Total land mass increased during the Blizzard of 1978 overwash event and continued to increase until 1987, but land mass was apparently lost during the 1994 northeaster (Fig. 13). Of particular interest is the change in beach area over this time period. During the 1970's, NPS put considerable effort and resources into preserving the existing beach and parking lot. This involved dumping approximately 10,000 cubic yards of concrete and rock on the upper shore, and bulldozing and dredging sand up from the shallows to rebuild the beach. However, it became apparent that these practices were not effective, and in fact were having a negative effect on the beach (US Army Corps of Engineers 1979). By dredging sand from the shallows, resource managers converted the profile of the shallows into a deeper zone that changes more abruptly at the beach/ocean interface. This caused the force and size of the waves to be higher than they would have been. In addition, the hard surfaces dumped on the beach were typically undermined by the increased wave energy, often increasing the loss of sand from the beach (Dolan and Godfrey 1973).

Table 1. Land mass and beach areas (ha), percent dune vegetation, percent marsh vegetation, and percent total vegetation for twelve years between 1938 and 2005 and an average for Coast Guard Beach.

Year	Land Mass Area	Beach Area	% Dune Vegetation	% Marsh Vegetation	% Total Vegetation
1938	19.4	2.0	18	50	67
1947	20.9	3.9	17	45	63
1960	20.1	3.5	7	49	56
1965	18.5	3.8	3	50	53
1970	18.4	3.6	4	50	54
1974	15.9	1.4	7	61	68
1977	14.8	0.6	12	66	78
1978	17.9	15.2	0	15	15
1987	20.2	4.8	24	27	52
1994	15.7	13.2	5	8	13
2001	17.7	5.6	34	27	60
2005	18.4	3.9	40	32	71
Average	18.2	5.1	14	40	54

We can see a substantial drop in beach area coinciding with this time of intense management, reflecting the lack of success of these methods (Table 1, Figs. 1 and 34). Prior to 1970, beach area was generally just less than 4.0 ha (Table 1). The peak in beach area in 1978 is deceptive in that a large portion of what appear to be the beach is sand that has overwashed on to the dune vegetation. Therefore it does not really signify an increase in actual beach area, such as when sand deposition at the periphery increases total land mass (Fig. 11). In addition, it is difficult to measure beach area without having the vegetation as a guide. However, in 1987, with the re-establishment of the dune vegetation to delineate the upper edge of the beach, we can detect a significant increase in actual

beach area from 1977 (Table 1, Figs. 10, 12 and 34). This is followed by another peak in 1994 from the second overwash event and a return to a beach similar in size to the beaches prior to 1970 (Table 1, Figs. 13 and 34).

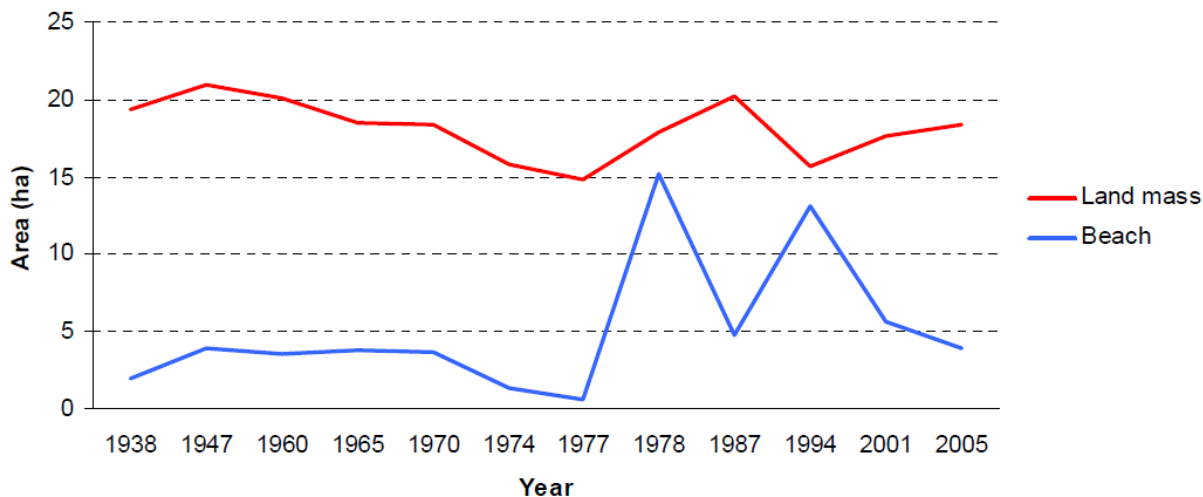


Figure 34. Land mass area and beach area at Coast Guard Beach from 1938 to 2005. For beach area, there is a generally consistent area of approximately 4 ha from 1947 to 1970, followed by a decline. Two overwash events led to a subsequent return to 4 ha in 2005. The most intense period of active beach protection occurred between 1970 and 1977.

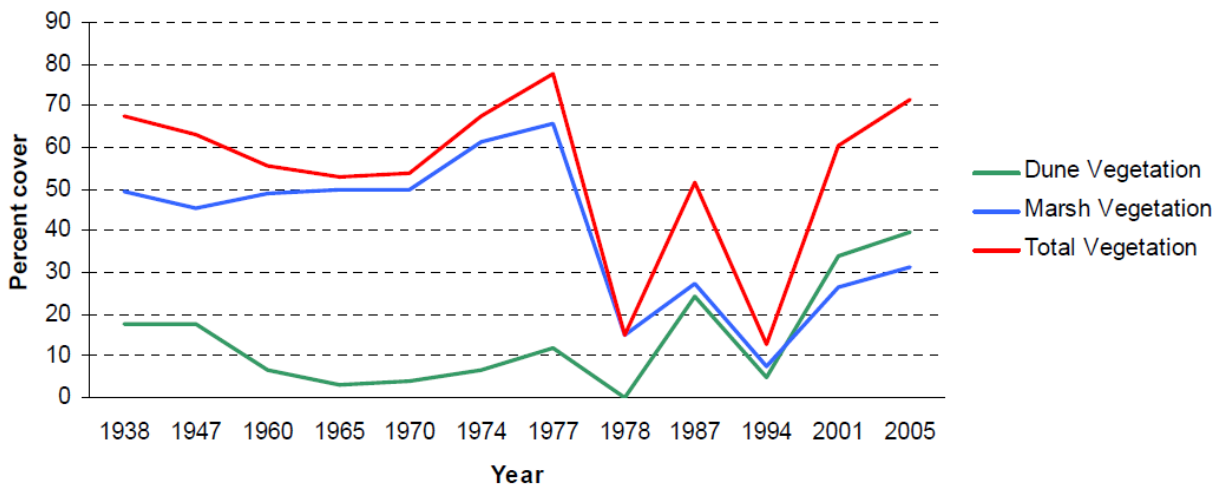


Figure 35. The percentages of the study area covered with dune vegetation, marsh vegetation, and total vegetation at Coast Guard Beach from 1938 to 2005. Note the overall trend of increasing dune vegetation.

Based on historic photographs, field notes, and our 2007 site visit, I determined that beach grass (*Ammophila breviligulata*) was the dominant dune vegetation species at Coast Guard Beach throughout the study period. Dune vegetation appears to have been highly fragmented from 1938 to 1987 (Figs. 4-12). Much of this fragmentation appears to have been started by human activity within the dunes, as depicted as linear unvegetated areas that we interpreted as ORV roads and hiking trails in the 1938 and 1947 images (Figs. 4 and 5). We can see the lasting effects of these impacts through 1977 (Figs. 6-10). In 1960 there was a sharp reduction in the amount of dune vegetation within the study area (Table 1, Figs. 6 and 35), which begins to recover sometime between 1974 and 1977 (Figs. 9 and 10). The Blizzard of 1978 overwashed the area in February, and we see practically no evidence of dune vegetation in the image from later that year (Figs. 11 and 36). However, no ORV use was permitted within this area after 1978, and in 1987 we see that the dune vegetation has made a strong recovery; however, it is overwashed by the second major northeaster occurring in February 1994 (Gross 2009) (Figs. 12 and 13). Then once again we see dramatic increases in dune vegetation in 2001 and 2005, with much less fragmentation than at any other time within the study period (Table 1, Figs. 14, 15, and 35). We believe this is due in large part to the lack of ORV use and reduction in foot traffic. During our 2007 site visit we observed that the dune vegetation was abundant, suggesting a healthy dune vegetation community (Fig. 36).

When we look at percent cover of dune vegetation over time, the trends become apparent. We see a decrease from 1947 to 1965, followed by only a slight increase from 1965 to 1977 (Fig. 35). Overall, there is a dramatic increase between 1977 and 2005, although there are two severe drops in percent cover due to the two overwash events. This increase leads to more than double the percent cover of dune vegetation in 1938. One may think that this occurred despite the two overwash events of 1978 and 1994, but in fact, the overwash events were beneficial to the dune community. Overwashes of fresh sand provide the nutrients needed for the active growth of beach grass. Without these natural overwash events, beach grass will only thrive along the edges of dunes facing the ocean (fore dunes), while the back dune vegetation undergoes succession to other dune species that are often less effective at securing the dunes. Throughout the study period, marsh vegetation (dominated by cordgrass species, *Spartina spp.*) shows a different trend than dune vegetation, with little or no fragmentation from anthropogenic activity within the marsh area. The only apparent negative impacts come from the two overwash events in 1978 and 1994, when the marsh vegetation is covered with sand (Figs. 11 and 13). Marsh vegetation can be seen recovering well in 1987 and 2001, following each of these storms (Figs. 9, 11, and 35). However, as of 2005 the percent cover of marsh vegetation has not recovered to levels prior to 1977 (Table 1, Fig. 35).

As may be expected, total vegetation also fluctuated during the study period (Table 1, Fig. 35), although there is no readily apparent trend. Changes in land mass area and in percent total vegetation showed similar trends. We see a clear decline in vegetation from 1938 to 1965, probably in part from the effects of ORV use; however, there is a recovery trend from 1970 onwards, particularly when we look at the images of 1977 and 2005, two years with no direct effects from overwashes (Fig. 35). At these two points in time, total vegetation cover is higher than during any other year.



Figure 36. The same view of Coast Guard Beach and the Coast Guard Station in February 1978 (top) and August 2007 (bottom).

Race Point

Land mass at Race Point shows a slow, but steady increase throughout the study period (Table 2, Figs. 37 and 38). As of 2005, land mass has increased by 6.6 ha. This steady increase is most likely due to constant increase in beach area from sand brought in by littoral drift.

Table 2. Land mass area (ha) and percent dune vegetation for eight years between 1947 and 2005 and an average for Race Point.

Year	Land Mass Area	% Dune Vegetation
1947	13.8	15
1960	14.6	0
1977	15.6	35
1986	17.8	52
1987	17.3	59
1994	19.6	1
2001	19.3	24
2005	20.4	28
Average	17.3	27

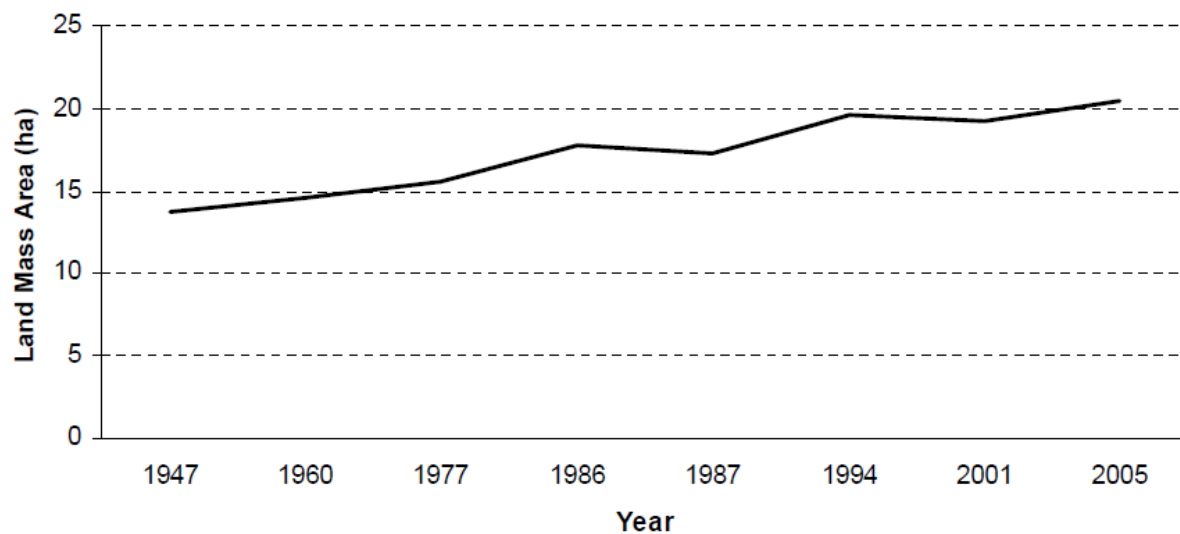


Figure 37. Land mass area at Race Point from 1947 to 2005.

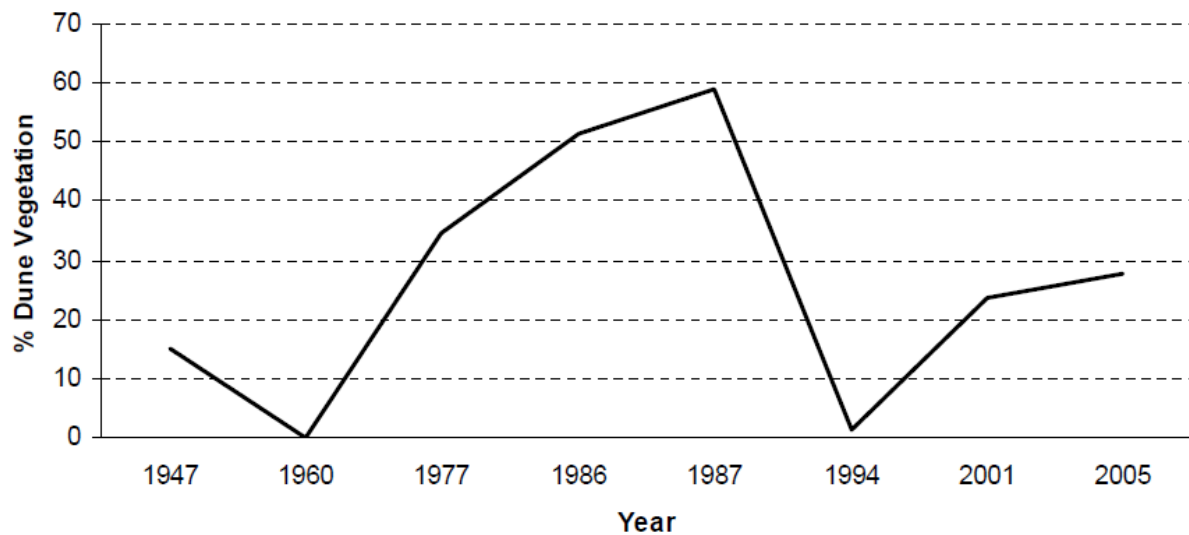


Figure 38. The percentage of the study area covered with dune vegetation at Race Point from 1947 to 2005.

As seen at Coast Guard Beach, the dune vegetation (primarily beach grass) was highly fragmented in 1947 (Fig. 17), partially due to human activity. Two parallel roads are clearly visible and there is very little vegetation in the back dunes. By 1960 almost all dune vegetation was gone, but there was a marked increase in vegetation in both the fore and back dune areas by 1977 (Figs. 18 and 19). The 1977 image also shows the visual results of one of Dr. Godfrey's research projects. To quantify the impacts of off-road vehicle traffic on dune vegetation, Dr. Godfrey's team laid out a track in a figure eight pattern on which a jeep was driven for a set number of passes over different portions of the track in 1974 (Fig. 19). Even less than 50 passes killed the vegetation and left a gap that can still be seen in 1987 (Fig. 21). This allows us to estimate a general recovery period of at least 13 years for beach grass after off-road impacts.

We don't know how much longer recovery may have actually taken; by the next available image for 1994, there was an overwash event coinciding with the northeaster in 1994 that covered the dune vegetation (Fig. 22). The gradual re-vegetation of former roads and paths within the dune area is clear in the images from the 1980's, as well as an increase in vegetation in the back dunes (Figs. 20 and 21). Following the 1994 overwash, we see a strong recovery of the fore dune, but only weak recovery of the back dune, as seen in 2001 and 2005 (Figs. 23 and 24). However, we did find a nearly fully recovered dune ecosystem in 2007, although there were still many unvegetated areas in the back dunes (Fig. 39).

In contrast to land mass, percent vegetation cover fluctuated throughout the study period, with two sharp declines, one in 1960 due to ORV use and possibly a storm, and a second in 1994 (Table 2, Figs. 37 and 38). Both declines are followed by fairly rapid recovery. It is important to note that at

Dr. Godfrey's suggestion, ORV use was banned from most of the study area in 1977, and aside from the 1994 storm event, dune vegetation increased from 1977 to the present.



Figure 39. Views of the site of experimental treatment of off-road vehicle (ORV) impact to dune vegetation (beach grass) in August 1974 (top) and August 2007 (bottom) at Race Point.

Hatches Harbor

Land mass increased slightly throughout the study period (Table 3 and Fig. 40). As of 2005, there has been an increase in land mass within the study area of 1.0 ha, added by tidal infilling. Infilling is caused by sediment deposition from littoral drift and sands from the dunes settling on to the tidal zone.

Table 3. Land mass area (ha), percent dune vegetation, percent marsh vegetation and percent total vegetative cover for five years between 1960 and 2005 and an average for Hatches Harbor.

Year	Land mass area	% marsh vegetation	% dune vegetation	% total vegetation
1960	14.6	3	10	13
1977	14.6	5	22	26
1986	15.2	18	41	59
1994	15.3	17	16	33
2001	15.5	14	14	28
2005	15.7	25	20	45
Average	15.2	14	20	34

The marsh vegetation within this study area was heavily affected by ORV traffic associated with shell fishing and other traffic to the beach prior to restrictions implemented by NPS. In 1960 the only marsh vegetation is within the northeast corner of the study area that was apparently less popular for recreational activities (Fig. 26). In 1977 we see the early stages of re-vegetation in the central marsh soon after the tidal flats were closed to all traffic as a result of ORV impact experiments (Fig. 27). By 1986 the central marsh is almost fully revegetated and continues to increase up to 2005 (Figs. 28-31). By 2005 marsh vegetation covers about 25% of the study area, and two distinct marsh vegetation types are apparent; however, this may be due to improved color imagery rather than a recent change in vegetation (Fig. 31).

In contrast to the marsh, the dunes remain sparsely vegetated throughout the study period. If we assume that the 2005 image shows a fully recovered marsh system, then approximately 75% of the study area should be covered with dune vegetation; however, dune vegetation generally only covers between 10% to 20% of Hatches Harbor, with a peak in 1986 of 40% (Table3, Fig. 41). The percent cover of dune vegetation increased until 1986, and then declined between 1994 and 2001, only beginning to recover by 2005. In contrast, marsh vegetation shows almost continuous increase or stability from 1977 onward, with only a slight period of decline between 1986 and 2001, increasing to peak coverage in 2005. The dramatic increase starting in 1977 was due to the restrictions in ORV traffic within the marsh. Total vegetation cover followed the general trends seen for the dune vegetation, with peak coverage of approximately 60% in 1986, followed by a decline in overall vegetation through 2001 and then an increase to 45% by 2005. In 2007 we see that the central marsh area had nearly fully recovered (Fig. 42).

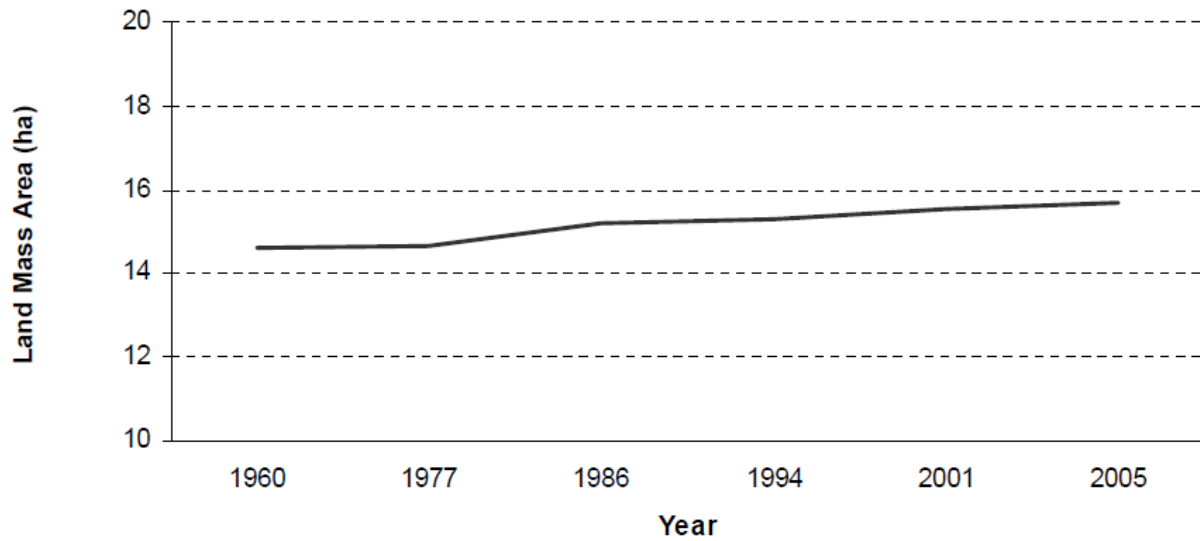


Figure 40. Land mass area at Hatches Harbor from 1960 to 2005.

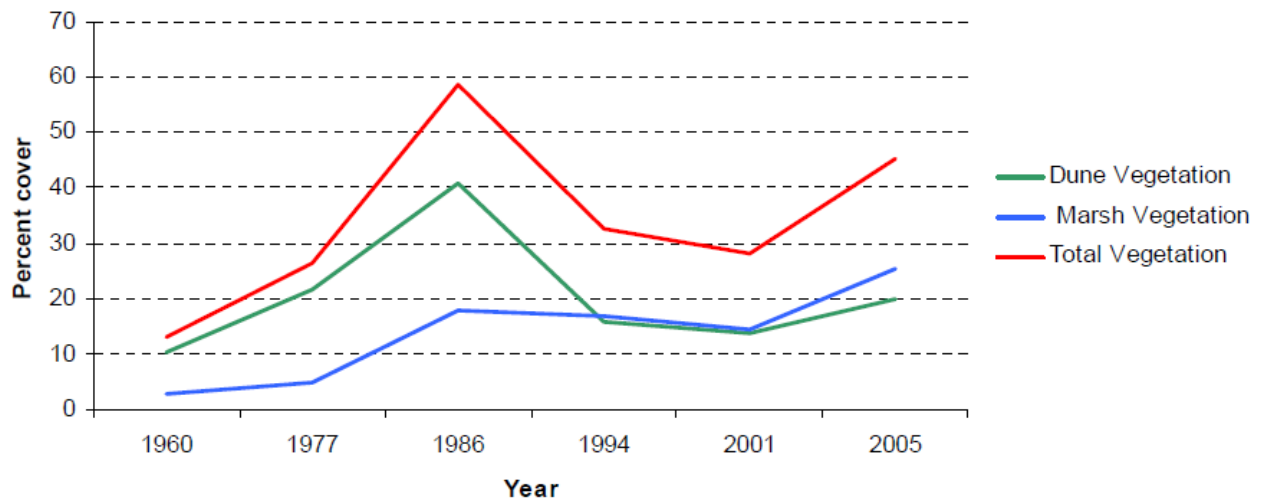


Figure 41. Percent dune vegetation, percent marsh vegetation, and total vegetation at Hatches Harbor from 1960 to 2005.



Figure 42. The same view of Hatches Harbor in 1974 (top) and in August 2007 (bottom).

Overall Trends

Changes over time in both land mass and percent vegetation cover were clearly evident at all three locations. There appears to be no apparent overall trend in changes in land mass area (Fig. 43); while there was a slow but steady increase at Race Point and Hatches Harbor, Coast Guard Beach showed more unpredictable fluctuations in land mass. This may be due in large part to the dynamic nature of the beach systems of Cape Cod - there is a steady movement of sand from the upper Cape to the beaches of the lower Cape. In addition, Coast Guard Beach is positioned such that it is exposed to greater wave action than the two sites located on the lower Cape. There appears to be more consistency among the sites regarding dune and total vegetation cover. There is a general trend for slow and steady increases in both dune and total vegetation until 1986 or 1987 (aside from the 1978 decline seen at Coast Guard Beach), followed by a sharp decline in vegetation in 1994 due to overwash from the storm of that year. From 1994 to 2005, there is again a period of general recovery, or increase in vegetation cover (Figs. 44 and 45).

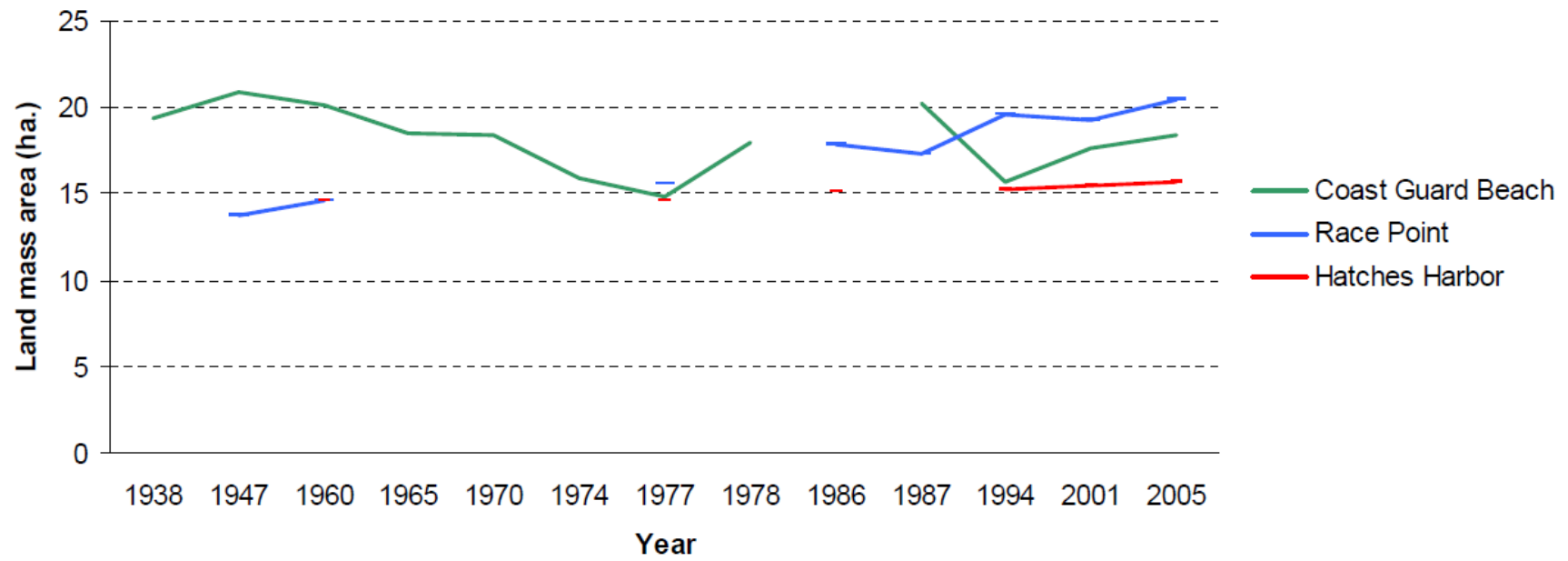


Figure 43. A comparison of land mass area from 1938 to 2005 at Coast Guard Beach, Race Point, and Hatches Harbor.

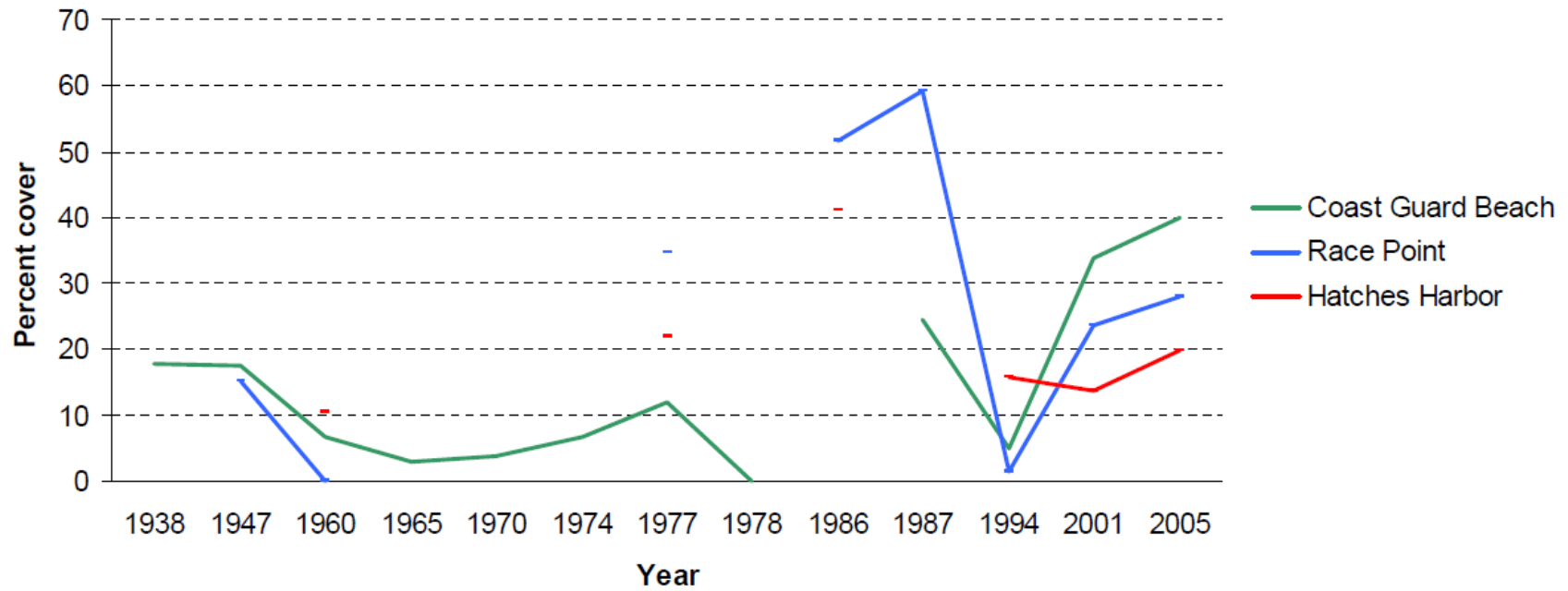


Figure 44. A comparison of percent dune vegetation from 1938 to 2005 at Coast Guard Beach, Race Point, and Hatches Harbor. Note the sharp decline at Coast Guard Beach in 1978 and at all three sites 1994.

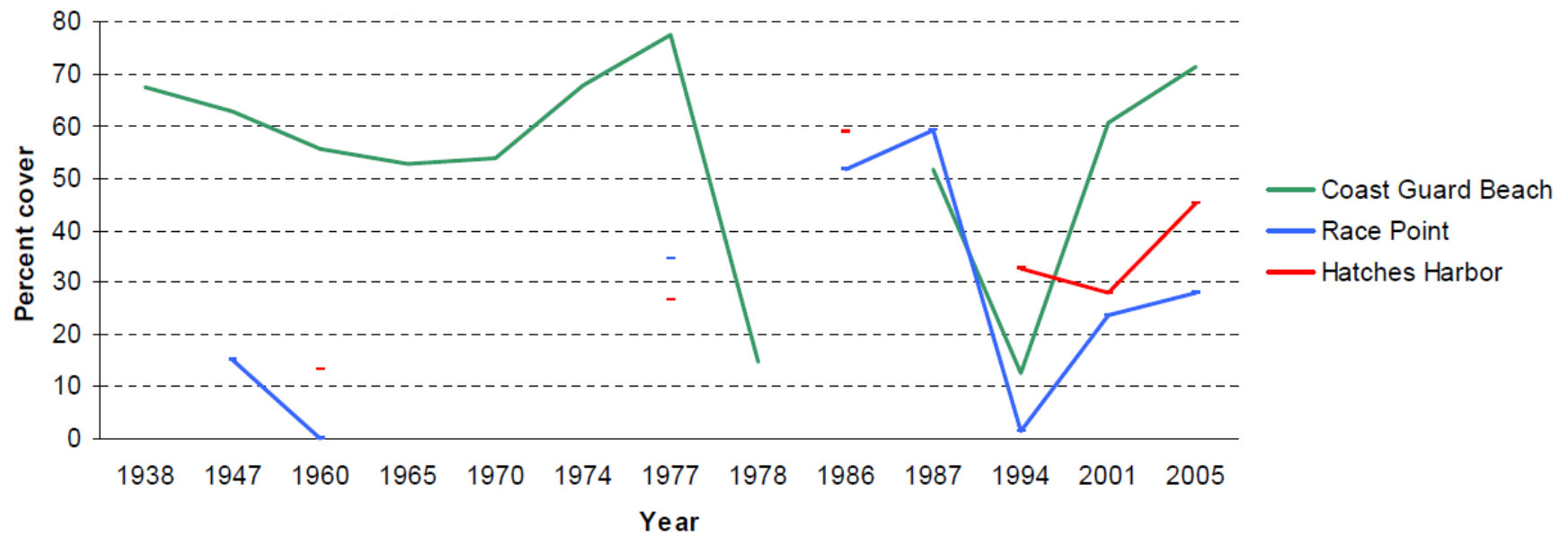


Figure 45. A comparison of percent total vegetation from 1938 to 2005 at Coast Guard Beach, Race Point, and Hatches Harbor. Note the sharp decline at Coast Guard Beach in 1978 and at all three sites in 1994.

Conclusion

The results of this study suggest that the management strategy of reducing anthropogenic impacts, including both recreational use and anti-erosion management, at all three study sites has been highly successful. In each case, there were periods of intense, negative impacts (human and natural) that resulted in the dramatic loss of vegetation, particularly dune vegetation. Beach grass is a key plant species in reducing dune erosion in New England, and Dr. Godfrey's research showed that this species is highly sensitive to impacts from human activities, leaving bare areas of sand open to the erosive effects of severe storms. However, overwash events, while they may appear to be devastating by burying the vegetation, are in fact beneficial to the beach grass, in the long-term. The current conditions at all three sites indicate that both the dune and marsh ecosystems have recovered from anthropogenic disturbance and appear to be restored to fully functioning habitats.

In the case of Coast Guard Beach, unvegetated pathways and open areas caused by human activities, the large paved parking area situated close to the beach, and the dredging of sand in an attempt to rebuild the beach may have all contributed to the apparently devastating effects of the winter storm of 1978. However, dune vegetation recovered rapidly and was far less fragmented than at any point previous to this in the study. A second storm in 1994 had a similar effect on the beach and marsh habitats, despite the fact that human impacts within the dunes had been greatly reduced. Following this second overwash, the dune vegetation recovered to levels higher than at any period prior to 1947. This illustrates the importance of these natural overwash events that import fresh sand and nutrients to dune communities. Human impacts were also apparent at both Race Point and Hatches Harbor up to 1978, affecting dune plant communities at both sites and playing a key role in the reduction in marsh vegetation seen at Hatches Harbor.

An important point illustrated in this study is that both dune and marsh vegetation communities have evolved to recover from natural impacts such as storm surges, and require little assistance from humans to recover, aside from the control of additional human impacts that may inhibit or slow recovery. Dr. Godfrey's advice to NPS was to let the dune communities reestablish themselves. He suggested that no erosion control structures such as rip-rap walls, or re-planting would be necessary for the recovery of these communities. NPS took this advice, and the history of these sites and their current conditions provide strong evidence that the best strategy for managing barrier beaches is to minimize anthropogenic disturbance and allow the ecosystem to recover from natural disturbances on their own. This way, these dynamic systems can fluctuate over time, responding to natural disturbances and rebounding relatively quickly, as they should.

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NPS 609/127577, January 2015

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