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Natural Resource Stewardship and Science

Development of the Geomorphological Map of Fire Island National Seashore (Post-Hurricane Sandy) and Metrics of Change

Natural Resource Report NPS/NRSS/GRD/NRR—2017/1420

ON THE COVER
Old Inlet, Otis G. Pike Wilderness Area
Fire Island National Seashore
Photo credit: USGS Marine Geology.
November 5, 2012.

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Norbert P. Psuty, William Schmelz, Joshua Greenberg, Irina Beal, and Andrea Spahn

Sandy Hook Cooperative Research Programs
New Jersey Agricultural Experiment Station
Rutgers University
74 Magruder Road
Highlands, New Jersey 07732

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Executive Summary

This report incorporates the geomorphological map, its philosophical underpinnings, legend descriptions, and the GIS data layers for the Fire Island National Seashore, Patchogue, New York in the aftermath of Hurricane Sandy, October 2012. The theme of the map follows the current scientific organization of geomorphological mapping that includes morphometrics, causative processes, and evolutionary stages. Surface form was interpreted from a combination of recent orthophotos, Post-Hurricane Sandy Light Detection and Ranging (LiDAR) data sets, spatial information on soils and vegetation, and field visits.

The geomorphological features of the site include: 1) coastal topography that was created during an early phase of coastal barrier island development; 2) coastal topography that developed seaward of the early stage of barrier island evolution; 3) topographical modifications created by Hurricane Sandy, and 4) anthropogenic modifications to the natural topography, consisting of fill or excavation. The geomorphological map and its legend portray the spatial and temporal association of the surface features created during these stages of landscape development, as well as the broad anthropogenic alterations of the landscape. These processes continue to influence development of the landscape and, as a result, this map will serve to identify a stage in the evolution of the geomorphology of Fire Island. Many of the geomorphological features incorporated on these maps were affected by processes and responses associated with Hurricane Sandy in October 2012. A comparison with a map representation of the pre-storm geomorphological configuration (2011) is tabulated. Thus, this report is organized into two sections:

- Part 1: A Post-Hurricane Sandy geomorphological map of Fire Island National Seashore.
- Part 2: Quantification of the dimensions of change in the magnitude and distribution of geomorphological features as a result of Sandy.

The geomorphological map is viewable as a full compilation of all of the data layers as well as user specified combinations of the data. Each of the map layers contained in this report meets the standards of Federal Geographic Data Committee (FGDC) compliant metadata. The full set of organized data layers is available from the Geologic Resources Division, National Park Service, PO Box 25287, Denver, Colorado 80225 or via the Geologic Resources Inventory publications page http://go.nps.gov/gripubs.

Acknowledgments

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Part 1. Development of the Geomorphological Map of Fire Island National Seashore (Post-Hurricane Sandy)

Introduction

Fire Island National Seashore (FIIS) is one of 270 National Park System units designated to have a digital geological map and an accompanying geologic resources inventory report. These products are intended to provide a valuable synthesis of the physical makeup of the site and assist in applying appropriate strategies in the management of its natural and anthropogenic resources. Under the sponsorship of the NPS Geologic Resources Division, a scoping meeting was held at the Fire Island National Seashore Headquarters on June 24, 2010 to discuss and identify the geological character and variety of resources extant at the site, and to provide direction to the compilation of the geological map. The product of the scoping meeting was a document that identified themes of interest to the managers of the site, sources of data appropriate to the mapping effort, potential geomorphological features, and considerations for inclusion (Thornberry-Ehrlich 2011).

The traditional geological map incorporates many rock formations that extend across time horizons and shows considerable structural control of the surface configuration. However, the relatively small size of Fire Island National Seashore and the existence of a limited sedimentary formation required a restructuring of the map to focus on the geomorphological character of the site; i.e., the configuration of the surface topography. As a result, FIIS is being represented by the elements of a geomorphological map rather than a geological map.

The concept of a geomorphological map traces its origins to Passarge (1914) and his representation of the surface character of the Stadtremba, Germany quadrangle that emphasized the presence of river terraces as specific physical features in the landscape. Subsequent portrayals of the geomorphological character of the earth surface incorporated elements of the morphology as well as the origins of the features (processes) and chronological development (sequence of formation) (St. Onge 1968). The modern geomorphological map incorporates the elements of form, functional processes, and sequential development to depict the evolution of surficial and spatial characteristics (Dramas et al. 2011). The geomorphological map presented in this report follows the three-fold communication of form in the landscape, developmental processes, and stages in spatial evolution. It has a temporal sequence of features that is related to the stages of development of the surface characteristics of the site. It addresses the action of the earth-forming processes on the deposition, mobilization, and subsequent accumulation of sediments to produce the resulting geomorphological characteristics at FIIS.

Coastal areas are especially dynamic because of the interaction of variable sediment supply, sea-level rise, aperiodic storm events, and the influence of human manipulation on the drivers of change as well as the products of change. Following the production of a geomorphological map based on orthophoto and LiDAR data from 2011 (Psuty et al. 2015), a major storm occurred in October 2012 (Hurricane Sandy) and produced significant changes to the surface characteristics of Fire Island, both in distribution and the extent of landform features. As a result, the focus of this report is the creation of a geomorphological map representing the landform characteristics following Hurricane Sandy and the subsequent identification and quantification of distribution and magnitude of the changes utilizing the pre-Sandy maps as a reference.

Site and Situation

Fire Island National Seashore is located on Fire Island, a barrier island situated on the south shore of Long Island, in Suffolk County, New York (Fig. 1). The entire barrier island extends east-west approximately 50 km between Moriches Inlet and Fire Island Inlet. The western 7.6 km is the site of Robert Moses State Park, whereas the eastern 10.3 km is occupied by Smith Point County Park. The central 32.3 km portion of the island includes Fire Island National Seashore and 17 private communities. FIIS jurisdiction incorporates Smith Point County Park as well as a portion of the adjacent submarine environment (Fig. 1). At present, the surface of the island retains much of its geomorphological heritage, although there are locations that have been greatly altered by Hurricane Sandy as well as by the anthropogenic development in the several parks and in the communities.

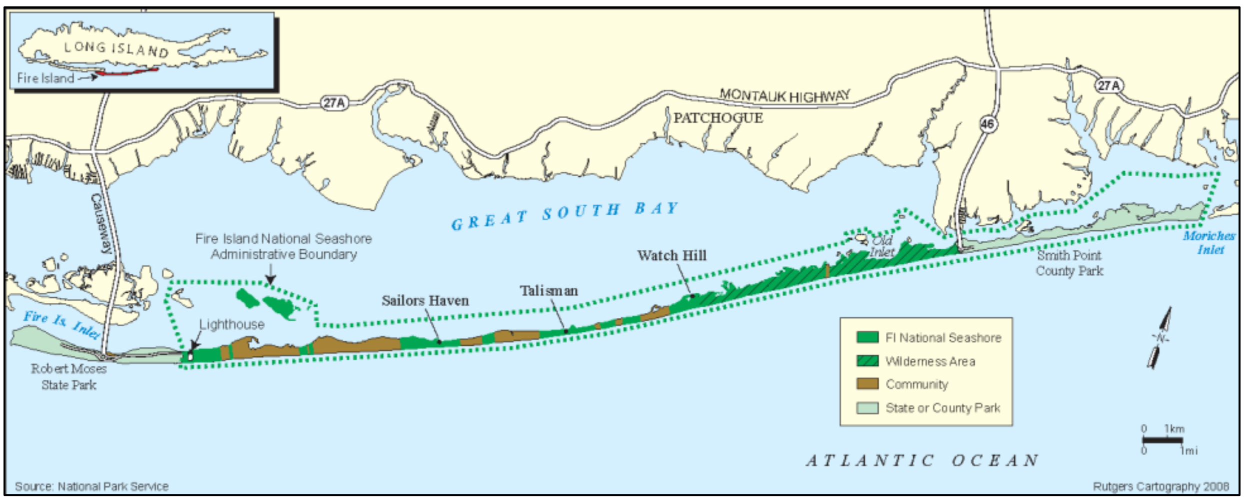

Figure 1. Location of Fire Island and FIIS on the south shore of Long Island, New York; with locations of Robert Moses State Park, Smith Point County Park, and FIIS jurisdiction.

Geomorphological Evolution

The conceptual approach to describing, depicting, and mapping the geomorphological characteristics of Fire Island is based on the components of morphometrics, causative processes, and temporal sequence of development of the surface of the island. This tripartite organization is the essence of modern geomorphological maps (Dramis et al. 2011) that combine the processes and the surface expression of the sedimentary formations (either in their erosional or depositional form). Further, the map legend (discussed later) is developed to track the evolution of the surface features and their associated causative processes, and to add the cultural imprint on to the landscape.

The surface topography of Fire Island represents several stages of sediment accumulation, sediment erosion, and sediment transport by a variety of formational processes over the span of the last ~3,000 years (McCormick and Toscano 1981; Psuty et al. 2005). Essentially, Fire Island is a barrier island that has been created as sediment accumulated at modern sea level and amalgamated from a series of smaller barriers to form a longer, relatively narrow island (Taney 1961; Leatherman and Allen 1985).

The dominant geomorphological processes creating the surface topography are the coastal waves and currents that transport and shape the ambient sediment supply to form an active beach and adjacent foredune. The foredune feature is the primary landform throughout Fire Island, as it is on all barrier islands. The active foredune represents the sand in storage above the active beach, and abandoned foredunes represent periods and locations of sediment accumulation that have prograded the island seaward and/or extended the island downdrift (to the west). The erosion, transport, and deposition of sediment by the agents of wind and water are the important formational processes that move sediment from the beach into the foredune position. Wind currents and flowing water also aid in the disruption of the foredune, creating breaches and blowouts and breaks in continuity of the linear foredune feature.

Whereas the primary sand dune ridge is the active foredune immediately inland of the beach, there are many other dune ridge forms located inland from the beach (former foredunes). The entire barrier island is replete with abandoned foredune ridges that mark earlier shoreline positions as the barrier island went through stages of accumulation and erosion, as well as westward extension (Leatherman and Allen 1985; Allen et al. 2002; Psuty et al. 2005). In addition to the newer linear ridges, there are older groups of sand dunes that are less extensive and less continuous. They are remnants of ancestral barrier islands that are now at the inner margin of the current Fire Island (Leatherman and Allen 1985; Psuty et al. 2005). Locations of former inlets are discerned in the pattern of foredune ridges, and the 1931 breach of the island to create Moriches Inlet has its own series of foredune ridges as the shoreline responded to the sediment transfers associated with the inlet. Hurricane Sandy caused a breach that altered the foredune topography, which is retained in the landscape.

The temporal sequence of the geomorphological evolution of Fire Island consists of the oldest series of foredune ridges near the bayside. The largest and most coherent ancestral component is at Sailors Haven where a former individual island can be identified as consisting of a series of accretionary foredune ridges, marked with many blowouts and depressions. This area and similar inland features are ancestral components of the present-day barrier. Some of the ancestral landforms are major features in the landscape, other ancestral units are more subdued and less continuous, having been subjected to erosion, especially by wind, and also inundated by sea-level rise since their development. The ancestral groupings of dune features have been succeeded by a sediment accumulation phase that has shifted the shoreline seaward and has created a continuous beach-dune topography that extends along the length of Fire Island. During Hurricane Sandy, the active foredune was severely eroded and dissected. Several breaches developed that at least temporally segmented the barrier island, thereby adding a very recent chapter in the developmental history of the geomorphological character of Fire Island.

Thus, the surface topography of the Fire Island barrier consists of a classic combination of ancestral and modern geomorphological features including 1) an older segmented dune system on the inland side of the barrier island, 2) a more continuous, more recent foredune system on the seaward side of the island, 3) an active foredune system immediately adjacent to the modern beach, 4) sites of recent dune removal, washover features, and island breaches, and 5) the imprint of anthropogenic manipulation of the surface topography. Together, they recount the variation in sediment supply interacting with the ambient coastal processes to create a geotemporal association of surface landforms, in keeping with the coastal foredune model and form assemblages described by Psuty (2004).

Resources to Aid in the Spatial Recognition of Features

A geographic information system (GIS) was developed for the construction of the geomorphological map of FIIS. The GIS includes orthophotos, light detection and ranging (LiDAR) data sets, and additional sources of geographical information that are described below (Table 1).

Orthophotography

A total of 52 image tiles collected by the National Oceanic and Atmospheric Administration (NOAA) National Geodetic Survey (NGS) with 0.35 m spatial resolution were accessed online from the NOAA Coastal Services Center (NOAA 2012a).

LiDAR

The LiDAR data set was collected on November 20th, 2012 by the USGS and Woolpert Inc. and made available online through the NOAA Coastal Services Center (USGS 2013). The data set incorporated topographical LiDAR data in LAS format with points classified as unclassified, ground, and water. The dataset also included LiDAR return intensity.

Additional Sources

The primary additional source of spatially-organized data was the pre-Sandy report and map produced by Psuty et al. (2015). Also, 58 image tiles collected by the NOAA NGS in 2011 with a 0.35 m spatial resolution (NOAA 2012b), a LiDAR data set collected on November 25, 2011 (NOAA 2012c), a soils map (NPS 2005) and a vegetation map and report (Klopfer et al. 2002) downloaded from the NPS Integrated Resource Management Application (IRMA) site, plus several geological reports (Gray Smith et al. 1999; Leatherman 1985; Psuty et al. 2005; Psuty and Silveira 2008), and sets of 9X9 stereo-pair aerial photos, 1:2400 scale, taken in 1992 were utilized in a supplementary capacity. A recent anthropogenic history (Koppelman and Forman 2008) offered perspective on the variety and extent of anthropogenic modifications. Locations of buildings, infrastructure, and boundaries were accessed from the NPS IRMA website. Roads and walkways were digitized from the orthophotos.

Table 1. Sources and quality of spatial data

Data	Year	Resolution	File Type	Source
Geomorphological map	2014	-	.gdb	NPS IRMA
Orthophotos	2011	0.35 m	.jp2	NOAA
Orthophotos	2012	0.35 m	.jp2	NOAA
9x9 stereo aerial photos	1992	0.5 ft	paper	Rutgers University
LiDAR (bare earth) LiDAR (bare earth)	2011 2012	0.73 m (0.89 m)*	LAS LAS	NOAA USGS and Woolpert
LiDAR (bare earth)	2010	0.72 m (1.17 m)*	LAS	Sanborn
Soil Map	2005	-	.shp	NPS IRMA
Vegetation	2002	-	.shp	NPS IRMA
Road/Walkways	2007	-	.shp	NPS IRMA and digitized from orthophotos

* = point spacing

Methodology of Topography Development

The initial approach of landform identification used 2012 orthophotos of FIIS (Fig. 2) to establish the geographical coordinates of the geomorphological units. The next phase utilized a 2012 bare earth LiDAR data set for FIIS, provided by the USGS and Woolpert, to create a digital elevation model (DEM). However, the LiDAR bare earth DEM produced by this data set exhibited some noise in areas of dense vegetation and/or buildings. To minimize these surface perturbations, the raw LiDAR data points were filtered using the Reduce Point Density method via Airborne LiDAR Data Processing and Analysis Tools (ALDPAT) (Zhang and Cui 2007) software to create a new bare earth DEM. The Reduced Point Density method searches for and chooses the point of minimum elevation within a specified area, or window, to represent that location. Three iterations of this filtering were applied to the bare earth LiDAR points, enlarging the window each time (three iterations [1m, 3m, and 5m windows]). Each subsequent iteration was applied to the filtered data points of the previous iteration. The third iteration of this filtering process provided a bare earth LiDAR surface with sufficient relief to determine the spatial boundaries of the geomorphological features while discarding most noise associated with non-ground points. The reduced density point cloud was then interpolated into a 2.5 m resolution DEM using the Kriging method with a 50 m search radius. The resulting reduced point density DEM layer was somewhat less detailed because the more minor variations were smoothed to emphasize the general trends in elevation (Fig. 3).

Figure 2. 2012 Post Hurricane Sandy orthophotos of Otis G. Pike Wilderness Area, Fire Island National Seashore, (Source: NOAA).

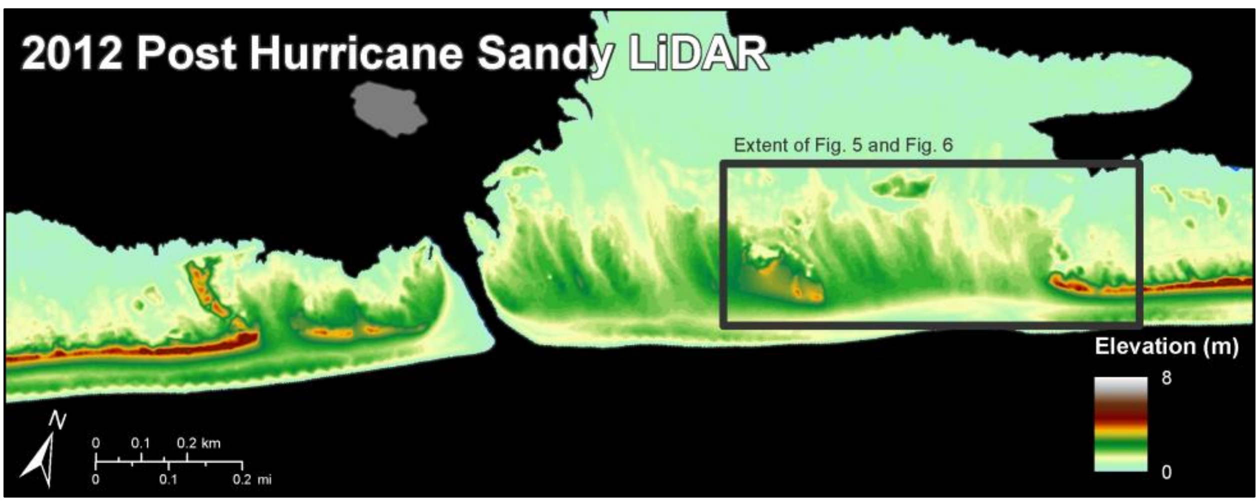

Figure 3. Digital elevation model (DEM) with elevation categories created from 2012 Post Hurricane Sandy LiDAR data set with reduced point density, Otis G. Pike Wilderness Area, Fire Island National Seashore (Data available through USGS (Woolpert, 2012)). Inset window identifies location of the area incorporated in Figures 5 and 6.

A further refinement of the DEM incorporated the identification of changes in slope and dimensions of relief to help define the boundaries of the geomorphological categories and focus on the major changes. Thus, isolines of slopes were plotted to depict boundaries between ridges and swales, as well as the boundary of washover deposition (Fig. 4). The result was a landform categorization into ridges, swales, and planar surfaces of various dimensions and continuity based on boundaries determined by changes in slope and local relief. After the juxtaposition of topographical features was determined, their sequential evolution was interpreted using the fundamentals of sediment transport direction, sediment supply, and sediment budget. This process eventually outlined the distribution of beach, active and abandoned dune ridges, swales, and zones of washover deposition (Fig. 5). An additional enhancement of the elevation portrayal was performed by adding a shading effect generated by applying the hillshade tool in ArcGIS on the reduced point density DEM layers and incorporating that view in the geomorphological map (Fig. 6). The hillshade tool simulates illumination and shading of a 3-dimensional topographic surface, creating the appearance of relief on a 2-dimensional surface.

A vegetation map was used as supplemental information in the manual digitization of geomorphological features. Specifically, the 2008 vegetation map of FIIS and 2012 orthophotos were used to identify the extent of marsh. Orthophotos provided contextual information regarding the positioning of modification of the landscape, erosion-control structures, beaches on the oceanside and bayside, and other natural and anthropogenic features on the landscape. The topographical interpretations of areas of dense vegetation and low relief were verified through field visits.

Throughout the map generation process, all of the ancillary resources were consulted to help in the identification of the surface features, their characteristics, and their boundaries. Continuous feedback between site-specific landform designation and general categorization resulted in a consistent classification of landform features throughout FIIS.

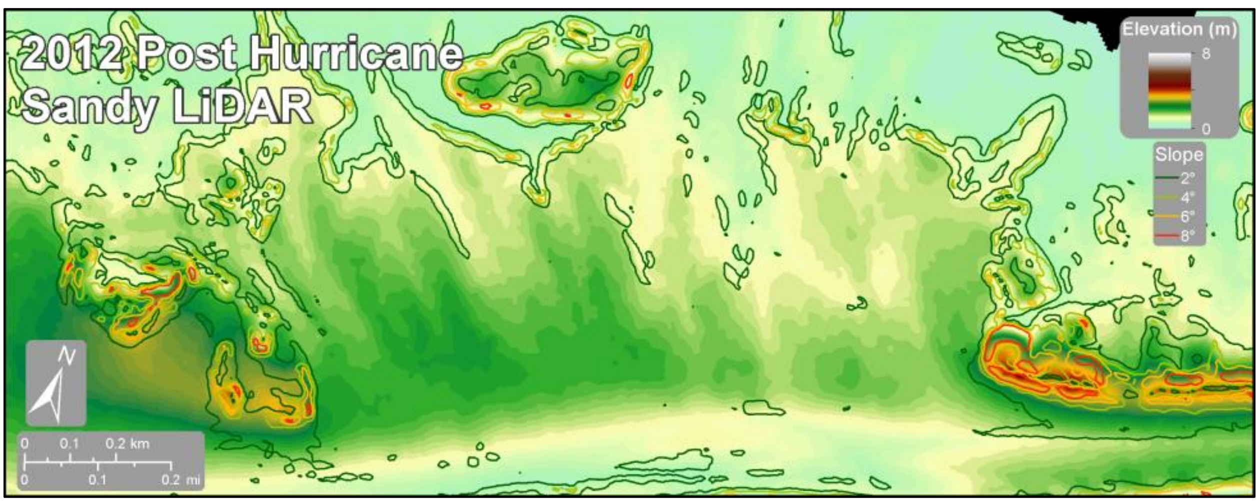

Figure 1. Incorporation of slope isolines to define landform boundaries within the DEM, Otis G. Pike Wilderness Area, Fire Island National Seashore.

Figure 5. Distribution of geomorphological features, with boundaries created using elevation, relief, and slope criteria, plus supporting resources.

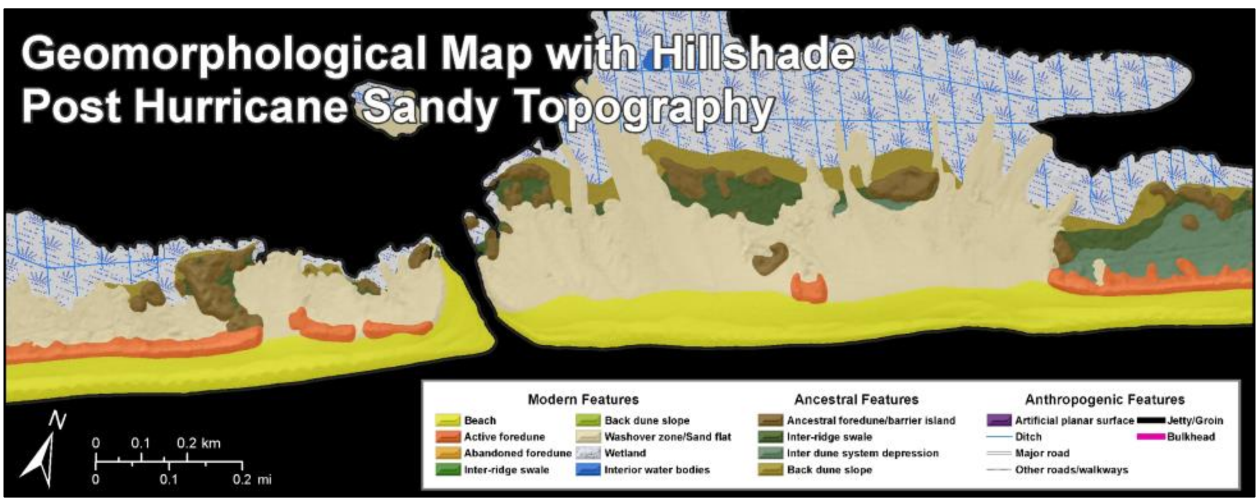

Figure 6. Distribution of geomorphological features, incorporating the modern, ancestral, and anthropogenic characteristics of the post Hurricane Sandy topography with relief emphasized through the application of hillshade, Otis G. Pike Wilderness Area, Fire Island.

Legend: Categories and Symbolization of Geomorphological Features

The legend is organized relative to the geomorphological evolution of the site, incorporating the spatial sequence of coastal landform development composed of ancestral and modern features (Fig. 7 and Table 2). Ancestral features are elements of the landscape that were created at an earlier time when the shoreline and shore processes were active at that location. It is likely that the ancestral features composed a series of smaller separate barrier islands. They are now represented by groupings of discontinuous dune features in the present landscape, usually at or near the inland margin of the barrier island. These groupings subsequently coalesced into a single island through the accumulation of sediment that has both joined the several smaller islands and has displaced the shoreline and its accompanying geomorphologies seaward. The modern features are associated with the lengthier continuous barrier that tends to have a more linear array of progradational dunal ridges parallel to the present shoreline. Their more uniform and consistent morphologies are distinct from the irregular and far more variable topographies of the ancestral groups, and thus establish a morphological distinction between the ancestral and modern features. In the broad spatial context of landform features on Fire Island, there is a separation between the segmented ancestral dunal features and the more continuous modern linear dune topographies, and there is a pattern of active and abandoned linear foredunes in the modern series. The most recent major change was a breach produced by Hurricane Sandy that segmented Fire Island into two main units. Hurricane Sandy also affected other portions of Fire Island by producing major erosion of existing dune features as well as forming extensive sand flats and washover fans. In addition to the evolving topography created by natural processes, some portions of Fire Island have been largely modified to accommodate park development and occupation (primarily in the county and state parks). Thus, a category of 'planar surface' has been added to the legend to describe topographies that are essentially a level surface in the landscape created by human manipulation. In a few locations, primarily on the bayside, some anthropogenic features (bulkheads, artificial fill) are superposed on the geomorphology.

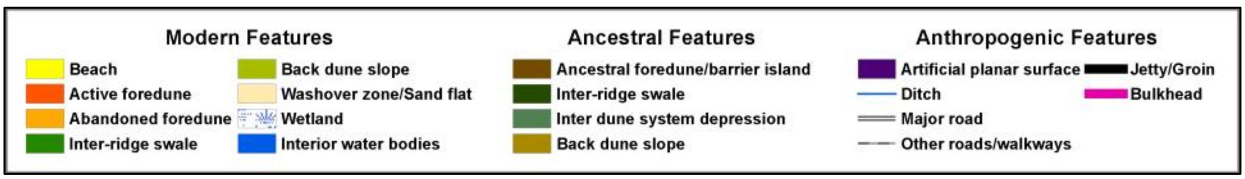

Figure 7. Map legend, incorporating categories of geomorphological features, sequence of modern and ancestral features, and anthropogenic features.

Table 2. Geomorphological Features in the Fire Island National Seashore.

Geomorphological classification	Conceptual Basis	Physical Description and Identification
Active Features		
Beach	Wave-deposited accumulation of sediment, specifically the seaward portion of a beach profile between the low tide line and the upper limit of storm wave action.	Alongshore area of low, nearly planar elevation on the oceanside and bayside margin of the barrier island. A very prominent feature that tends to be broad, continuous, and has sparse to no vegetation. The mapped feature extends from NAVD88 to the toe of the active foredune.
Foredune	Ridge formed by wind- and water-deposited sand at the inland margin of a beach, parallel to the coastline. It is vegetated by pioneer plant species that trap sediment. The foredune is actively participating in sediment exchange with the beach.	A continuous, linear feature of elevated topography (positive relief) that is parallel to the shoreline and immediately inland of the oceanside or bayside beach. Foredunes may be irregular in areas of dissection by wind and/or water.
Wetland	A general term describing swamps and marshes in areas of very low elevation. Often found in areas sheltered from ocean waves such as the bayward side of the barrier island or isolated islands on the bayside.	A flat surface in the intertidal zone characterized by wetland vegetation identified through the use of vegetation maps and aerial imagery. Drainage ditches were often excavated in wetland areas in an attempt to control mosquito populations.
Interior water bodies	Areas of open water within the boundaries of the barrier island, not connected by tidal channels to the bay or ocean. Often occurs as ponds within wetlands but may exist in other areas as well.	Distinctly visible on orthophotos. Only water bodies identified at the 1:12000 map scale are delineated in this category.
Abandoned Features		
Abandoned foredune	A previously active foredune ridge that is no longer in sediment exchange with the beach because of shoreline progradation. It may form on the oceanside or bayside margins of the barrier island and may have been reworked by winds into parabolic, hummocky, or dissected features.	A dune ridge inland of the active foredune, it may be generally linear and intact or dissected. It is usually in relatively close proximity and parallel to the active foredune ridge.
Inter-ridge swale	A topographical low area between shore-parallel dune ridges that forms during time of abundant sediment supply (shoreline progradation), and occupies the space between the sequential, parallel foredune ridges.	Swales are the continuous and low areas that occur between the sequential, parallel foredune ridges, usually parallel to the active shoreline.
Back dune slope	Low area immediately inland of the leeward slope of the inlandmost dune ridge. It is related to the foundation of the dune-forming processes	Located on the inland margin of a dune ridge or series of dune ridges. Elevation and slope are generally low and tend to decrease toward the bay side, i.e., slopes away from the dune ridge toward the water.

Table 2 (continued). Geomorphological Features in the Fire Island National Seashore.

Geomorphological classification	Conceptual Basis	Physical Description and Identification
Abandoned Features (continued)		
Washover zone/Sand flat	Feature caused by an episodic storm event that penetrated inland of the foredune ridge toward the bayside margin of the barrier. A relatively flat blanket of sediment deposited in place of previously existing features, often including a washover fan-shaped deposit on the landward side of the barrier island.	May be identified as an uncharacteristic break in continuous, shore-parallel linear features of positive relief such as the active foredune or abandoned foredune. It may be a fan-shaped positive elevation on a lower planar surface. Often visible on orthophotography as bare sand. The previously existing dunes may be retained adjacent to the washover fan as low, hummocky dune features.
Ancestral Features		
Ancestral foredune	An ancestral barrier island component that has been incorporated into and forms the accretionary core of the modern-day barrier island. This feature is temporally distinct from the more recently-created abandoned and active foredunes. The ancestral foredune is more dissected and less continuous than the modern foredune and its associated abandoned foredune ridges. There is a distinct spatial gap between the more recent coherent ridge forms and the more irregular ancestral foredune features, represented by a significant inter dune system depression.	Inactive dunal ridge at the inland margin of the barrier, it may be highly dissected and reworked by wind or overwash. Often physically separated from more recent ridges by a significant inter dune system depression. Forms the core of highly stable, broad sections of the barrier island. Feature may be large and coherent or low and dissected. It is spatially and morphologically separated from the shore-parallel active foredune.
Inter-ridge swale	Accumulation of sand between dune ridges that forms during a time of abundant sediment supply (shoreline progradation), and occupies the space between the sequential, parallel foredune ridges.	A linear hollow or topographical low between parallel dune ridges, that is usually parallel to the shoreline at that time. Swale will have lower elevation and negative relief in relationship to the adjacent dune ridges.
Back dune slope	Area immediately inland of the leeward slope of the inner dune ridge.	Elevation is generally low and tends to decrease toward bay side, i.e., slopes away from the dune ridge toward the water.
Inter dune system depression	Accumulation of sand that forms during a time of abundant sediment supply (shoreline progradation), it is a topographical low separating the development of modern foredune systems from the ancestral foredune system. It is a prominent linear depression at a lower elevation than adjacent ridge systems.	Substantial area of lower elevation (negative relief) between major dune systems. Often parallel to the coastline, separating the shore parallel modern dune ridges from the ancestral dune ridges. In some areas where the older dune system has been substantially reworked, the inter dune system depression merges with the back dune slope.

Table 2 (continued). Geomorphological Features in the Fire Island National Seashore.

Geomorphological classification	Conceptual Basis	Physical Description and Identification
Anthropogenic Features		
Artificial planar surface	A human-made flat or planar surface that has been leveled or built-up to site some sort of structure or human use, such as a building, parking area, or commercial activity. Underlying topography is destroyed or covered and replaced by created surface. Irregular dunal ridge and swale topography may be leveled to create a uniform surface. Or, sediment may be introduced by dredging or truck to elevate a surface above tidal levels.	Elevation of the surface is nearly or completely homogeneous and level. This surface produces an abrupt interruption of adjacent naturally-occurring topography. Boundary of surface is often sharply-defined and clearly visible on the orthophotos. On the bayside, it is usually associated with bulkheads and housing or marinas on the orthophotos and in the field. Fill may also cover pre-existing wetlands and provide a dry foundation for human occupation.
Jetty/Groin	An engineered structure that projects perpendicular to the shoreline. A jetty is a large structure with the purpose to stabilize the location of an inlet channel. A groin is a smaller structure in the beach, built to trap sand and stabilize a portion of a sandy beach.	Jetties and groins can be identified utilizing orthophotography. Their location is often indicated by the linear margin of an inlet, perpendicular to the trend of the shoreline, or as an offset in the beach that is the result of trapped sediment, respectively.
Bulkhead	An erosion control structure that is constructed at and parallel to the shoreline to harden the shoreline next to existing development or to maintain water-dependent uses such as marinas. Erosion-control structures include bulkheads, riprap, marinas or other structures that harden the shoreline.	Erosion control structures are identified from LiDAR, from orthophotos, and a field visit. These structures are found in developed portions of the island as a linear shoreline that separates land from water with an abrupt change in elevation.
Drainage ditch	Waterways historically dug in wetlands in a parallel grid pattern in order to drain wetlands and control mosquito populations. They are usually abandoned and no longer maintained as a water course.	Drainage ditches are identified from orthophotos as linear channels within the wetland area. Abandoned or unmaintained ditches may be filled in with sediment. Only ditches visible at the map scale are delineated as straight blue lines.

Final Product

The Fire Island geomorphological map is the spatial portrayal of the evolution of the barrier island system that developed from a series of several discrete ancestral units through its consolidation into a continuous barrier and subsequent separation by Hurricane Sandy. It has topographical features that show a series of accretionary dune ridges that recount the westerly extension into Fire Island Inlet, a series of accretionary ridges that show the enforced locational stability at the jettied Moriches Inlet, and major washover features that extend onto and across portions of the barrier island. The Fire Island geomorphological map consists of 17 panels, covering the extent of the island from Fire Island Inlet to Moriches Inlet. Two additional panels are provided that portray the geomorphological characteristics of several bay islands within the Park jurisdiction. One set of panels portrays the distribution of geomorphological features without hillshade. One set of panels incorporates hillshade in their depiction.

Part 2. Metrics of Change

Geomorphological Metrics

The completion of the post-Hurricane Sandy geomorphological map provided a representation of the geomorphological configuration at FIIS directly related to the collection of its source datasets, particularly the LiDAR elevation data. The LiDAR dataset, collected on November 5, 2012, provided a snapshot of the surficial topographical expression resulting from the interaction of antecedent geomorphological architecture and the physical processes associated with the storm. Application of the methodology for the geomorphological categorization of topography detailed in Part 1 of this report resulted in a mapped representation of the geomorphological features with dimensions derived from the LiDAR DEM. Therefore, the post-Hurricane Sandy geomorphological map was assigned the temporal value of November 2012, the date of the post-Hurricane Sandy LiDAR collection, and represented a stage in the development of the barrier island's geomorphology. Similarly, the 2011 geomorphological map, completed utilizing the same methodology as the post-Hurricane Sandy map, was created with LiDAR data collected on September 16, 2011, and assigned the temporal value of September 2011. The creation of two geomorphological maps from temporally distinct topographical data sources provided an opportunity for the comparison of the geomorphological features depicted on them.

The metrics derived from this comparison are primarily grouped as areal or linear, describing the spatial dimensions required for their quantification. The two-dimensional areal comparisons represented the change in spatial distribution of discrete geomorphological features defined by the spatially-registered polygons that comprised each geomorphological map. Alternatively, the one-dimensional linear displacement metrics described both the cross-shore and alongshore shift of geomorphological features that lie at finite and readily identifiable positions on the profile. Because each map dataset was considered as a representation of the geomorphological configuration at a given time, quantifications derived from the comparisons of the maps represented net change over time. In this case, the dimensional change was related to the occurrence of the Hurricane Sandy storm event. The spatial distribution of the changes are placed into an alongshore context by assigning their occurrence within three distinct units of consideration. They consist of: 1. each of the 17 map "Areas"; 2. each community; and 3. each management agency jurisdiction. The following geomorphological metrics were tabulated:

Areal

- The difference in spatial extent (area) for each geomorphological feature category.

Linear

- Displacement of the ocean-facing shoreline position.
- Displacement of the foredune crest, defined as the highest elevation within the "Active foredune" geomorphological feature category.
- Alongshore length of the ocean-facing shoreline and the "Active foredune" geomorphological feature category present within each geomorphological map dataset.

- The net foredune alongshore length represented as a percentage change from 2011 to 2012.

Together, these metrics offer an insight into the vectors of topographical evolution that occurred in the temporal span between September 2011 and November 2012, mostly as a result of Hurricane Sandy.

Methodology for the Derivation of Metrics

The methodology for the derivation of each metric of change involved the identification of a geomorphological feature's areal extent or position of each temporally distinct map dataset, the calculation of change in area or position between those two quantities or points, and the representation of that change within an alongshore context listed in the tables of results.

Areal Change

The single areal quantification was the change in distribution of the planimetric area of geomorphological features between the two map datasets, 2011 and post-Hurricane Sandy. At its base, each map dataset consisted of a group of polygons with digitized vertices registered in geographical coordinates of the spatial boundaries of the geomorphological features. Each of these polygons produced an areal dimension of a particular geomorphological feature. Once the calculation was achieved, the areas of polygons of a given classification were added to provide the total area for that classification across the entire map, or a segment of it.

The next step involved the division of the entirety of the Fire Island geomorphological map into smaller segments, and grouping them into: 1. each of the 17 map "Areas"; 2. each community; and 3. each management agency jurisdiction. In every one of these segments, the total area of individual polygons belonging to each of the geomorphological feature categories was calculated for both the pre- and post-storm maps (see Fig. 8 for an example of categories and comparative dimensions). Then the difference between the two maps was calculated for each individual category within that segment. This procedure was repeated for the geomorphological features within each of the segments and collated to create the dimensional changes according to: 1. map "Area"; 2. community boundary; and 3. management agency jurisdiction. The results of the calculations are in Table 3, Table 4, and Table 5, respectively.

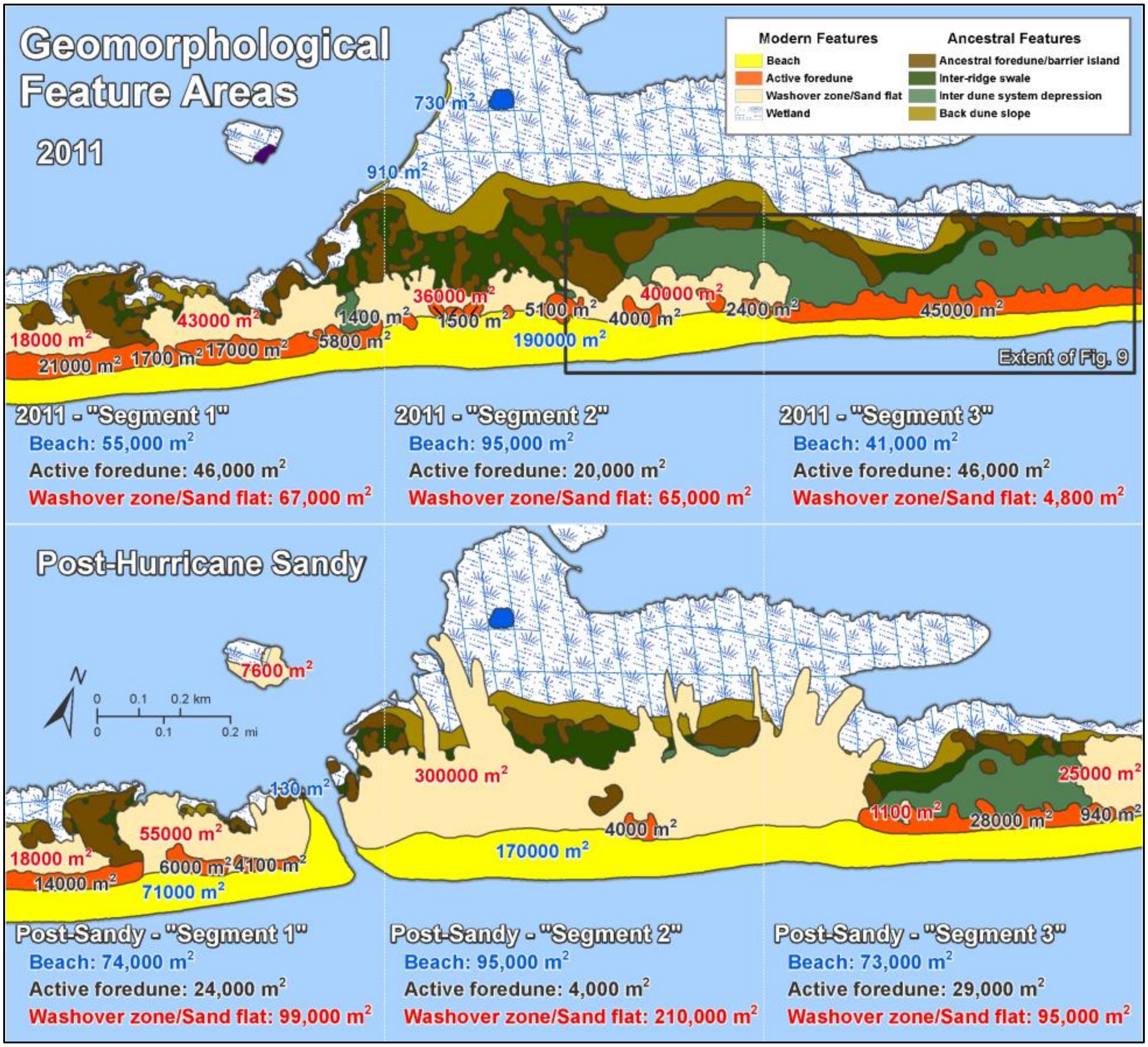

Figure 8. Planimetric area values for individual polygons of some geomorphological feature categories are represented and summed within sample alongshore segments for both the 2011 and post-Hurricane Sandy map datasets, Otis G. Pike Wilderness Area, Fire Island National Seashore.

Linear Change

A number of metrics were developed to measure the change of linear geomorphological features, including the displacement of the shoreline, the displacement of the foredune crest, the alongshore length of the foredune, and the change in alongshore length of the foredune. Each of these metrics represented the linear displacement of positions identifiable using the geomorphological maps and LiDAR elevation datasets. With the exception of the foredune crest, these positions coincided with geomorphological feature boundaries represented in the maps. For example, the position of the shoreline was at the seaward boundary of the beach category, defined as the intersection of the beach face and NAVD88, whereas the foredune crest was located within the Active foredune's boundary. Each of these quantifications used a characteristic criterion for the identification of the geomorphological feature they describe and, as with the areal metric, were tabulated according to their occurrence within defined alongshore segments of Fire Island. A mean value of discrete samples was required to describe the cross-shore change per alongshore component because the shoreline and foredune crest displacements were metrics describing cross-shore displacement per some unit length along each segment. Whereas the alongshore length of the foredune could be measured directly without the need for averaging, it did require the addition of individual foredune ridge lengths within a given segment (Fig. 9).

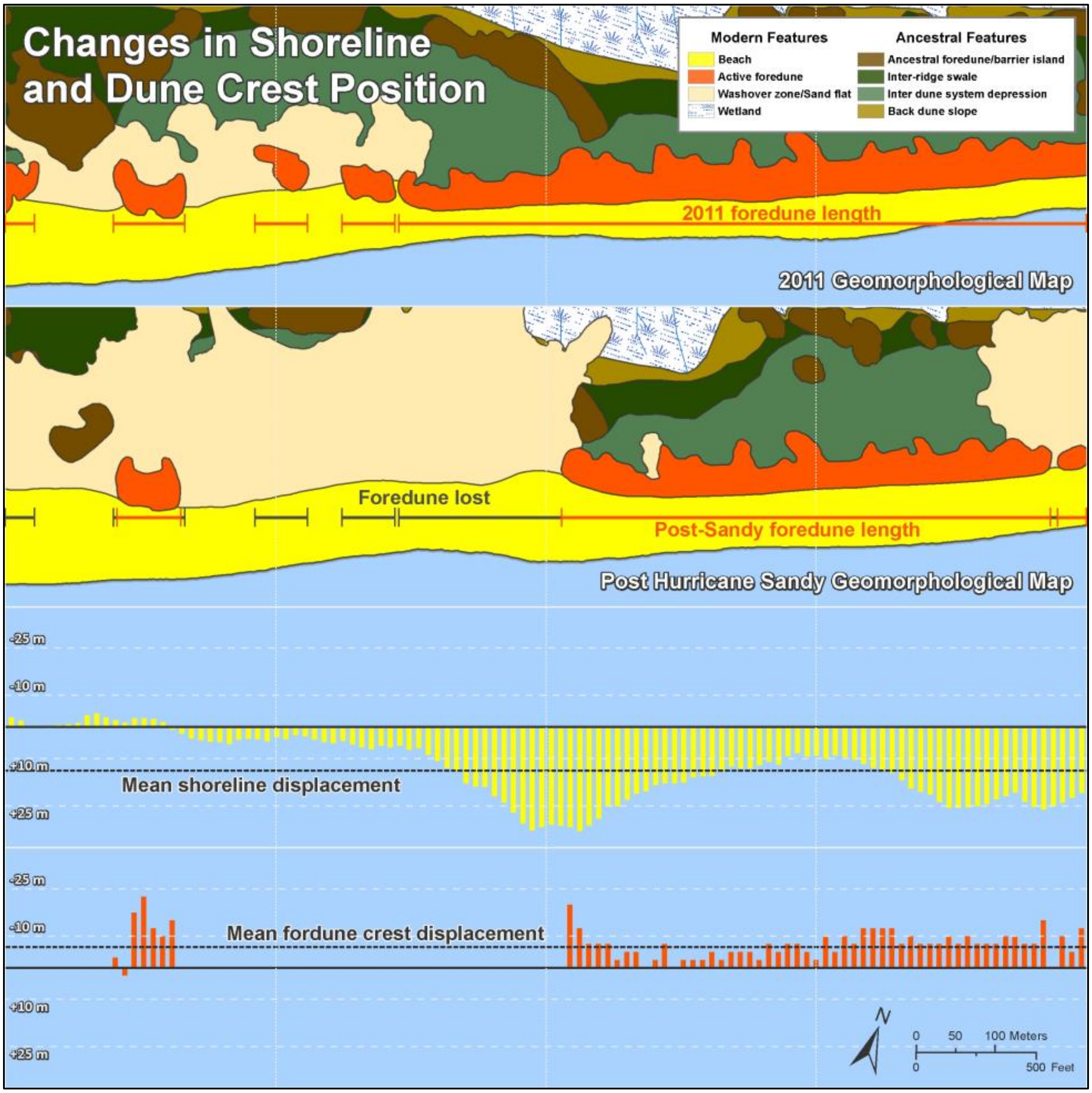

Figure 9. Portrayal of shoreline and dune crest position displacements as vectors extending from an offshore baseline, and the alongshore length of the Active foredune before and after Hurricane Sandy, Otis G. Pike Wilderness Area, Fire Island National Seashore.

The first linear metric, shoreline displacement, was defined as the cross-shore change in position of the seawardmost boundary of the "Beach" feature category, a position at NAVD88 on each geomorphological map dataset derived from LiDAR elevation data. Similar to the procedure utilized by the USGS Digital Shoreline Analysis System (Thieler et al. 2009), the shoreline position for each map dataset was quantified using the projected coordinates of the intersection of the NAVD88/Beach boundary line and cross-shore transects. For a given transect, the change in position was described by the vector that compared the intersection of the transect and the shoreline for each geomorphological map dataset. A standard interval of 12 m was applied between transects that created measurements of the cross-shore position of the shoreline every 12 m. All of the shoreline change measurements within a given alongshore segment were averaged, representing the mean displacement for that length of shoreline (Fig. 9). Mean shoreline displacement values were calculated for measurements within: 1. each map "Area"; 2. each community; and 3. each management agency jurisdiction. The results of the calculations are in Table 6, Table 7, and Table 8, respectively.

The foredune crest analysis was carried out utilizing a similar methodology to that used to derive the shoreline displacement metric. The same set of cross-shore transects used to sample the position of the shoreline was used to determine the position of the foredune crest, with mean displacement values calculated for the same alongshore segments. However, an additional step was required because the foredune crest did not lie on the boundary of a geomorphological feature polygon. First, the foredune crest was identified by utilizing the map and LiDAR datasets to determine the points of highest elevation within the boundary of the "Active foredune" category. This was accomplished by constructing cross-sectional elevation profiles along each transect represented in each geomorphological map (pre- and post-Hurricane Sandy). Utilizing these profiles, the highest elevation within the "Active foredune" category was extracted and its geographical coordinates were recorded. Similar to the shoreline analysis, the vector between this position for each set of temporal datasets on a given transect provided the displacement of the feature. The foredune crest change measurements within a given alongshore segment were averaged, representing the mean displacement of the foredune crest for that length of shoreline (Fig. 9). Mean foredune crest displacement values were calculated for measurements within: 1. each map "Area"; 2. each community; and 3. each management agency jurisdiction. The results of the calculations are in Table 6, Table 7, and Table 8, respectively.

In addition to cross-shore foredune crest displacement, a second foredune displacement metric was required to adequately describe the linear change to the foredune feature. Because of severe erosion, there were differences in the alongshore length of the foredune feature in the two map datasets. Therefore, displacement of dune crest could not be calculated at every transect. Instead it could only be calculated at transects that intersected "Active foredune" on both maps (Fig. 9). To quantify the variable alongshore distribution of the dune crest, the alongshore length of "Active foredune" was tabulated for both maps, and the change in its alongshore length was presented as the percentage of the "Active foredune" feature lost in the post-Hurricane Sandy maps. These metrics were calculated and spatially assigned by: 1. map "Area"; 2. Community; and 3. management jurisdictional boundary. The results of the calculations are in Table 6, Table 7, and Table 8, respectively. For comparison, the inherently consistent alongshore length of the shoreline was added to these tables.

The only area that had a different alongshore length of shoreline was the western end of the island because of its expansion caused by sediment transported alongshore in a westerly direction and into Fire Island Inlet.

Results

Table 3A. Areal change (m²) of modern active features sorted by map area.

Area	Beach			Active foredune			Wetland			Interior water bodies		
	2011	Post-S1	Dif. 2	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.
1	399,224	469,277	70,054	116,558	110,517	-6042	0	0	0	0	0	0
2	207,136	253,459	46,323	120,222	98,588	-21,634	0	0	0	0	0	0
3	159,194	298,452	139,258	143,429	80,426	-63,003	113,052	113,052	0	0	0	0
4	175,701	278,225	102,524	187,039	128,112	-58,927	85,313	85,313	0	2,673	2,673	0
5	166,493	259,221	92,727	130,169	82,927	-47,242	26,256	26,190	-65	515	515	0
6	172,028	267,769	95,741	136,441	84,890	-51,551	23,094	23,094	0	0	0	0
7	146,750	238,874	92,124	130,023	138,007	7,984	18,615	18,615	0	0	0	0
8	150,394	236,373	85,978	122,115	101,384	-20,730	7,805	7,805	0	0	0	0
9	170,417	265,525	95,109	84,818	90,567	5,749	8,680	8,680	0	0	0	0
10	161,101	254,786	93,684	141,613	115,825	-25,787	239,487	239,487	0	10,891	10,891	0
11	174,654	259,390	84,736	147,163	107,776	-39,387	455,050	455,050	0	3,042	3,042	0
12	158,021	250,837	92,816	150,150	101,122	-49,028	651,436	651,436	0	0	0	0
13	212,999	274,003	61,004	126,800	68,883	-57,917	775,846	716,491	-59,356	2,362	2,362	0
14	142,519	243,116	100,597	115,724	68,899	-46,826	78,605	78,599	-6	0	0	0
15	163,985	278,053	114,069	105,614	69,979	-35,635	268,365	248,414	-19,951	0	0	0
16	171,984	228,828	56,844	110,885	74,672	-36,212	1,079,685	1,053,470	-26,215	5,228	4,023	-1,205
17	160,598	177,895	17,297	105,402	108,514	3,112	253,053	252,479	-573	0	0	0

Table 3B. Areal change (m^2) of modern abandoned features sorted by map area.

Area	Abandoned foredune			Inter-ridge swale			Back dune slope			Washover zone/Sand flat		
	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.
1	522,326	497,433	-24,892	269,173	262,054	-7,119	37,045	32,751	-4,294	0	6,397	6,397
2	242,515	221,990	-20,525	114,834	111,022	-3,812	9,294	9,294	0	0	4,381	4,381
3	122,581	91,143	-31,438	178,771	153,654	-25,118	35,616	35,071	-544	17,641	57,223	39,581
4	394,397	278,872	-115,525	354,876	341,900	-12,976	26,937	26,937	0	0	111,638	111,638
5	411,514	308,620	-102,894	146,536	136,527	-10,009	168,675	164,170	-4,505	0	85,092	85,092
6	137,561	95,455	-42,106	108,697	84,295	-24,402	0	0	0	0	76,296	76,296
7	102,542	35,060	-67,482	21,988	17,212	-4,775	0	0	0	0	15,038	15,038
8	316,368	268,127	-48,241	82,661	74,593	-8,068	9,534	9,214	-320	0	13,736	13,736
9	235,483	167,241	-68,241	25,475	19,568	-5,907	28,618	28,374	-244	0	6,415	6,415
10	168,631	113,948	-54,683	23,937	22,350	-1,588	19,396	16,175	-3,221	0	21,113	21,113
11	222,982	204,099	-18,883	35,425	26,591	-8,834	110,476	98,642	-11,834	28,974	68,407	39,433
12	174,123	146,218	-27,906	37,149	26,742	-10,407	26,195	24,249	-1,946	0	38,218	38,218
13	4,056	4,056	0	84	84	0	0	0	0	213,505	459,059	245,554
14	31,399	24,807	-6,592	24,027	11,087	-12,940	127,883	120,046	-7,837	0	71,818	71,818
15	201,566	95,274	-106,291	59,202	11,827	-47,375	69,011	40,926	-28,084	4,002	233,307	229,304
16	124,586	57,483	-67,104	25,127	12,755	-12,372	94,925	70,220	-24,705	0	114,685	114,685
17	409,541	408,252	-1,289	64,198	64,964	766	119,268	119,268	0	0	0	0

Table 3C. Areal change (m^2) of ancestral features sorted by map area.

Area	Ancestral foredune/barrier island			Inter-ridge swale			Back dune slope			Inter-dune system depression		
	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	262,606	262,606	0	156,333	156,185	-148	27,837	27,837	0	92,122	64,157	-27,965
7	199,697	199,629	-68	60,979	59,077	-1,902	30,020	30,020	0	121,597	113,511	-8,086
8	173,437	173,437	0	58,818	58,818	0	1,306	1,306	0	73,276	73,276	0
9	61,688	61,688	0	1,542	1,542	0	15,870	15,870	0	35,830	35,830	0
10	122,587	122,587	0	93,386	93,386	0	44,382	44,382	0	103,901	103,202	-699
11	33,193	31,590	-1,603	21,319	21,470	151	61,539	61,576	37	30,999	28,779	-2,219
12	244,772	241,286	-3,486	118,205	115,502	-2,704	138,554	138,554	0	72,176	70,520	-1,656
13	165,833	106,744	-59,089	98,846	51,041	-47,804	75,895	51,112	-24,783	92,293	27,584	-64,709
14	40,357	16,622	-23,735	18,474	11,314	-7,161	13,373	12,039	-1,334	67,276	47,327	-19,949
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0

[1]Post-Hurricane Sandy; [2]Difference

Table 4A. Areal change (m^2) of modern active features sorted by community.

Community	Beach			Active foredune			Wetland			Interior water bodies		
	2011	Post-S[1]	Dif. [2]	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.
Kismet	15,697	27,487	**11,790**	14,421	7,937	**-6,484**	0	0	**0**	0	0	**0**
Saltaire	54,717	82,454	**27,737**	70,535	49,441	**-21,094**	85,313	85,313	**0**	0	0	**0**
Fair Harbor	34,640	55,011	**20,371**	46,344	35,604	**-10,739**	0	0	**0**	0	0	**0**
Dunewood	14,586	20,167	**5,581**	15,255	10,482	**-4,773**	0	0	**0**	0	0	**0**
Lonelyville	17,756	26,729	**8,973**	16,475	9,473	**-7,002**	814	814	**0**	238	238	**0**
Atlantique	16,017	24,931	**8,914**	12,235	1,458	**-10,777**	0	0	**0**	0	0	**0**
Robbins Rest	5,648	9,626	**3,978**	5,074	1,596	**-3,478**	0	0	**0**	0	0	**0**
F. I. Summer C.	7,529	16,311	**8,782**	9,289	1,640	**-7,649**	0	0	**0**	0	0	**0**
Corn. Estates	4,284	8,640	**4,356**	3,737	4,688	**951**	0	0	**0**	0	0	**0**
Ocean Beach	22,844	37,934	**15,090**	14,783	14,678	**-105**	0	0	**0**	0	0	**0**
Seaview	41,646	64,028	**22,381**	27,457	32,310	**4,853**	0	0	**0**	0	0	**0**
Ocean Bay P.	33,329	57,002	**-15,528**	23,782	15,528	**-8,254**	0	0	**0**	0	0	**0**
P. O'Woods	79,473	120,442	**40,969**	58,129	28,859	**-29,270**	14,444	14,444	**0**	0	0	**0**
Oakleyville	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Cherry Grove	42,536	70,333	**27,797**	31,690	52,998	**21,308**	0	0	**0**	0	0	**0**
F. I. Pines	90,559	142,507	**51,949**	90,528	60,080	**-30,449**	2,087	2,087	**0**	0	0	**0**
Water Island	14,563	24,242	**9,679**	6,749	6,138	**-611**	0	0	**0**	0	0	**0**
Blue Point B.	11,514	17,942	**6,428**	6,204	3,929	**-2,275**	1,938	1,938	**0**	0	0	**0**
Davis Park	75,096	109,296	**34,199**	50,214	44,021	**-6,193**	16,371	16,371	**0**	0	0	**0**

Table 4B. Areal change (m^2) of modern abandoned features sorted by community.

Community	Abandoned foredune			Inter-ridge swale			Back dune slope			Washover zone/Sand flat		
	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.
Kismet	43,816	31,330	**-12,486**	13,783	10,023	**-3,760**	0	0	**0**	0	13,393	**13,393**
Saltaire	103,526	91,679	**-11,847**	72,654	71,049	**-1,604**	9,578	9,578	**0**	0	14,887	**14,887**
Fair Harbor	98,091	98,091	**0**	53,796	53,796	**0**	33,909	33,909	**0**	0	0	**0**
Dunewood	38,901	38,894	**-7**	7,991	7,991	**0**	16,066	16,066	**0**	0	23	**23**
Lonelyville	25,845	25,254	**-591**	7,189	6,449	**-740**	37,344	37,192	**-153**	0	1,804	**1,804**
Atlantique	19,424	7,946	**-11,478**	6,673	3,269	**-3,403**	20,306	19,209	**-1,097**	0	17,612	**17,612**
Robbins Rest	11,040	5,320	**-5,720**	788	491	**-297**	10,193	8,917	**-1,277**	0	6,525	**6,525**
F. I. Summer C.	24,507	12,175	**-12,332**	11,961	11,194	**-767**	31,032	31,032	**0**	0	12,791	**12,791**
Corn. Estates	23,343	17,968	**-5,375**	13,236	13,236	**0**	3,780	3,780	**0**	0	1,213	**1,213**
Ocean Beach	95,125	82,709	**-12,416**	44,854	44,854	**0**	0	0	**0**	0	1,554	**1,554**
Seaview	111,018	83,277	**-27,740**	41,004	40,168	**-836**	0	0	**0**	0	1,857	**1,857**
Ocean Bay P.	49,398	26,485	**-22,913**	59,723	51,636	**-8,087**	0	0	**0**	0	15,637	**15,637**
P. O'Woods	32,248	21,680	**-10,568**	18,164	2,908	**-15,256**	0	0	**0**	0	56,455	**56,455**
Oakleyville	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Cherry Grove	51,700	12,832	**-38,868**	8,281	8,281	**0**	0	0	**0**	0	0	**0**
F. I. Pines	199,294	185,556	**-13,738**	58,630	55,014	**-3,616**	520	469	**-51**	0	2,327	**2,327**
Water Island	34,786	27,172	**-7,614**	6,344	4,392	**-1,951**	1,446	1,446	**0**	0	451	**451**
Blue Point B.	13,830	13,830	**0**	1,255	1,255	**0**	0	0	**0**	0	0	**0**
Davis Park	74,119	50,634	**-23,485**	11,590	10,848	**-743**	8,732	8,732	**0**	0	9,248	**9,248**

[1]Post-Hurricane Sandy; [2]Difference

Table 4C. Areal change (m^2) of ancestral features sorted by community.

Community	Ancestral foredune/barrier island			Inter-ridge swale			Back dune slope			Inter-dune system depression		
	2011	Post-S[1]	Dif.[2]	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.
Kismet	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Saltaire	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Fair Harbor	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Dunewood	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Lonelyville	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Atlantique	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Robbins Rest	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
F.I. Summer C.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Corn. Estates	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Ocean Beach	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Seaview	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Ocean Bay P.	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
P. O'Woods	161,280	161,280	**0**	112,566	112,566	**0**	16,035	16,035	**0**	71,798	44,741	**-27,057**
Oakleyville	8,068	8,068	**0**	4,171	4,171	**0**	5,248	5,248	**0**	0	0	**0**
Cherry Grove	44,962	44,962	**0**	11,544	11,544	**0**	14,565	14,565	**0**	35,770	35,770	**0**
F.I. Pines	163,347	163,347	**0**	52,915	52,915	**0**	445	445	**0**	68,428	68,428	**0**
Water Island	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**
Blue Point B.	11,144	11,144	**0**	1,205	1,205	**0**	6,007	6,007	**0**	6,901	6,901	**0**
Davis Park	50,751	50,751	**0**	24,518	24,518	**0**	5,841	5,841	**0**	41,089	40,390	**-699**

[1]Post-Hurricane Sandy; [2]Difference

Table 5A. Areal change (m^2) of modern active features sorted by management agency.

Management	Beach			Active foredune			Wetland			Interior water bodies		
	2011	Post-S[1]	Dif. [2]	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.
R. M. State Park	732,224	948,631	216,407	355,333	281,387	-73,946	113,052	113,052	0	0	0	0
F.I. Natl Seashore	1,780,686	2,761,328	980,641	1,441,557	1,058,005	-383,551	2,734,041	2,674,614	-59,427	83,330	83,330	0
S.P. County Park	588,465	832,182	243,718	377,275	291,696	-85,579	1,611,922	1,565,183	-46,739	5,228	4,023	-1,205

Table 5B. Areal change (m^2) of modern abandoned features sorted by management agency.

Management	Abandoned foredune			Inter-ridge swale			Back dune slope			Washover zone/Sand flat		
	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.
R. M. State Park	821,481	770,198	-51,283	470,931	453,233	-17,698	75,457	70,853	-4,605	8,737	29,924	21,187
F.I. Natl Seashore	2,233,597	1,662,065	-571,533	933,598	823,359	-110,239	445,634	415,495	-30,140	251,383	1,004,906	753,523
S.P. County Park	767,092	585,816	-181,276	167,631	100,633	-66,998	361,780	308,991	-52,789	4,002	347,993	343,990

Table 5C. Areal change (m^2) of abandoned features sorted by management agency.

Management	Ancestral foredune			Inter-ridge swale			Back dune slope			Inter-dune system depression		
	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.	2011	Post-S	Dif.	2011
R. M. State Park	0	0	0	0	0	0	0	0	0	0	0	0
F.I. Natl Seashore	1,304,169	1,216,187	-87,982	627,904	568,336	-59,568	408,775	382,694	-26,080	689,469	564,186	-125,283
S.P. County Park	0	0	0	0	0	0	0	0	0	0	0	0

[1]Post-Hurricane Sandy; [2]Difference

Table 3. Metrics of shoreline and foredune change subdivided by map area.

Area	Shoreline Displacement (m)	Foredune Crest Displacement (m)	Shoreline Length (m)	2011 Foredune Length (m)	Post-S[1] Foredune Length (m)	% of Foredune Lost
1	-6.7	-10.6	2200*	1700	1600	6%
2	-2.3	-11.3	3000	3000	2900	3%
3	20.5	-11.3	3000	3000	1600	47%
4	8.5	-11.3	3000	3000	2300	23%
5	3.8	-16.7	3000	3000	2300	23%
6	8.3	-10.7	3000	3000	2300	23%
7	10.8	-16.6	3000	3000	3000	0%
8	6.2	-14.3	3000	3000	3000	0%
9	8.2	-18.0	3000	3000	3000	0%
10	8.4	-12.9	3000	3000	3000	0%
11	12.9	-6.0	3000	3000	2800	7%
12	11.1	-9.3	3000	3000	2800	7%
13	3.0	-7.7	3000	2600	1700	35%
14	14.0	-15.6	3000	2900	2000	31%
15	19.3	-18.2	3000	3000	2000	33%
16	-1.2	-6.5	3000	3000	2000	33%
17	8.3	-1.4	2100	2200	2200	0%

[1] Post-Hurricane Sandy; *2100 m 2011 and 2200 m Post-Hurricane Sandy

Table 4. Metrics of shoreline and foredune change subdivided by community.

Community	Shoreline Displacement (m)	Foredune Crest Displacement (m)	Shoreline Length (m)	2011 Foredune Length (m)	Post-S[1] Foredune Length (m)	% of Foredune Lost
Kismet	7.6	-37.2	300	300	300	0%
Saltaire	7.8	-6.3	1000	1000	950	5%
Fair Harbor	4.5	-38.5	660	660	660	0%
Dunewood	3.1	-11.5	240	240	40	0%
Lonelyville	4.7	-7.1	310	310	300	3%
Atlantique	-0.4	-36.0	290	290	60	79%
Robbins Rest	-2.7	-39.0	110	110	60	45%
F.I. Summer C.	3.4	-13.2	170	170	60	65%
Corn Estates	11.1	-50.8	96	84	84	0%
Ocean Beach	8.1	-14.6	530	530	490	8%
Seaview	0.7	-15.4	840	840	790	6%
Ocean Bay P.	-0.1	-25.8	710	710	460	35%

Table 7 (continued). Metrics of shoreline and foredune change subdivided by community.

Community	Shoreline Displacement (m)	Foredune Crest Displacement (m)	Shoreline Length (m)	2011 Foredune Length (m)	Post-S[1] Foredune Length (m)	% of Foredune Lost
P. O Woods	11.3	-5.6	1300	1300	830	36%
Oaklyville	-	-	-	-	-	-
Cherry Grove	11.0	-25.3	920	920	920	0%
F.I. Pines	13.8	-7.9	1900	1900	1900	0%
Water Island	-1.1	-31.0	290	290	280	3%
Blue Point B.	19.0	-6.5	260	260	260	0%
Davis Park	8.3	-12.0	1300	1300	1200	8%

1 Post-Hurricane Sandy

Table 8. Metrics of shoreline and foredune change subdivided by management agency.

Management	Shoreline Displacement (m)	Foredune Crest Displacement (m)	Shoreline Length (m)	2011 Foredune Length (m)	Post-S[1] Foredune Length (m)	% of Foredune Lost
R. M. State Park	4.5	-10.7	007600*	07100	06100	14%
F.I. Natl Seashore	8.4	-12.7	32000	32000	27000	16%
S.P. County Park	9.8	-10.0	10000	09900	07400	25%

1 Post-Hurricane Sandy *7500 m 2011 and 7600 m Post-Hurricane Sandy

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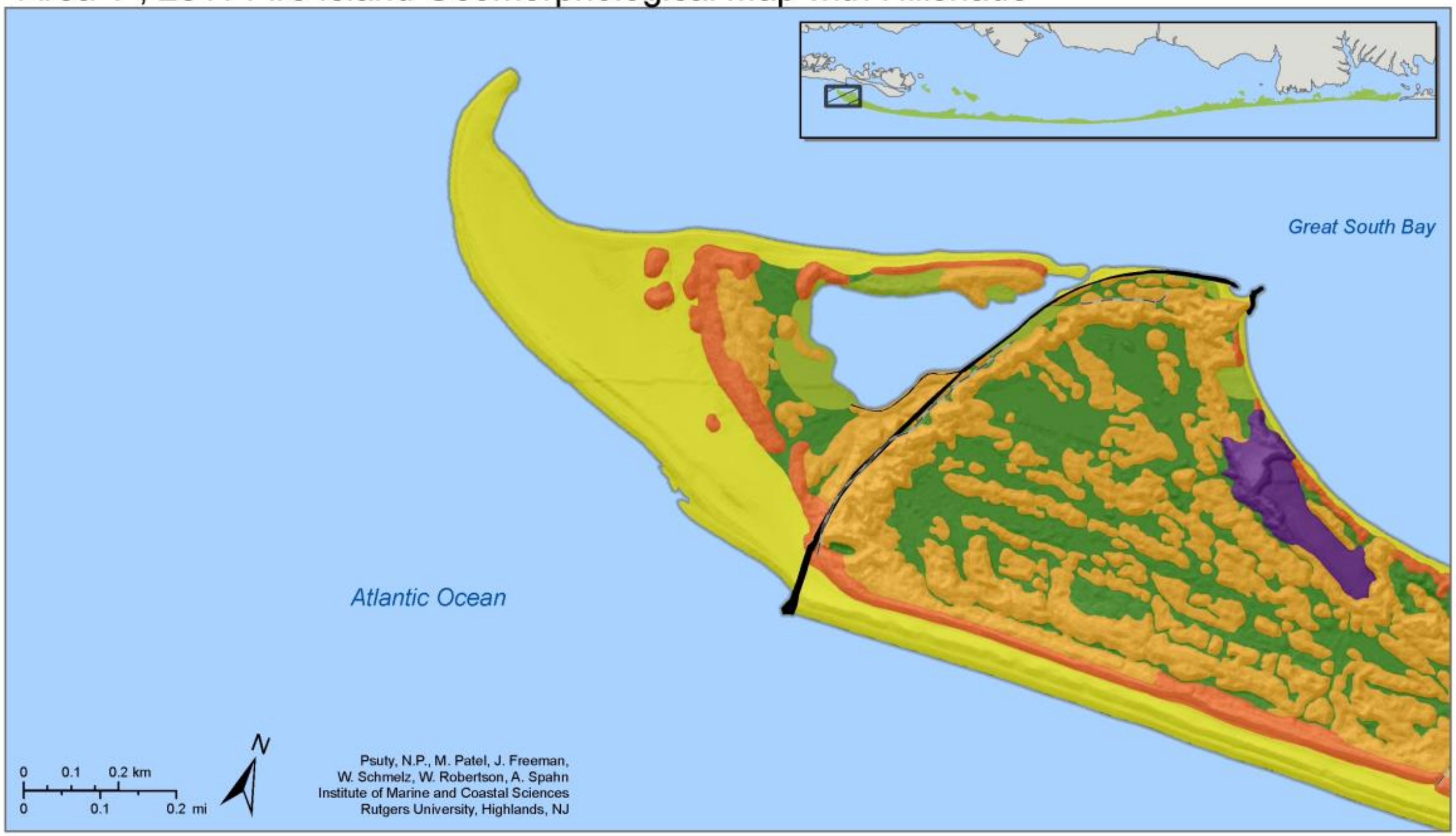
Appendix I: 2011 Maps of Fire Island Geomorphology, with and without Hillshade

"Area 1", 2011 Fire Island Geomorphological Map with Hillshade

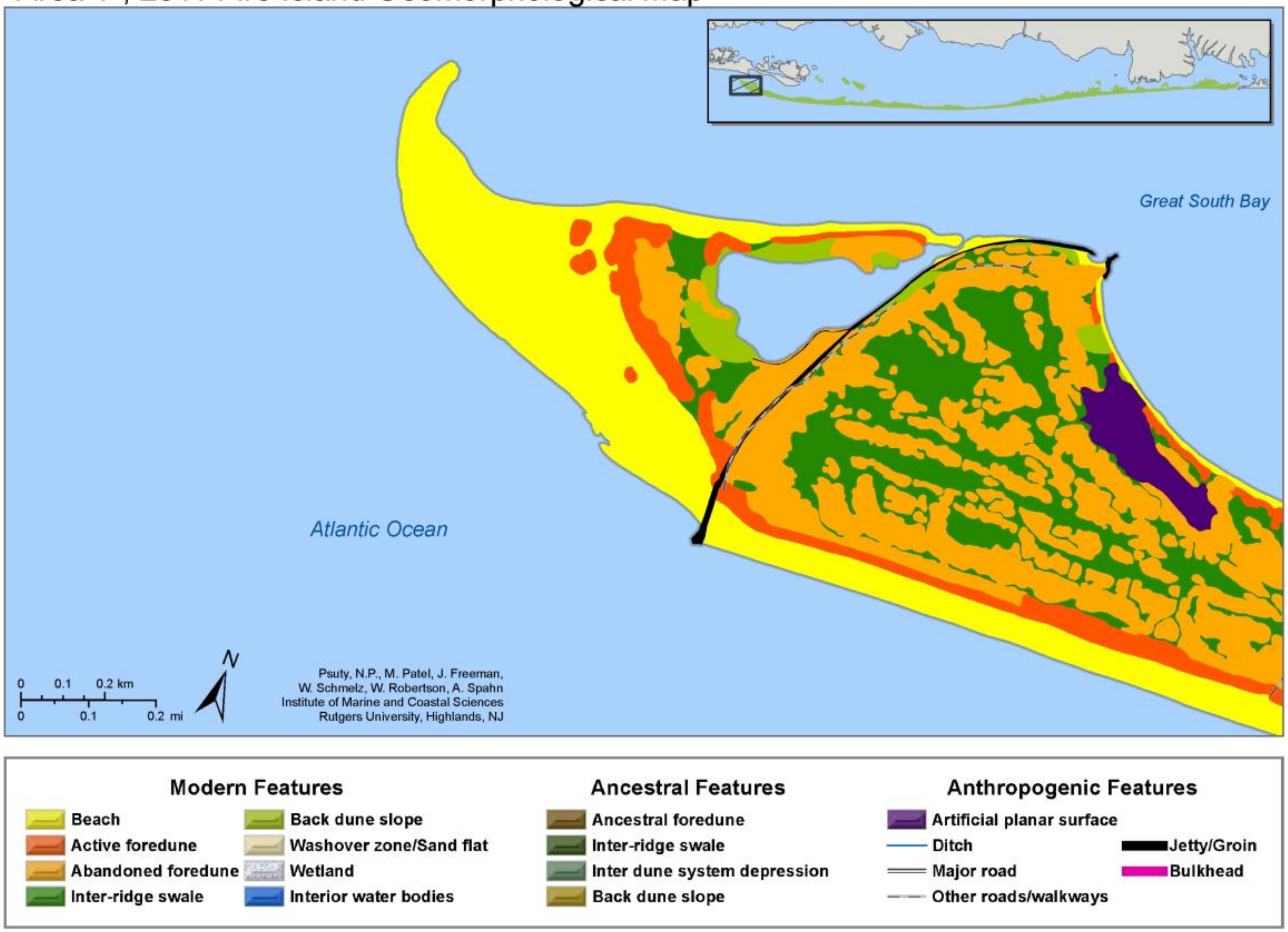


Modern Features
- Beach
- Active foredune
- Abandoned foredune
- Inter-ridge swale
- Back dune slope
- Washover zone/Sand flat
- Wetland
- Interior water bodies

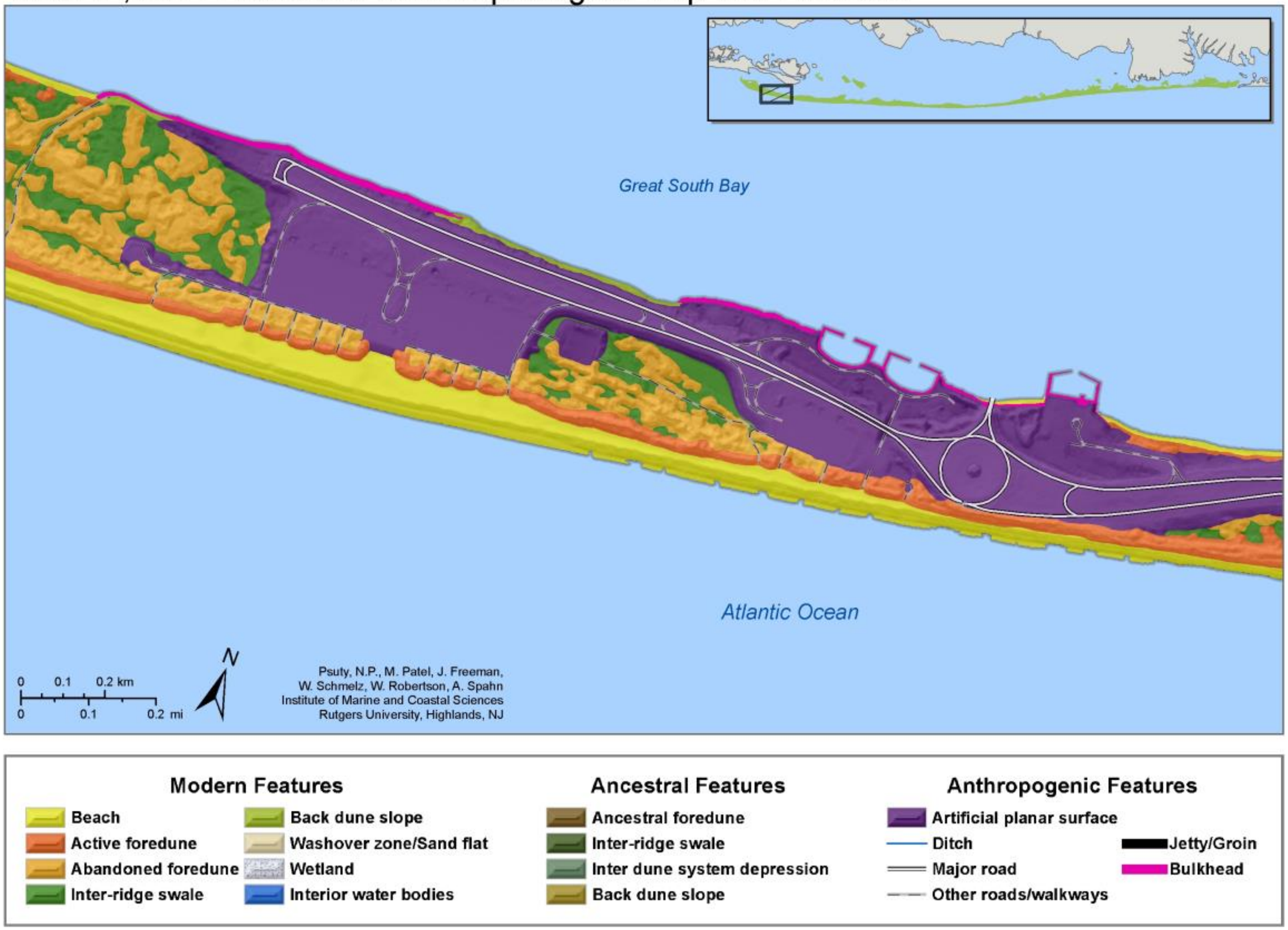
Ancestral Features
- Ancestral foredune
- Inter-ridge swale
- Inter dune system depression
- Back dune slope

Anthropogenic Features
- Artificial planar surface
- Ditch
- Major road
- Other roads/walkways
- Jetty/Groin
- Bulkhead

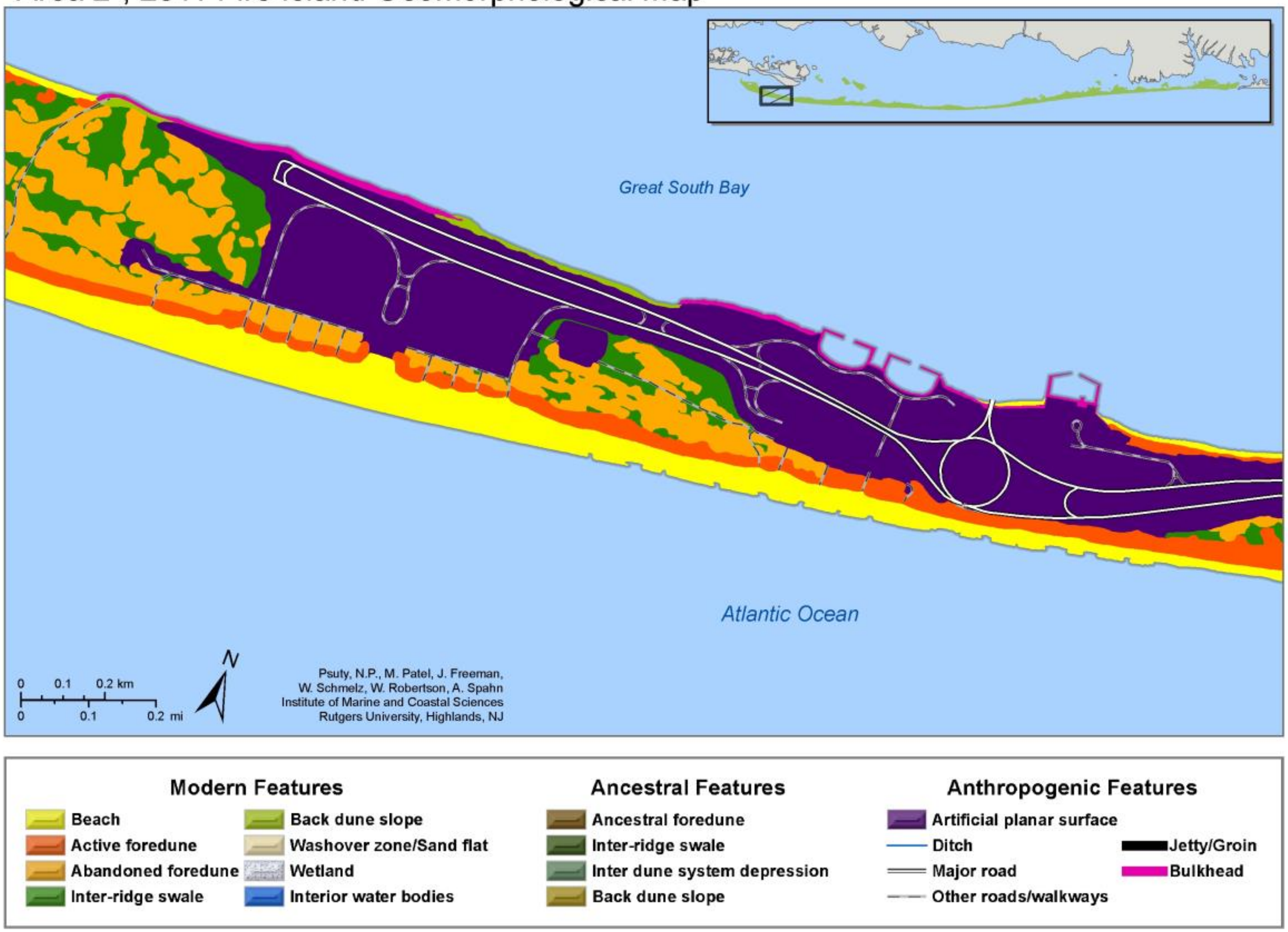
"Area 1", 2011 Fire Island Geomorphological Map



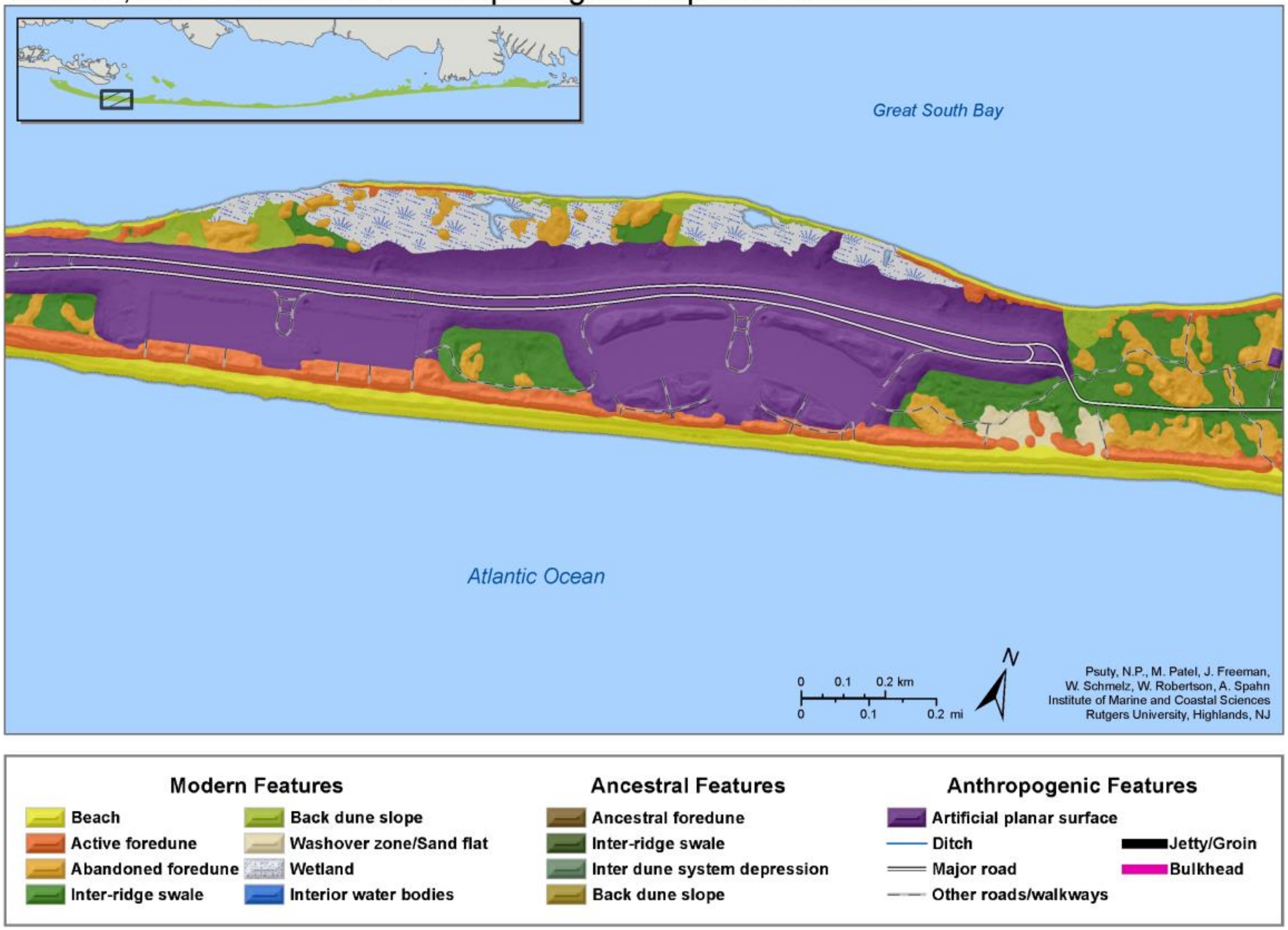
"Area 2", 2011 Fire Island Geomorphological Map with Hillshade



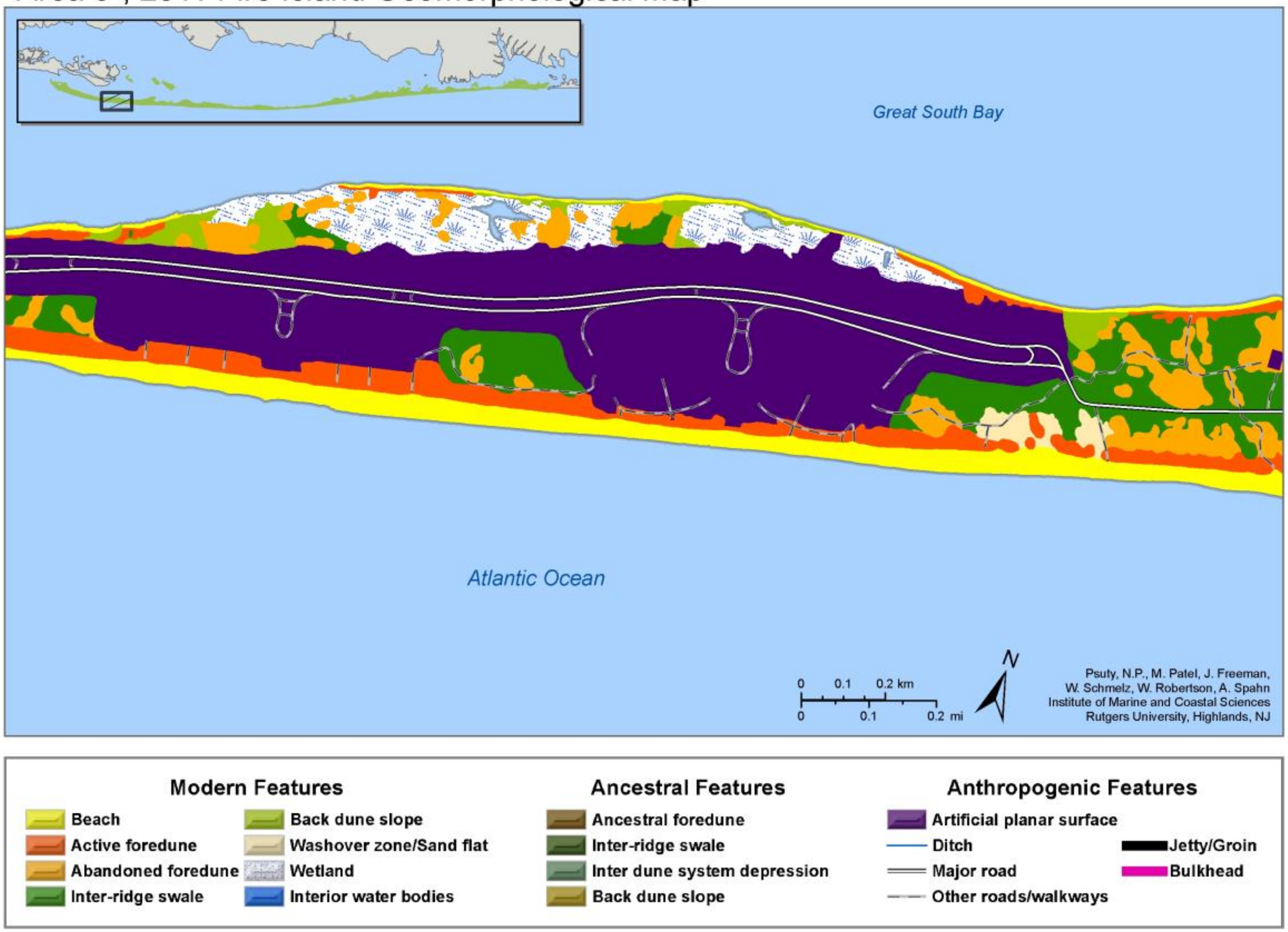
"Area 2", 2011 Fire Island Geomorphological Map



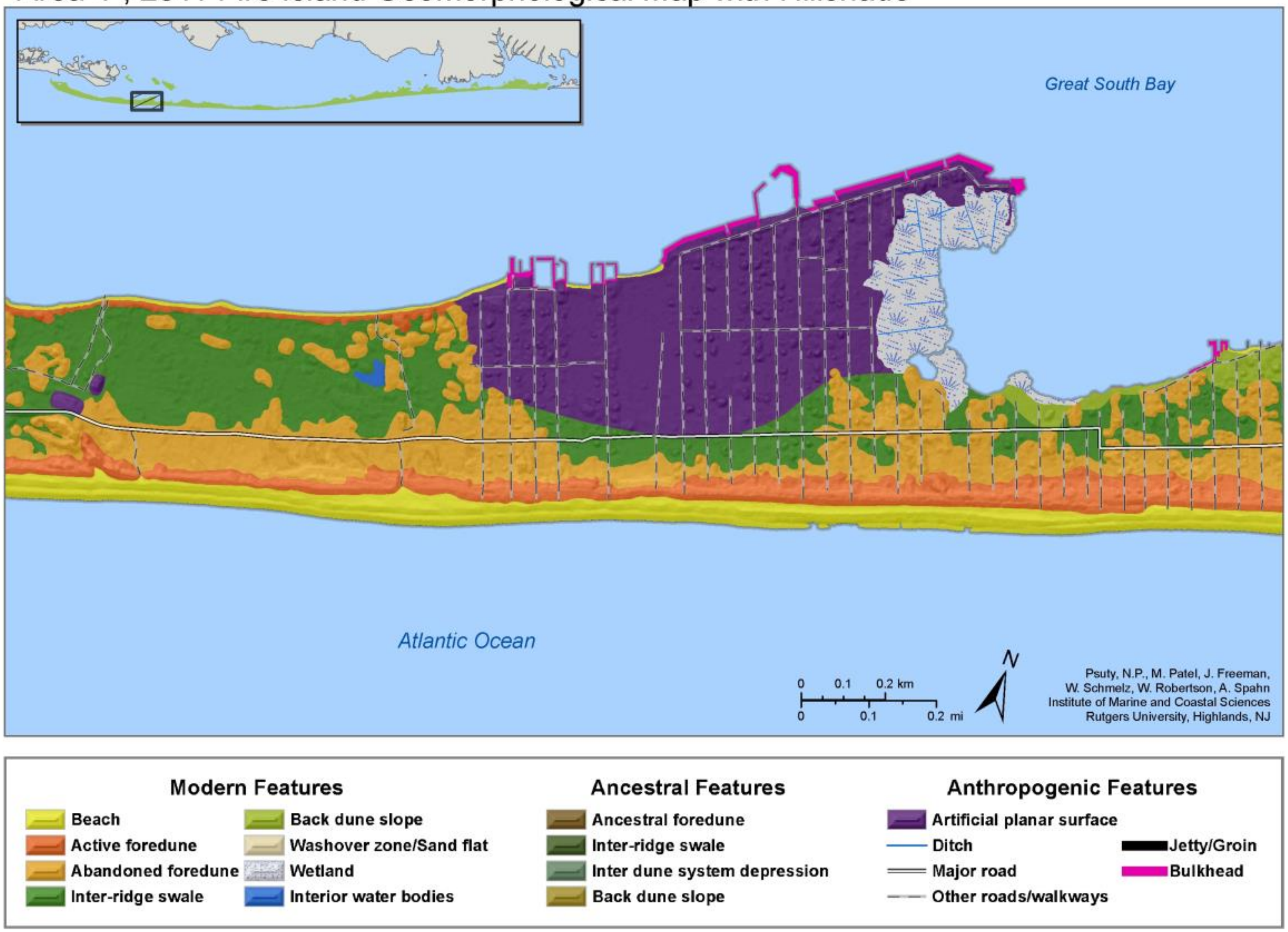
"Area 3", 2011 Fire Island Geomorphological Map with Hillshade



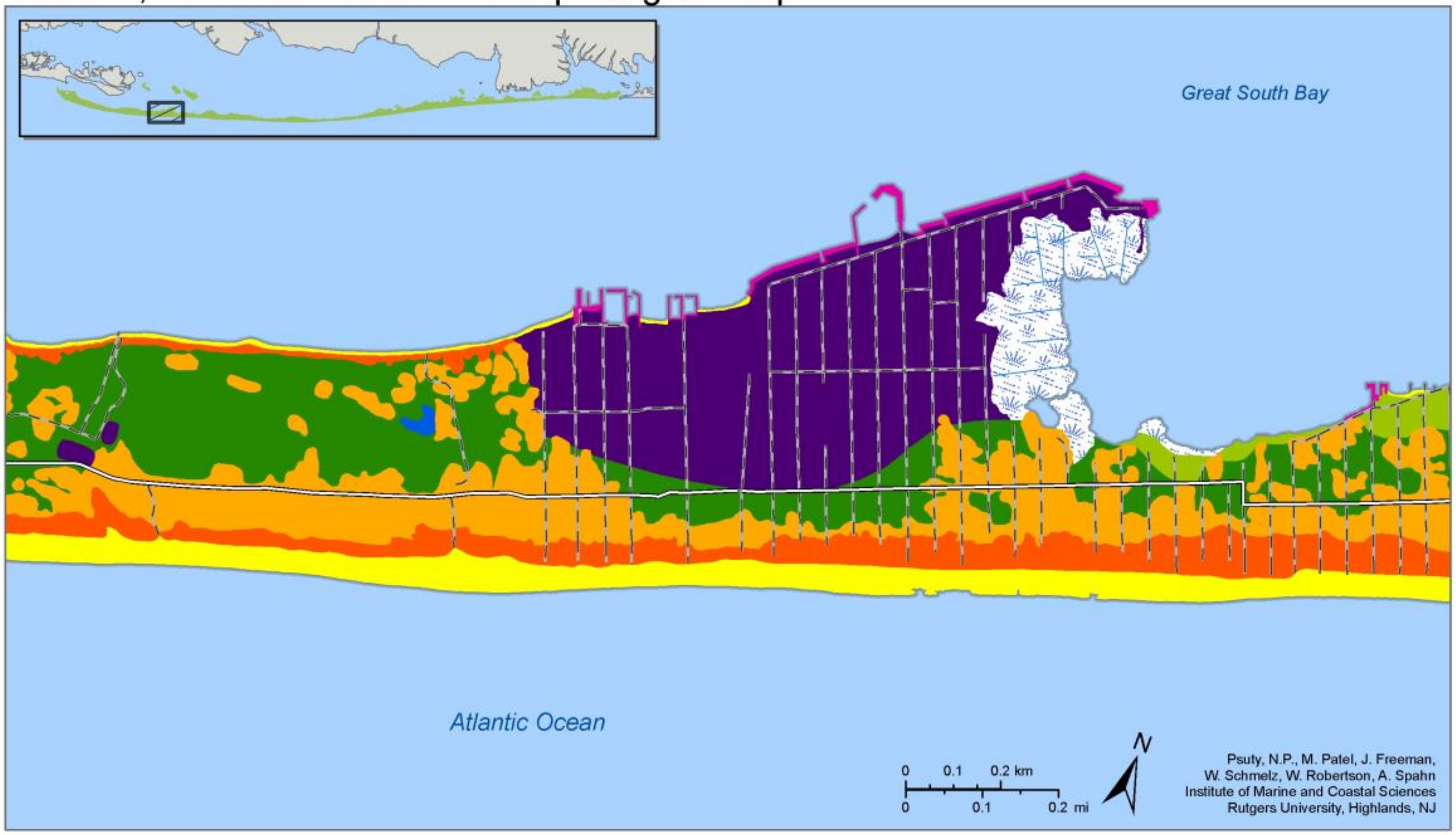
"Area 3", 2011 Fire Island Geomorphological Map



"Area 4", 2011 Fire Island Geomorphological Map with Hillshade



"Area 4", 2011 Fire Island Geomorphological Map

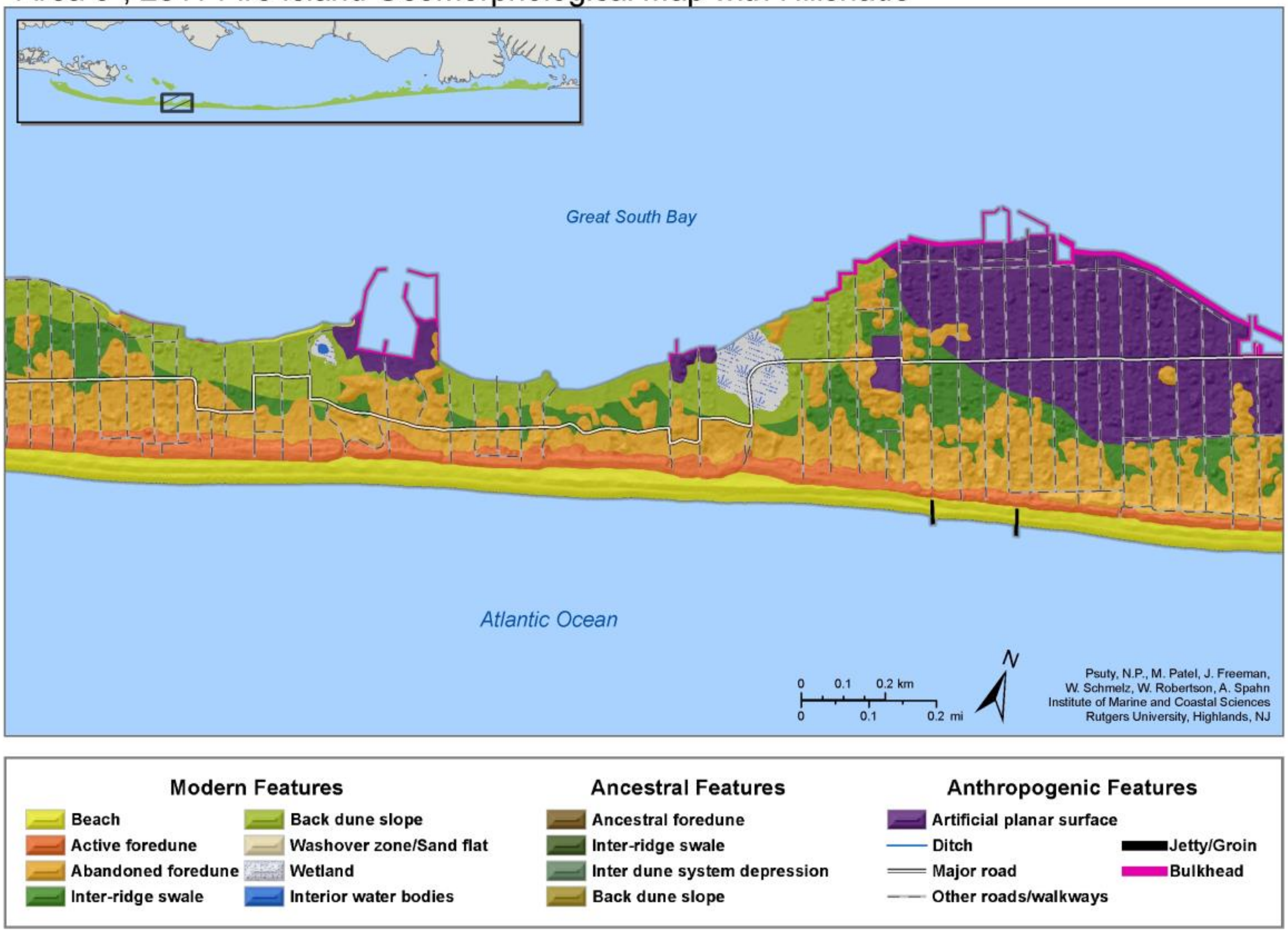


Modern Features
- Beach
- Active foredune
- Abandoned foredune
- Inter-ridge swale
- Back dune slope
- Washover zone/Sand flat
- Wetland
- Interior water bodies

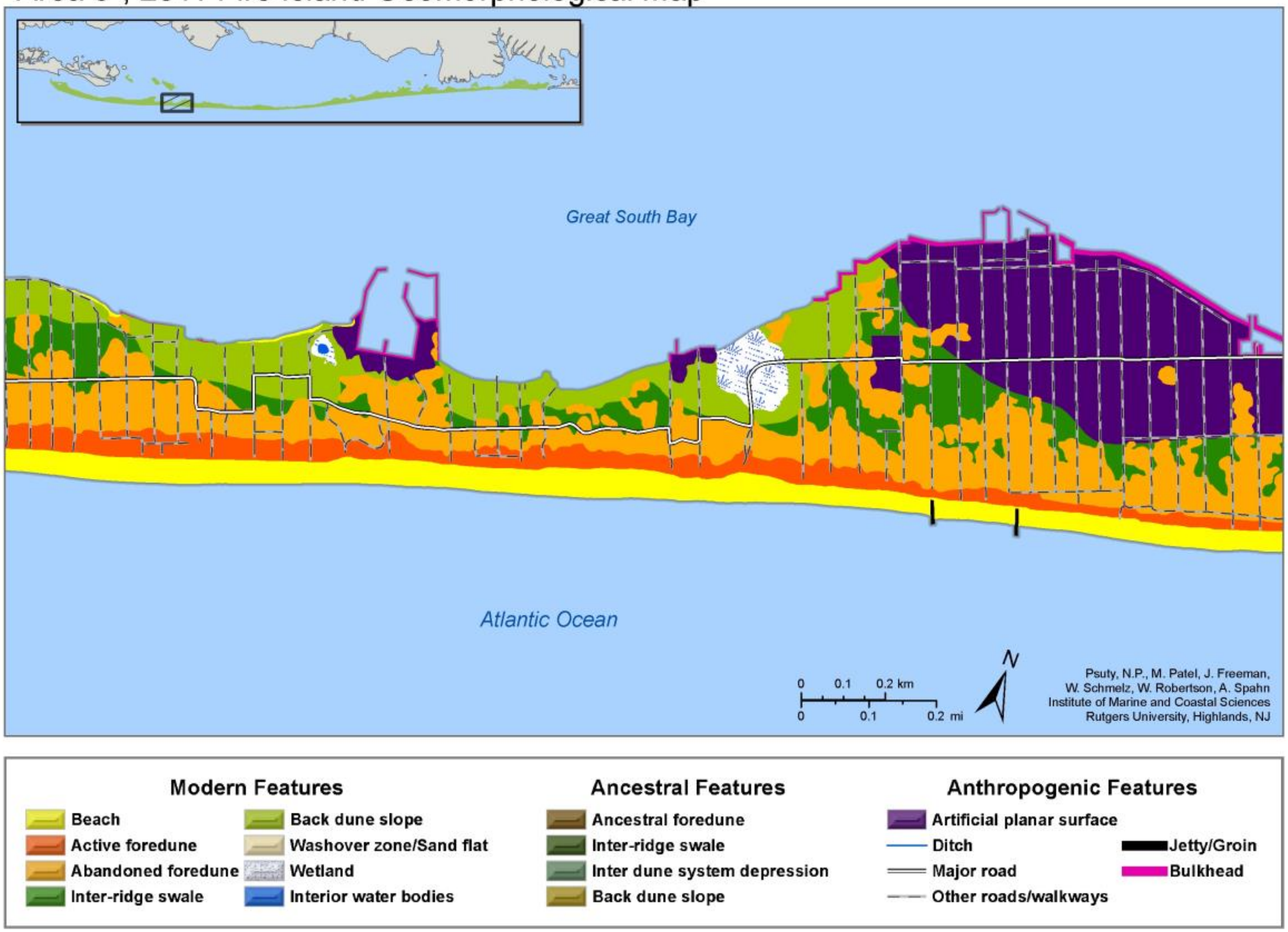
Ancestral Features
- Ancestral foredune
- Inter-ridge swale
- Inter dune system depression
- Back dune slope

Anthropogenic Features
- Artificial planar surface
- Ditch
- Major road
- Other roads/walkways
- Jetty/Groin
- Bulkhead

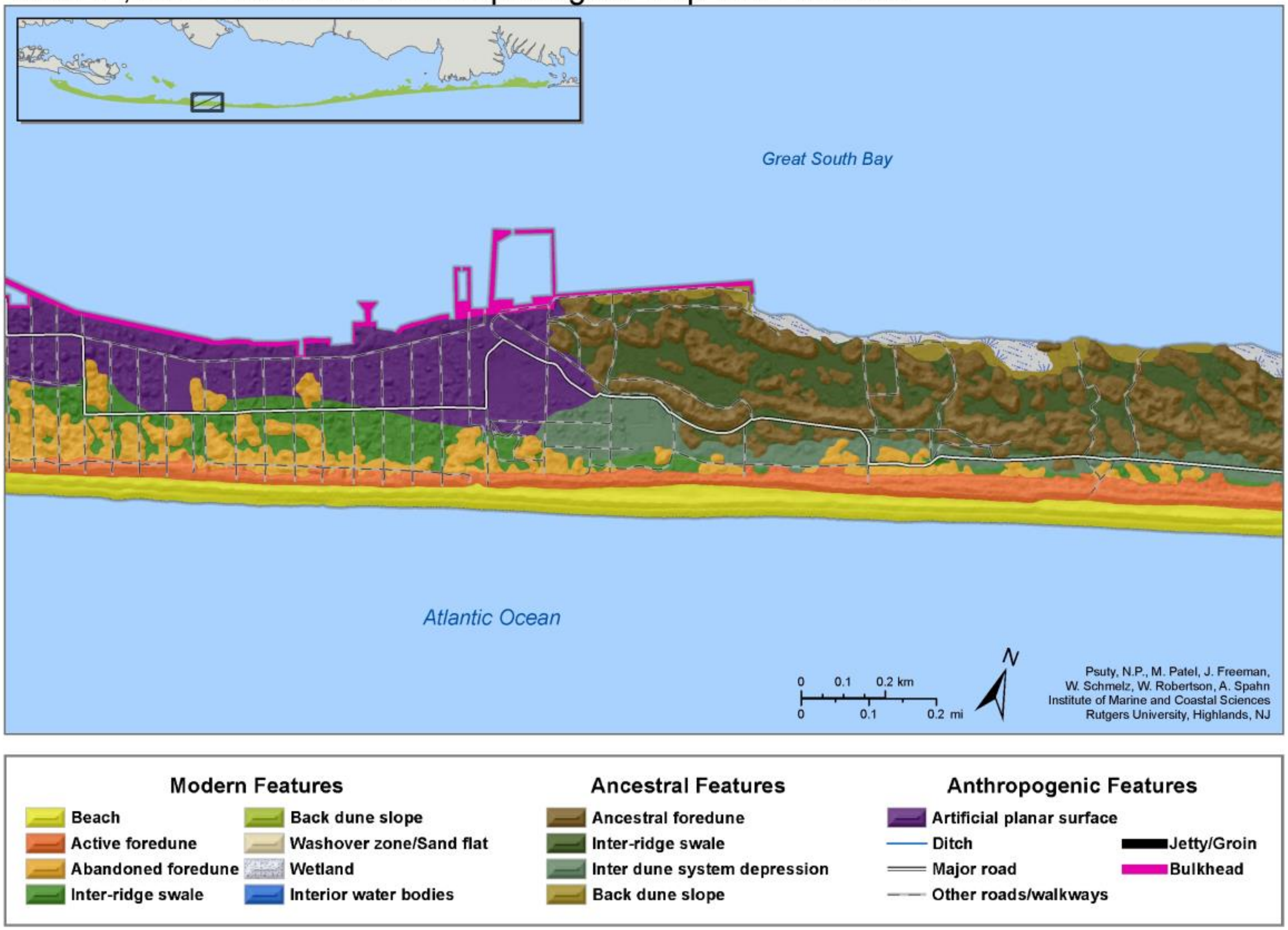
"Area 5", 2011 Fire Island Geomorphological Map with Hillshade



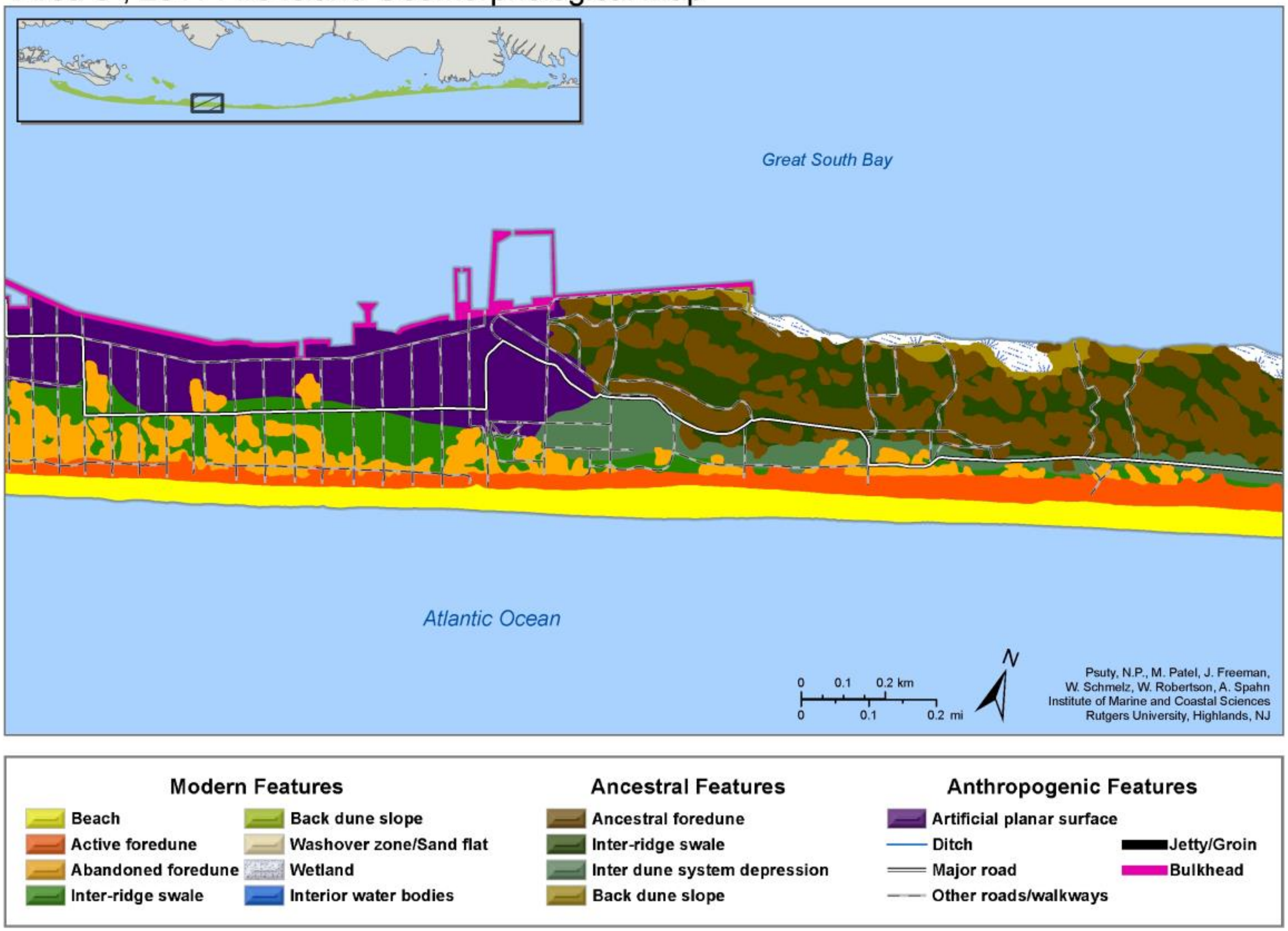
"Area 5", 2011 Fire Island Geomorphological Map



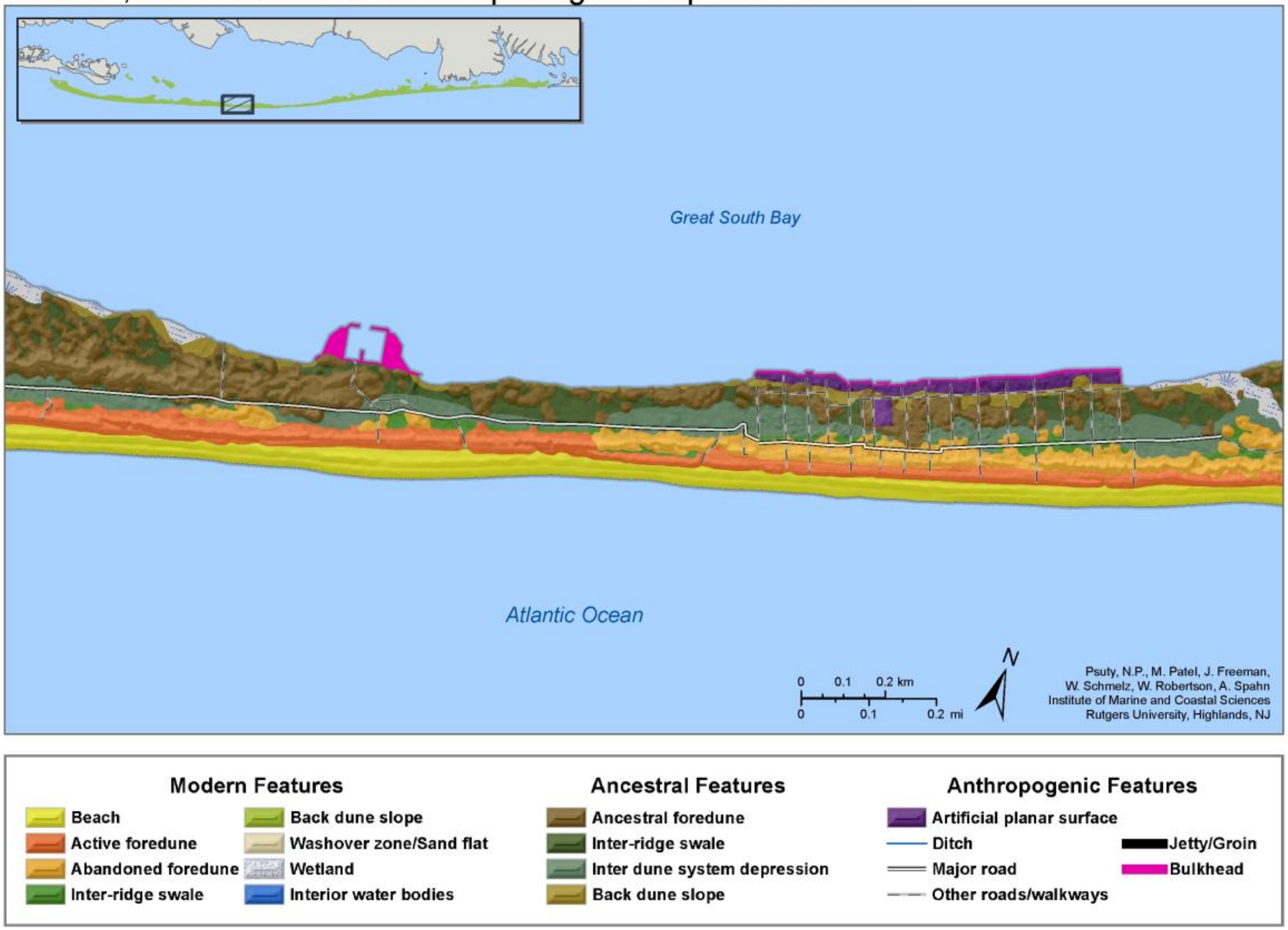
"Area 6", 2011 Fire Island Geomorphological Map with Hillshade



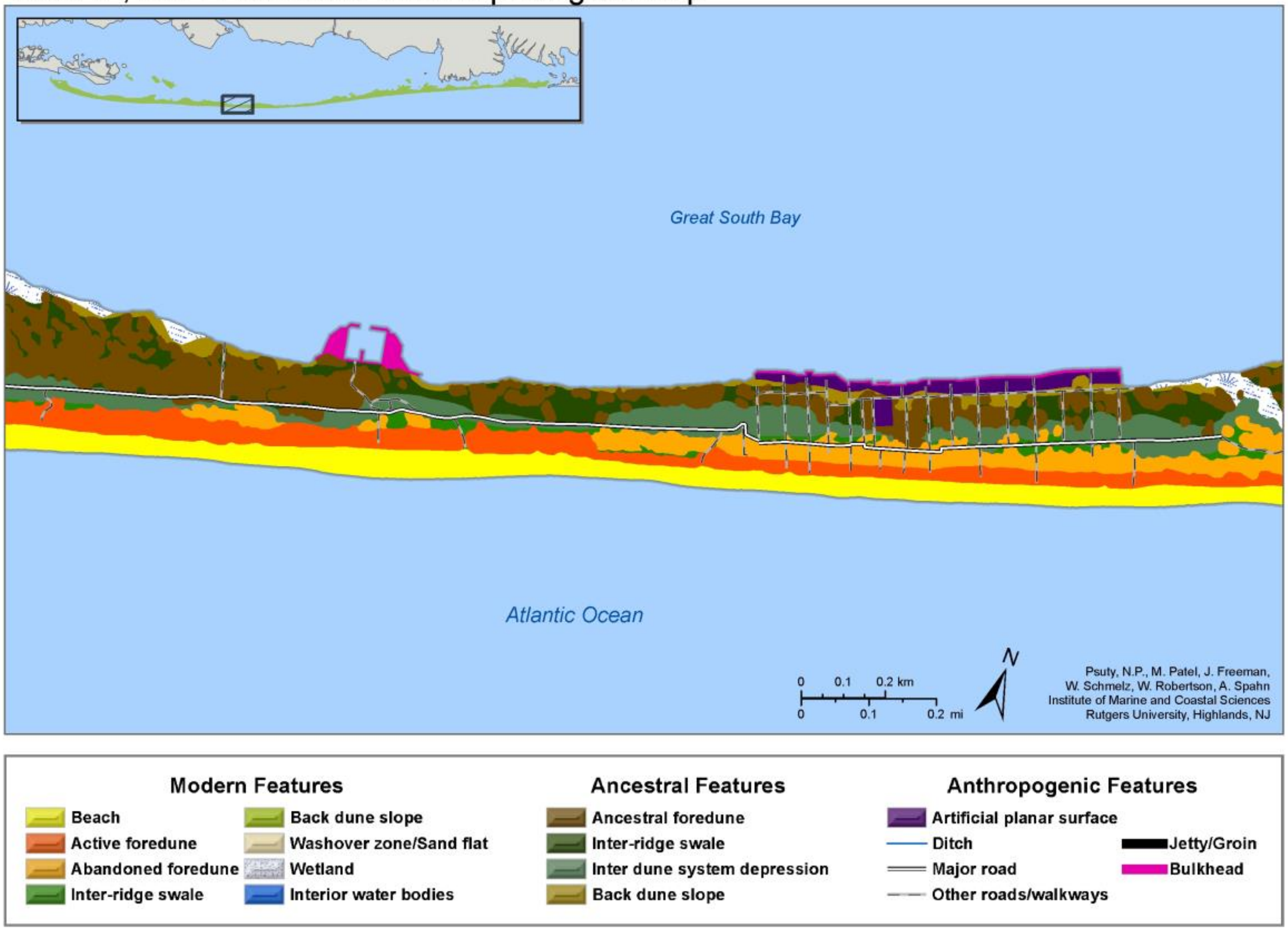
"Area 6", 2011 Fire Island Geomorphological Map



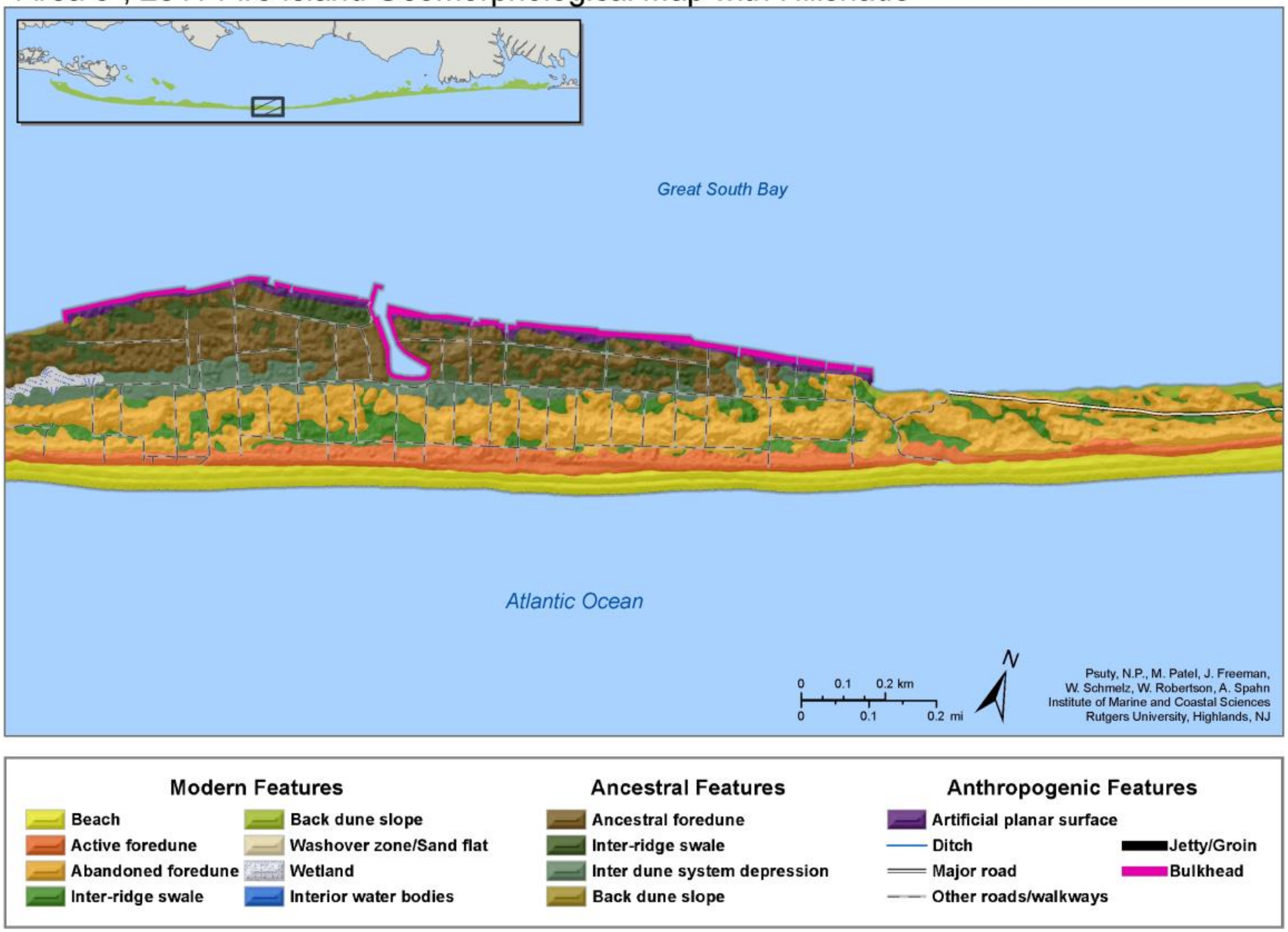
"Area 7", 2011 Fire Island Geomorphological Map with Hillshade



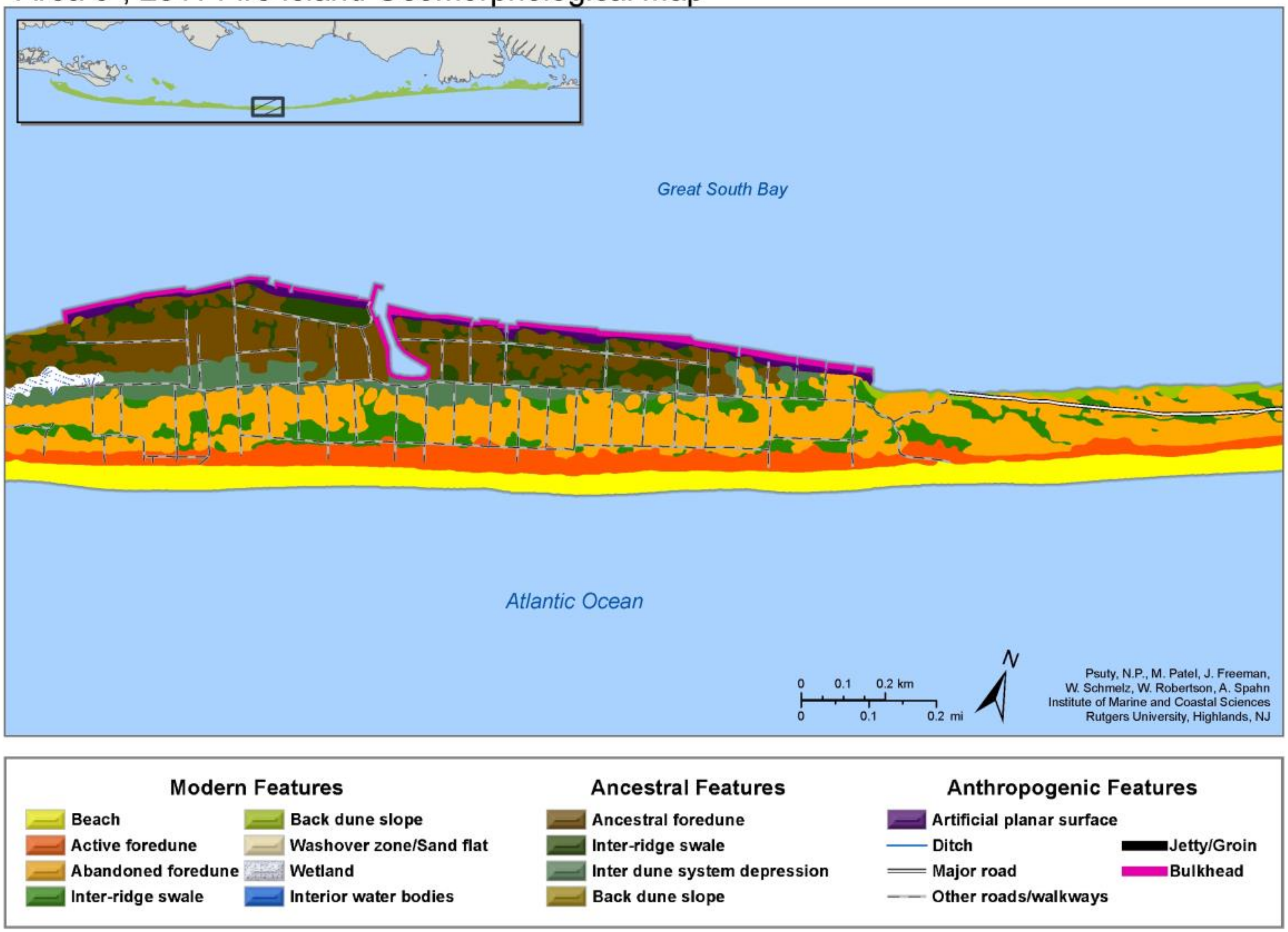
"Area 7", 2011 Fire Island Geomorphological Map



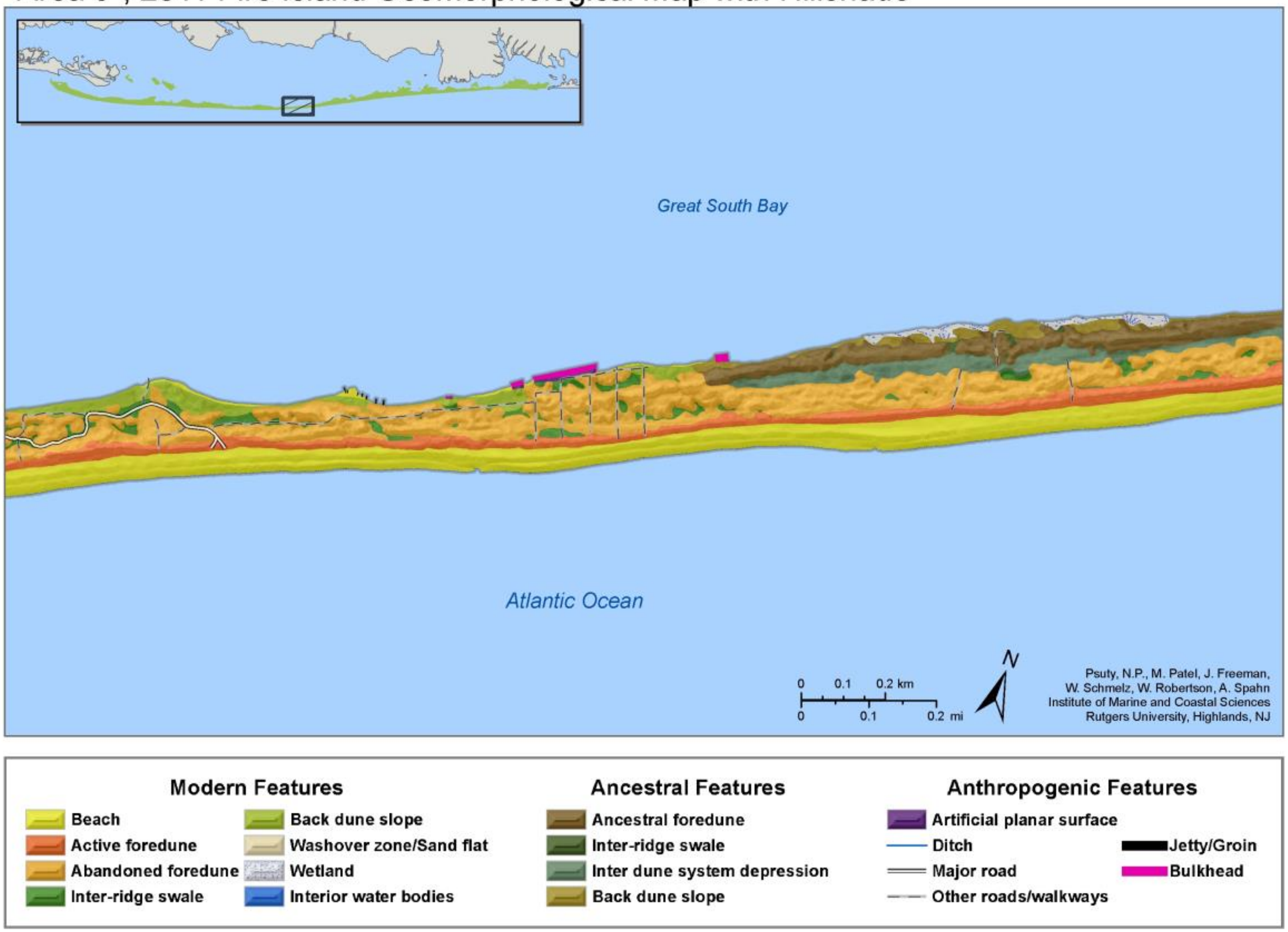
"Area 8", 2011 Fire Island Geomorphological Map with Hillshade



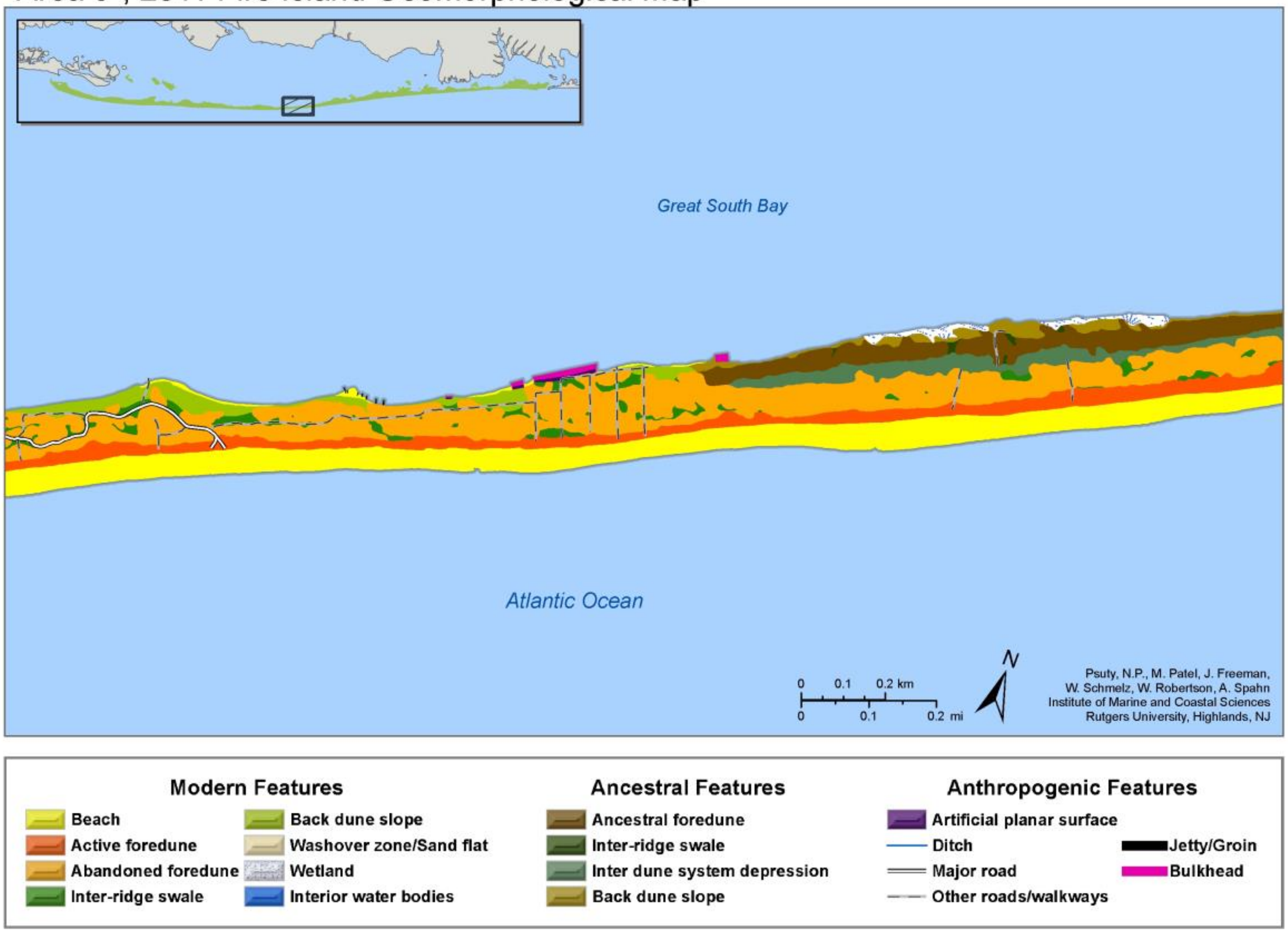
"Area 8", 2011 Fire Island Geomorphological Map



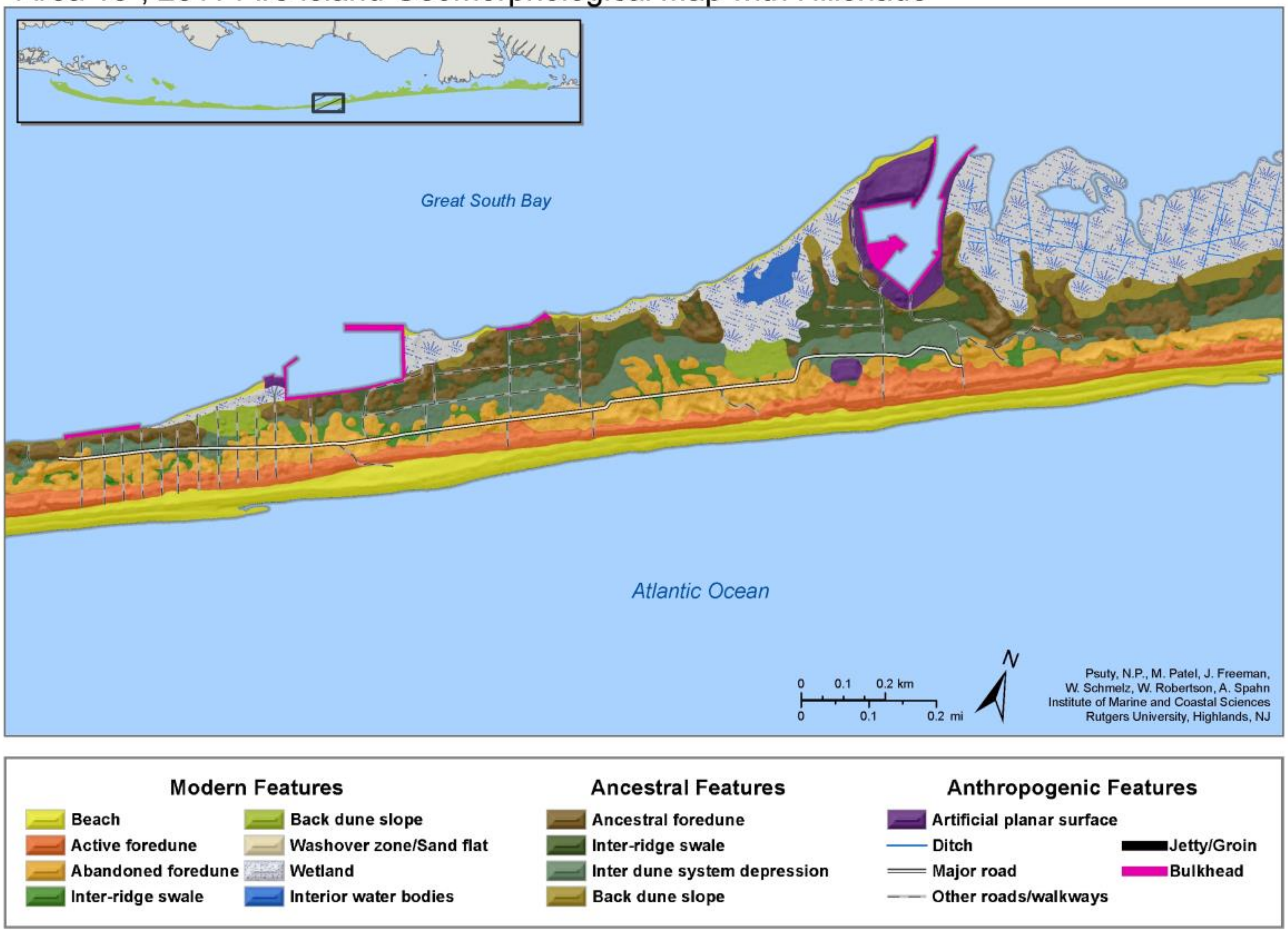
"Area 9", 2011 Fire Island Geomorphological Map with Hillshade



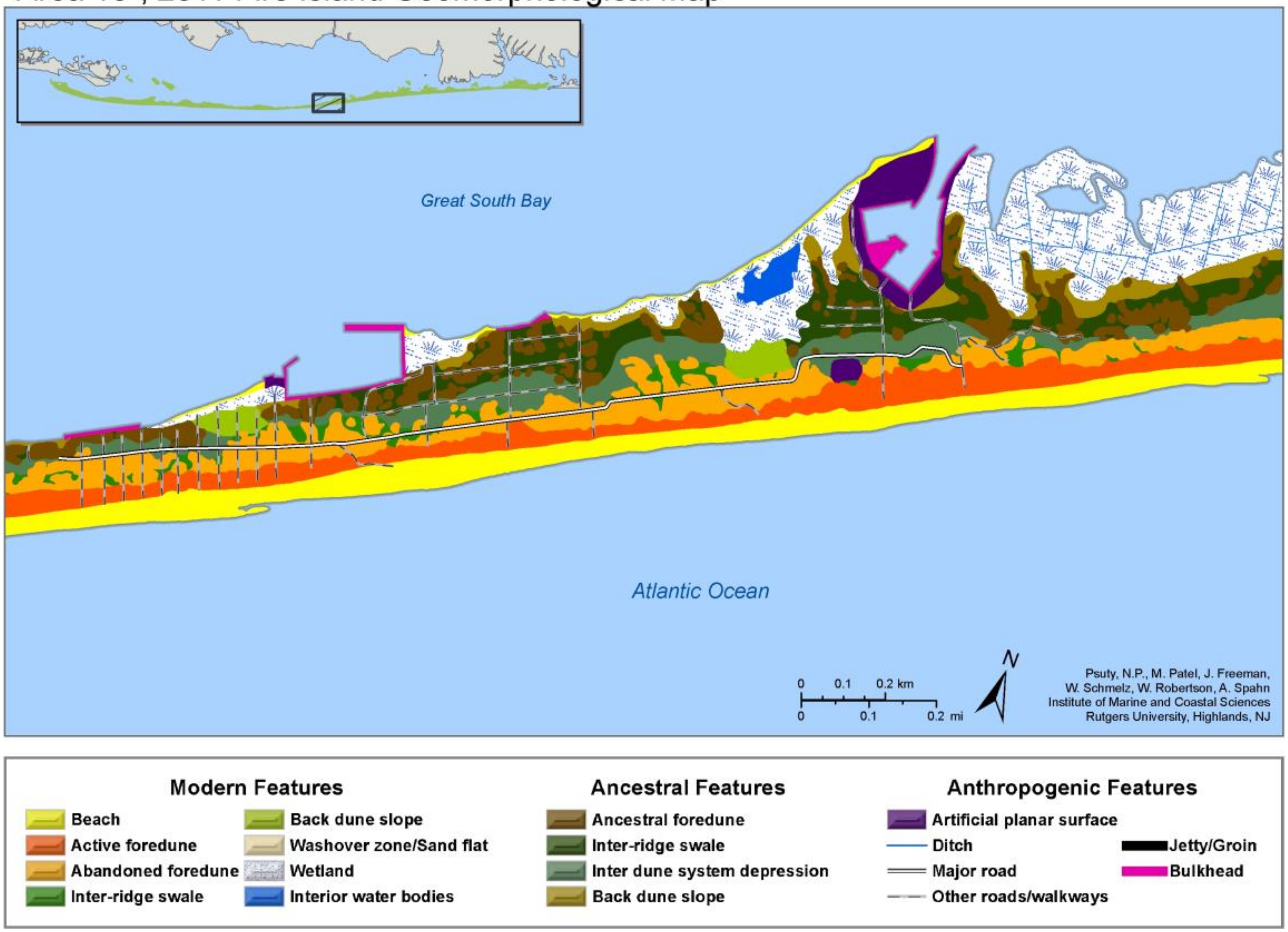
"Area 9", 2011 Fire Island Geomorphological Map



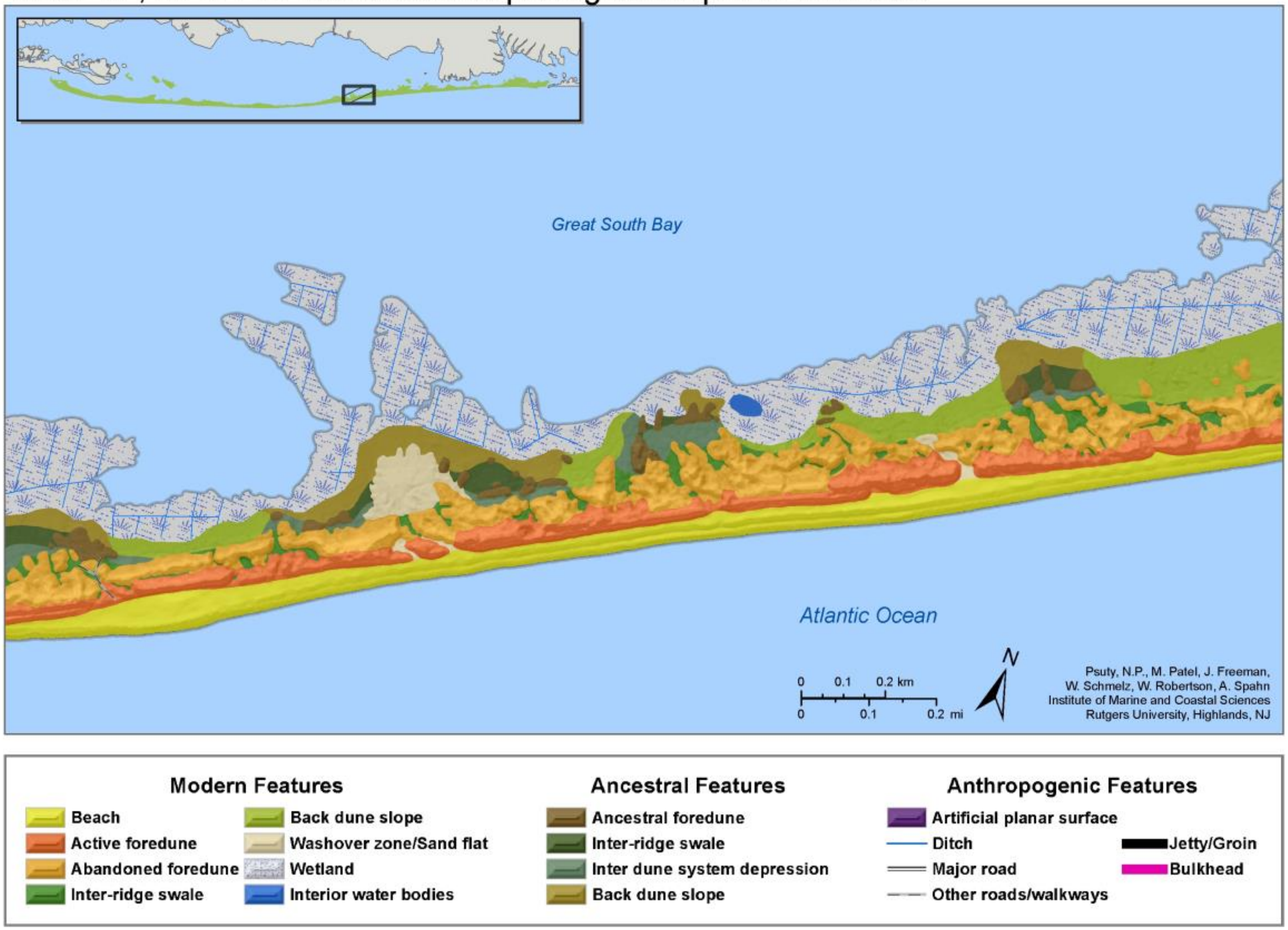
"Area 10", 2011 Fire Island Geomorphological Map with Hillshade



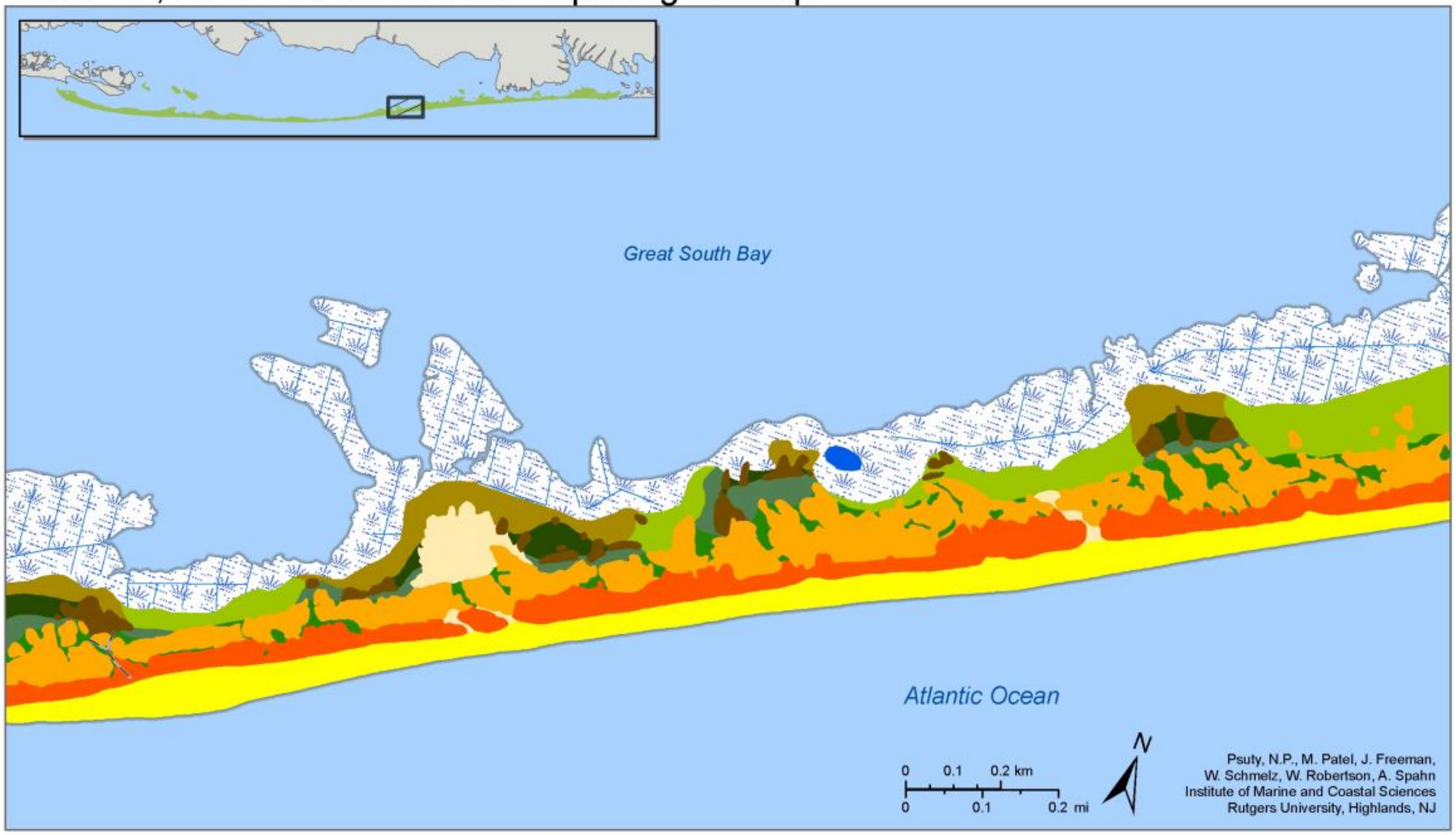
"Area 10", 2011 Fire Island Geomorphological Map



"Area 11", 2011 Fire Island Geomorphological Map with Hillshade

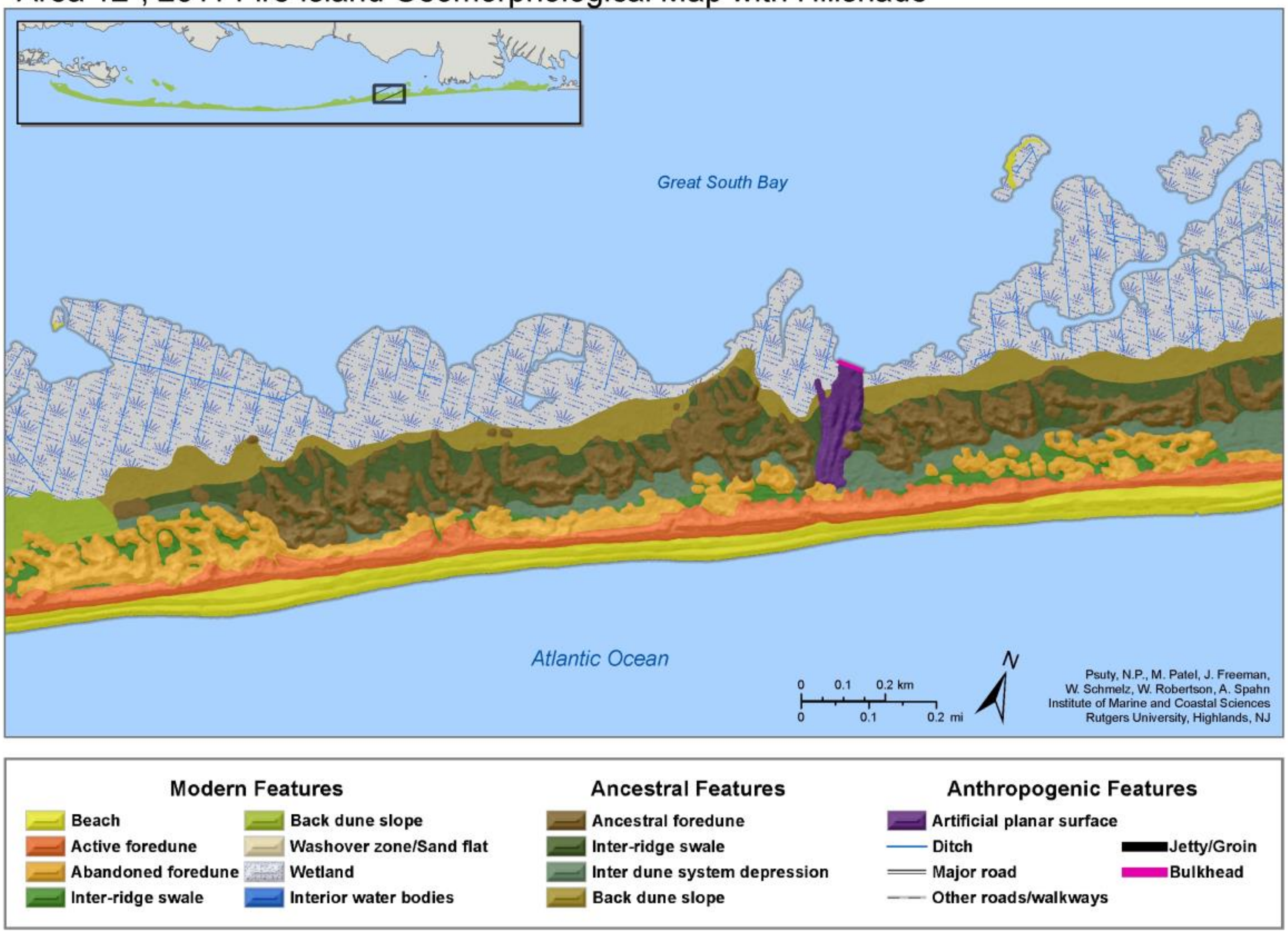


"Area 11", 2011 Fire Island Geomorphological Map

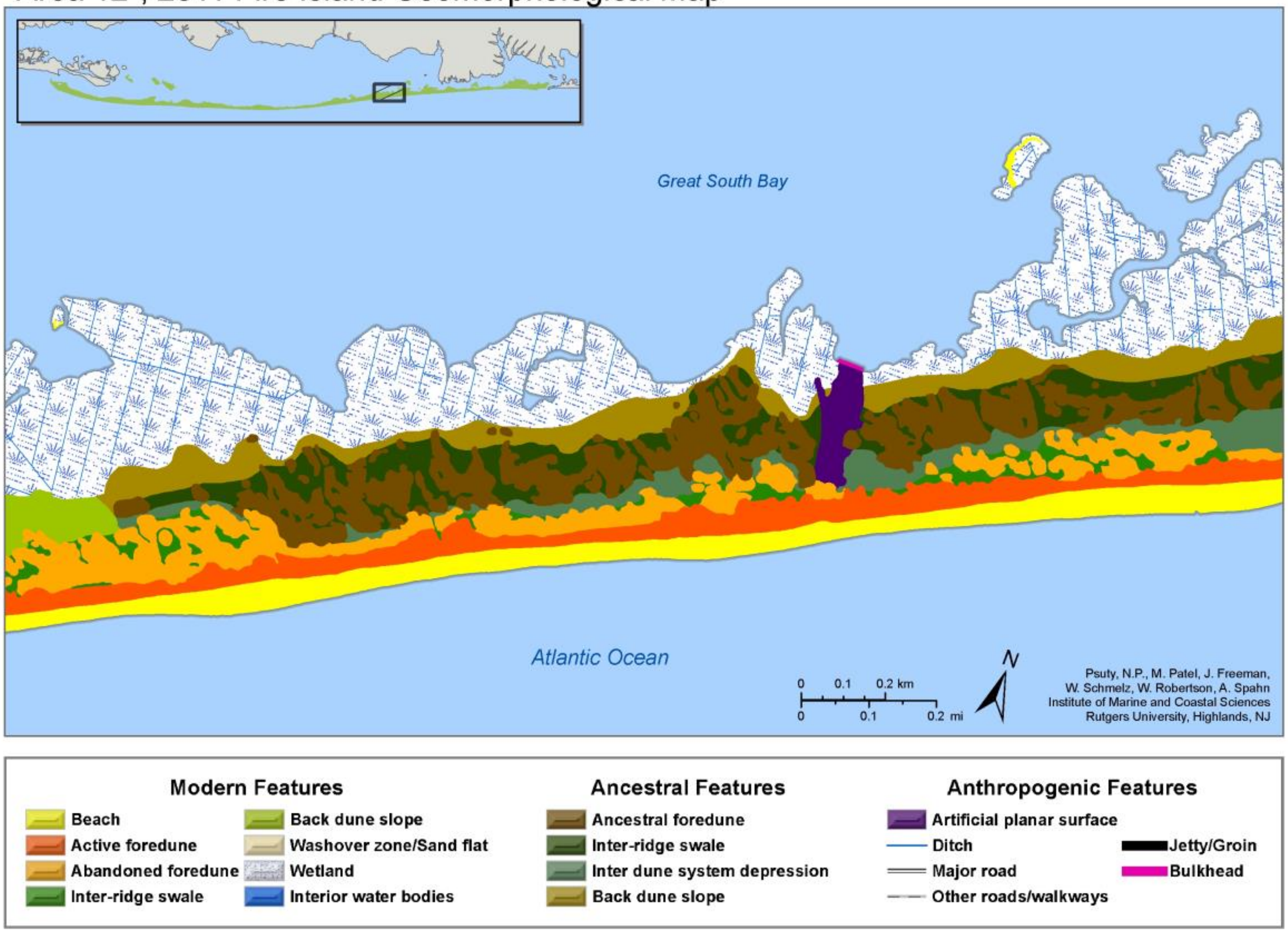


Modern Features		Ancestral Features	Anthropogenic Features	
Beach	Back dune slope	Ancestral foredune	Artificial planar surface	
Active foredune	Washover zone/Sand flat	Inter-ridge swale	Ditch	Jetty/Groin
Abandoned foredune	Wetland	Inter dune system depression	Major road	Bulkhead
Inter-ridge swale	Interior water bodies	Back dune slope	Other roads/walkways	

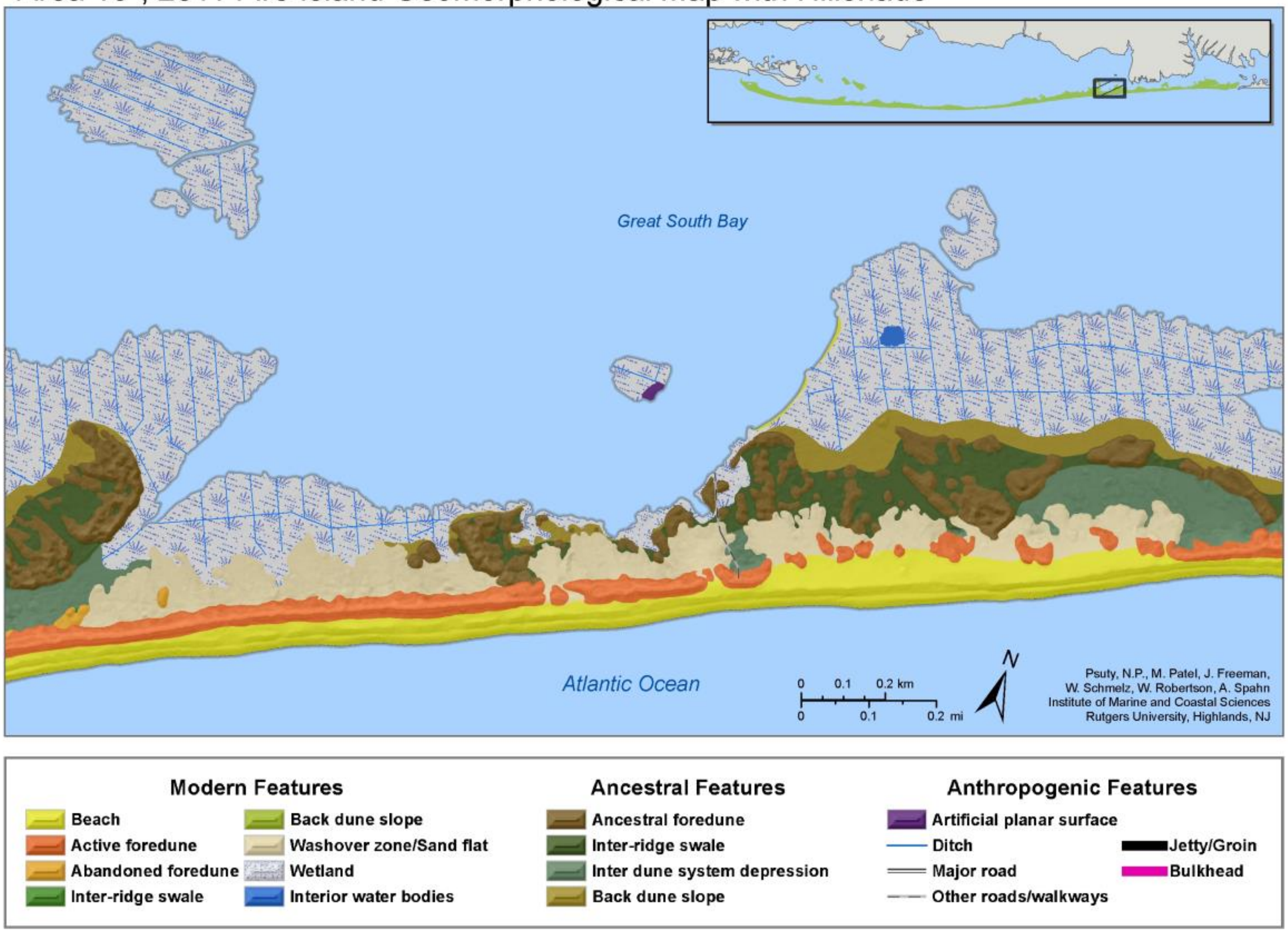
"Area 12", 2011 Fire Island Geomorphological Map with Hillshade



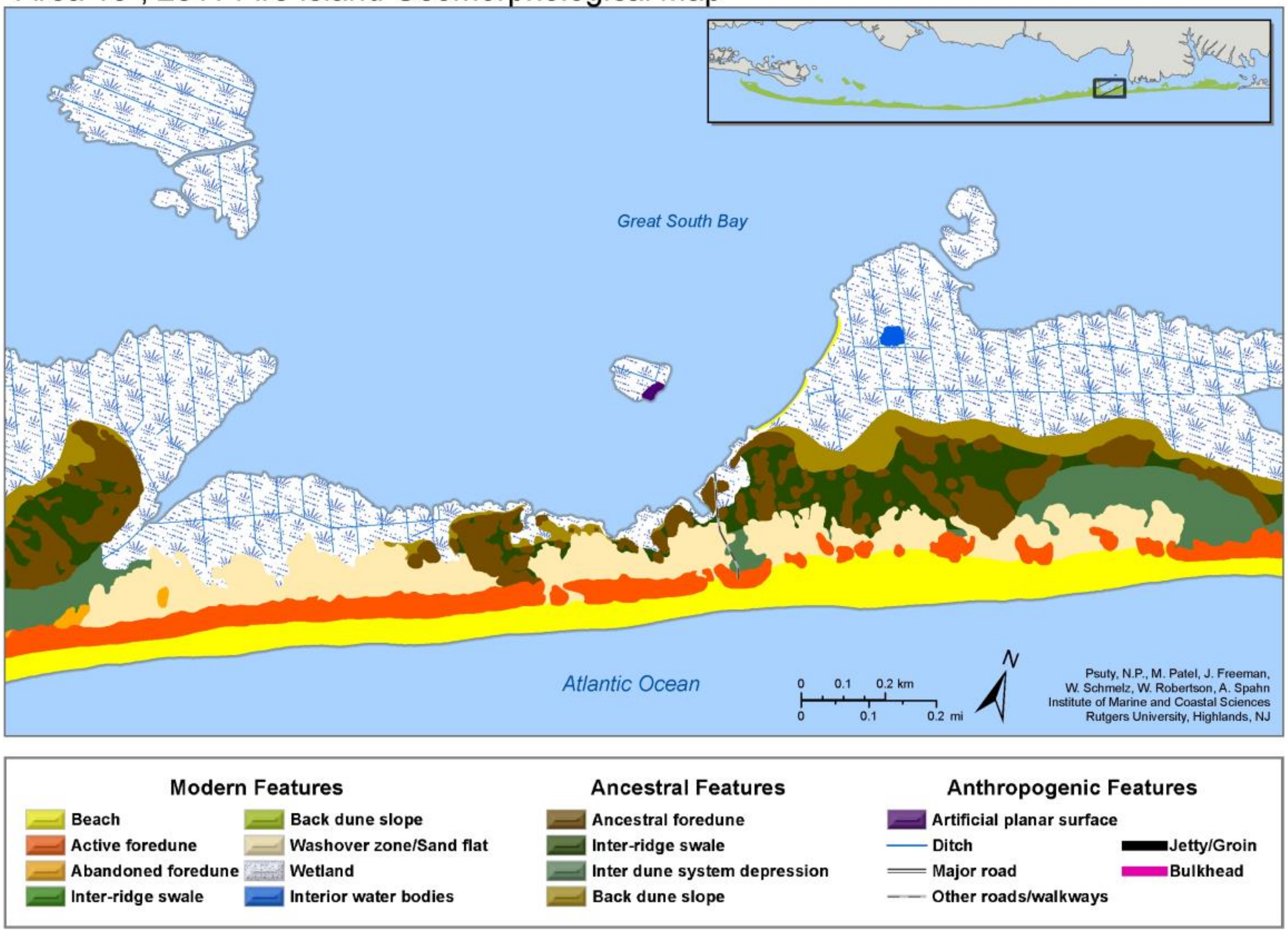
"Area 12", 2011 Fire Island Geomorphological Map



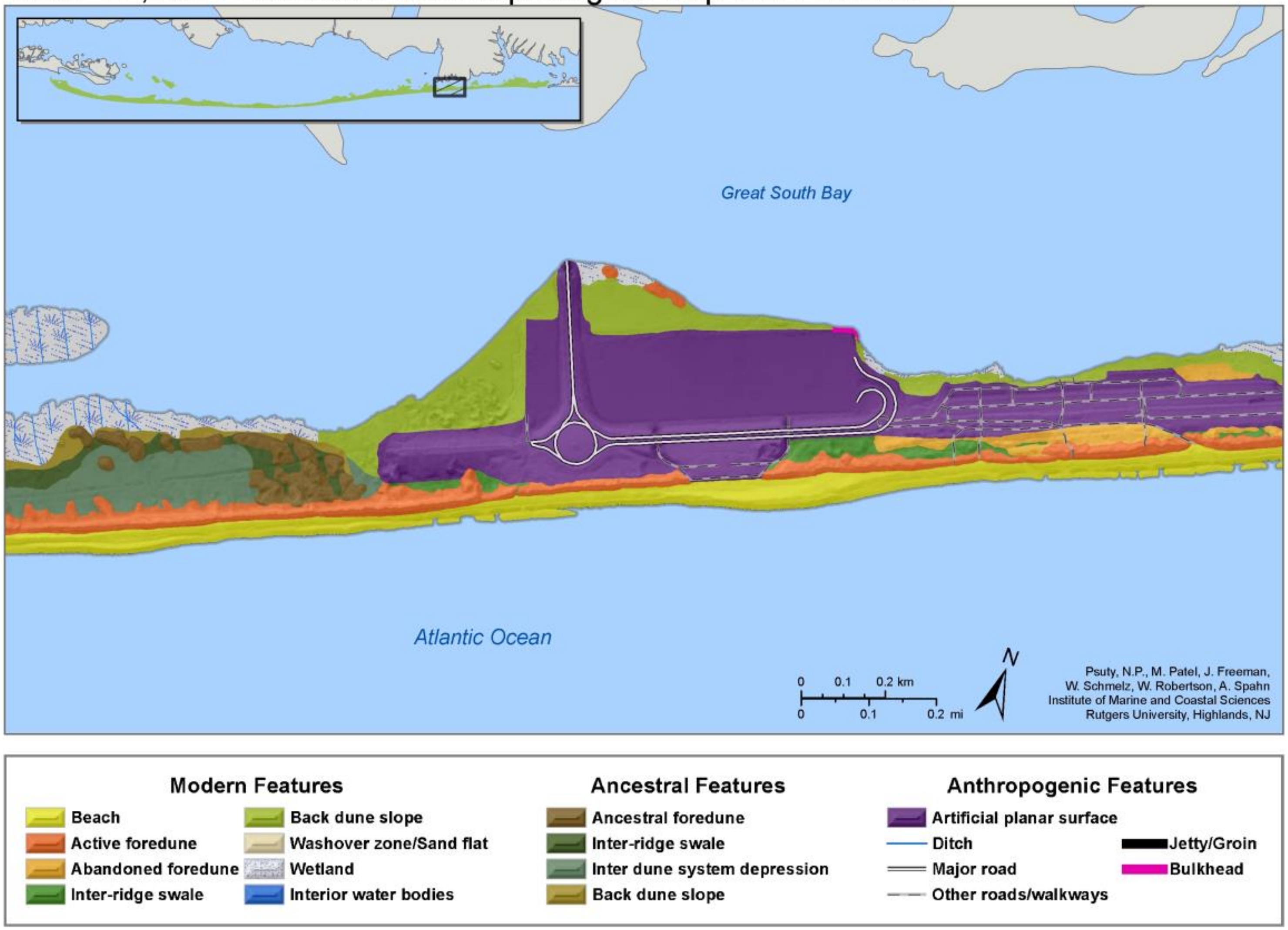
"Area 13", 2011 Fire Island Geomorphological Map with Hillshade



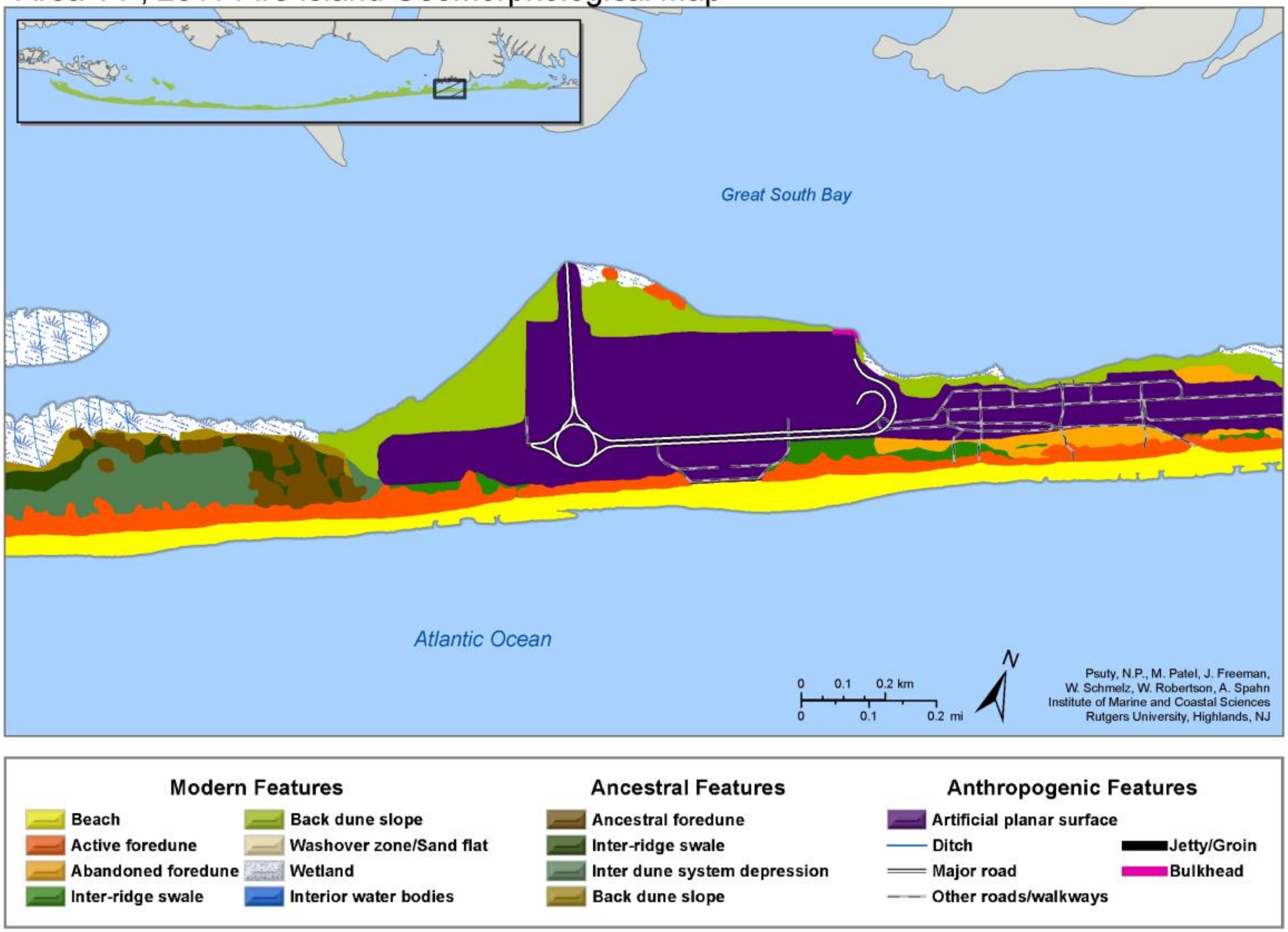
"Area 13", 2011 Fire Island Geomorphological Map



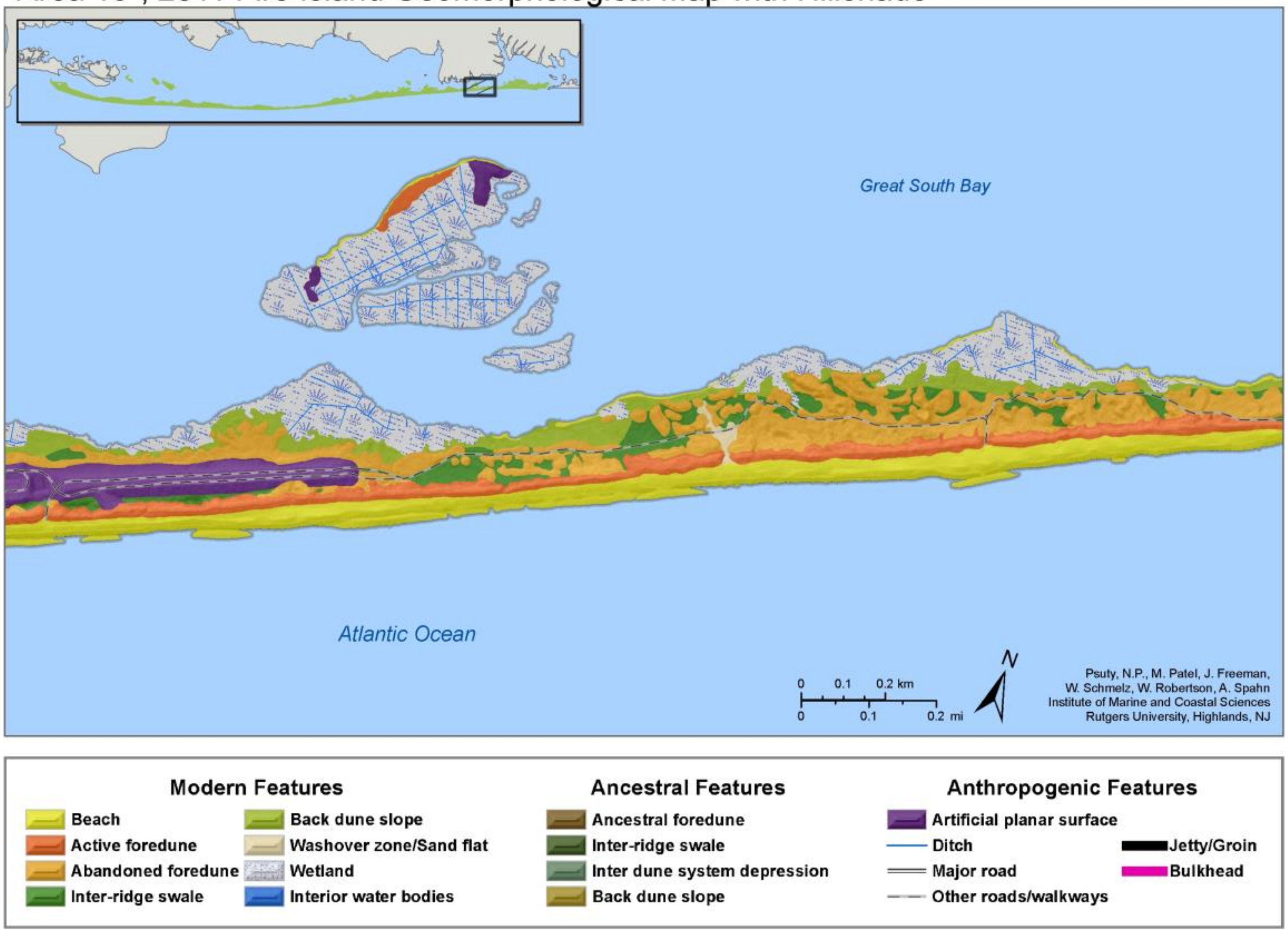
"Area 14", 2011 Fire Island Geomorphological Map with Hillshade



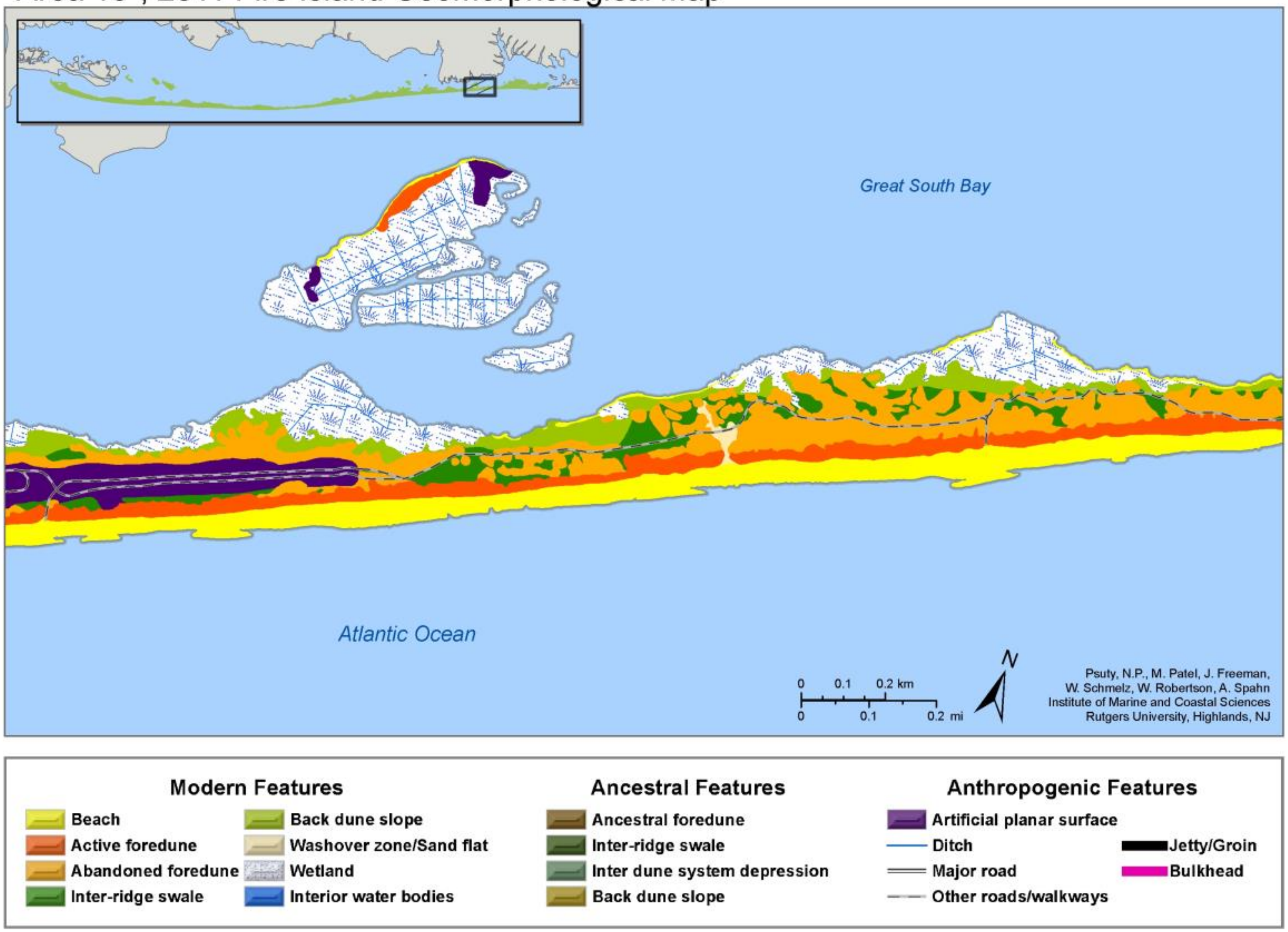
"Area 14", 2011 Fire Island Geomorphological Map



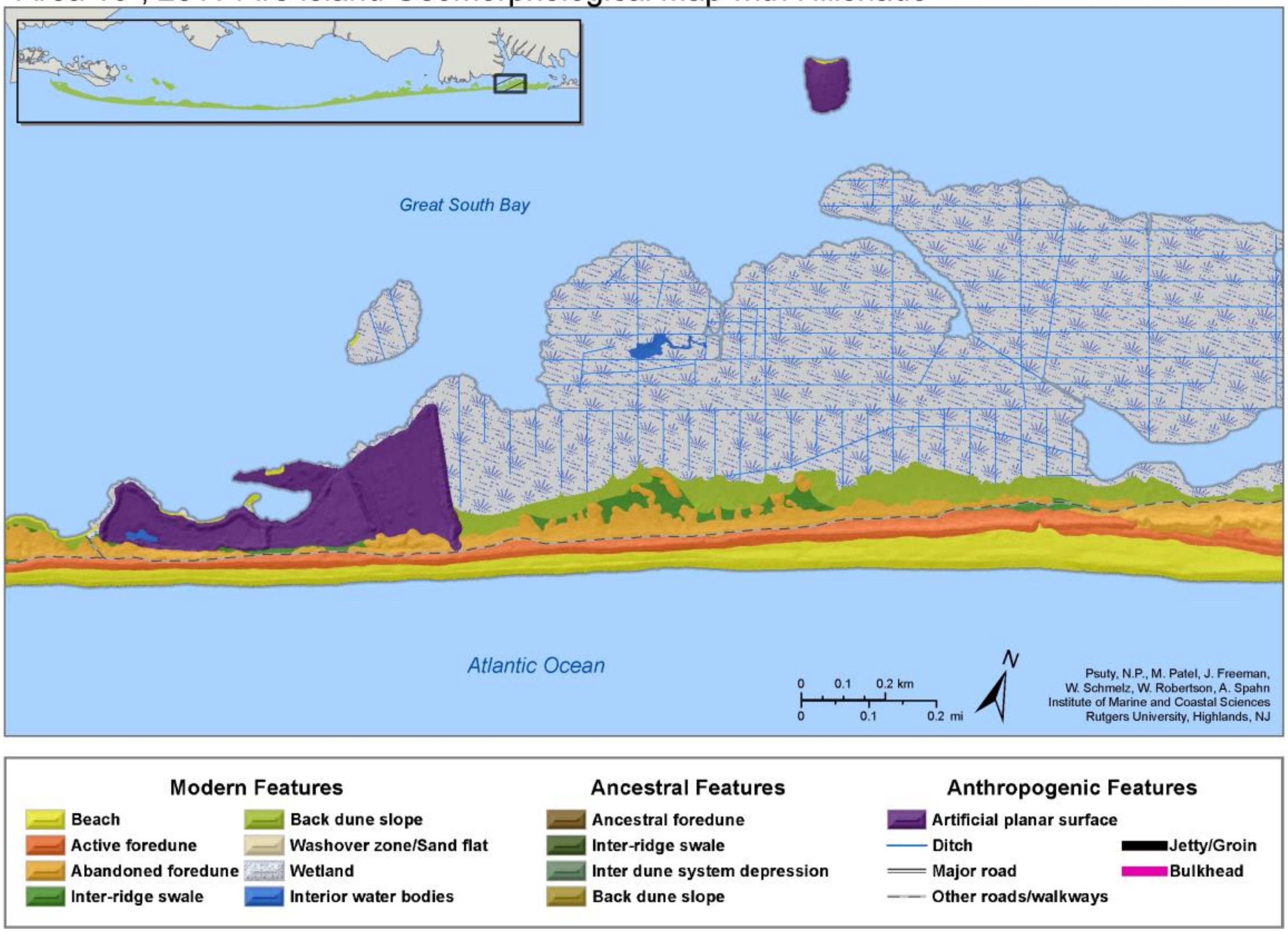
"Area 15", 2011 Fire Island Geomorphological Map with Hillshade



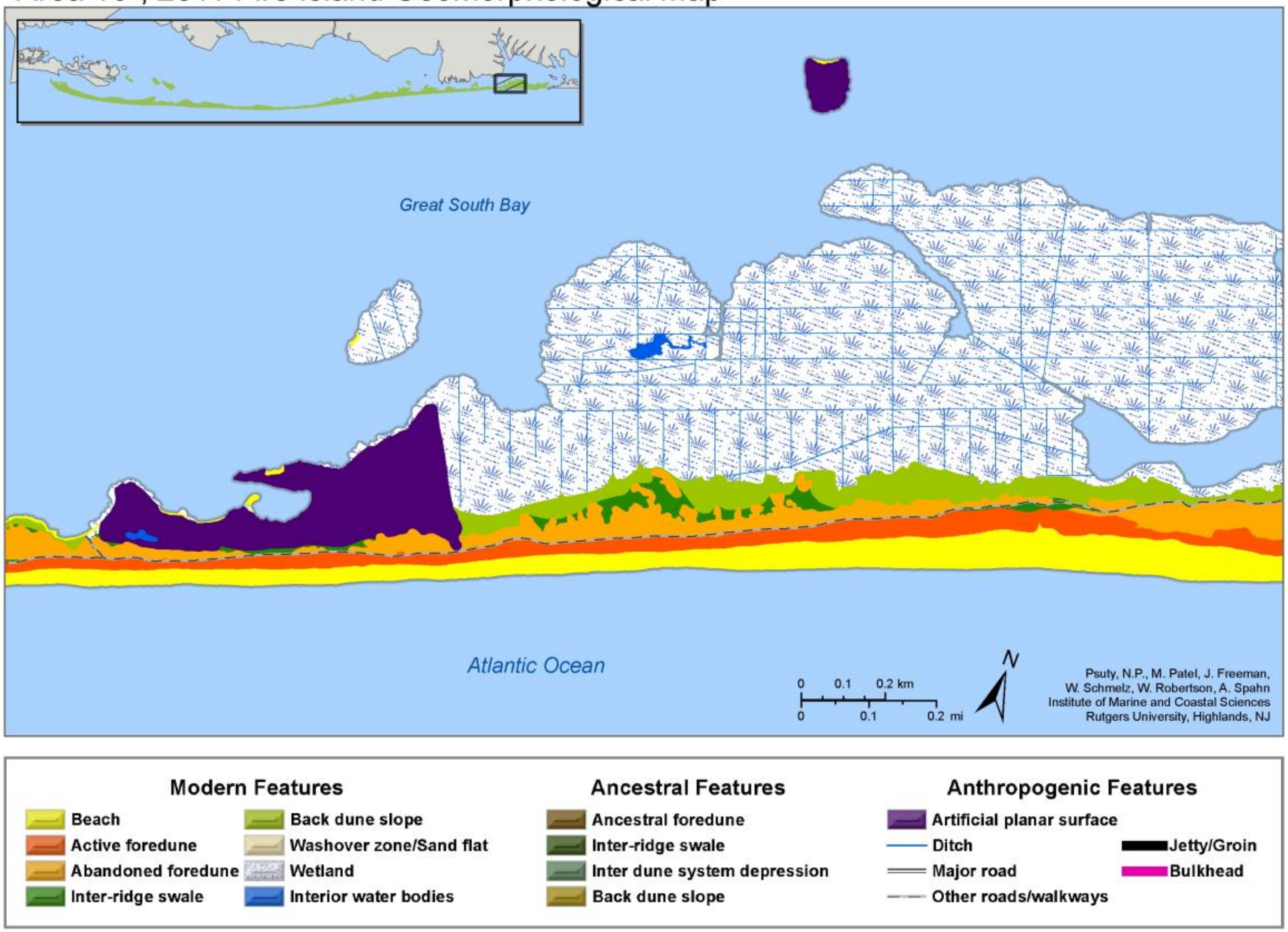
"Area 15", 2011 Fire Island Geomorphological Map



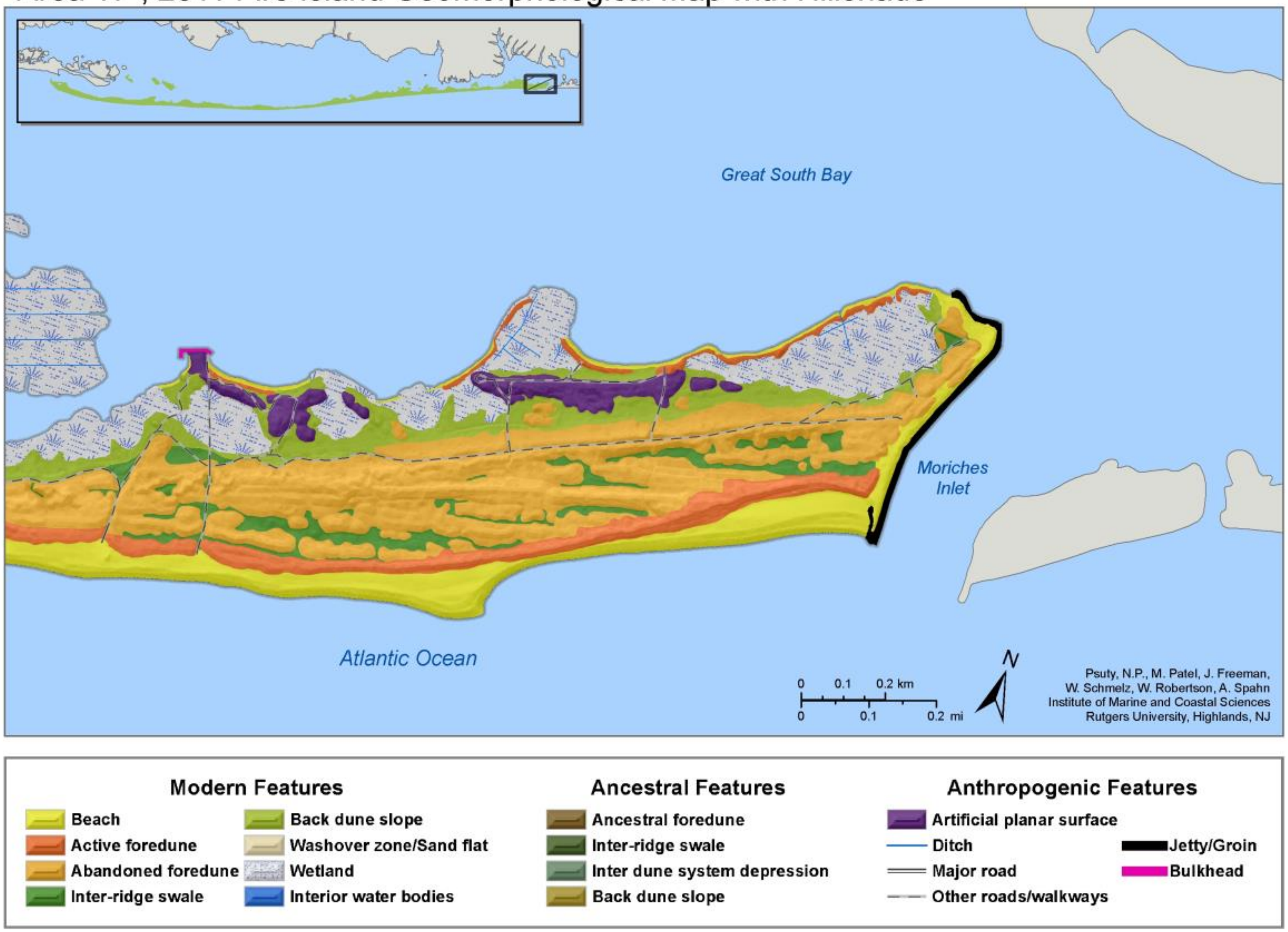
"Area 16", 2011 Fire Island Geomorphological Map with Hillshade



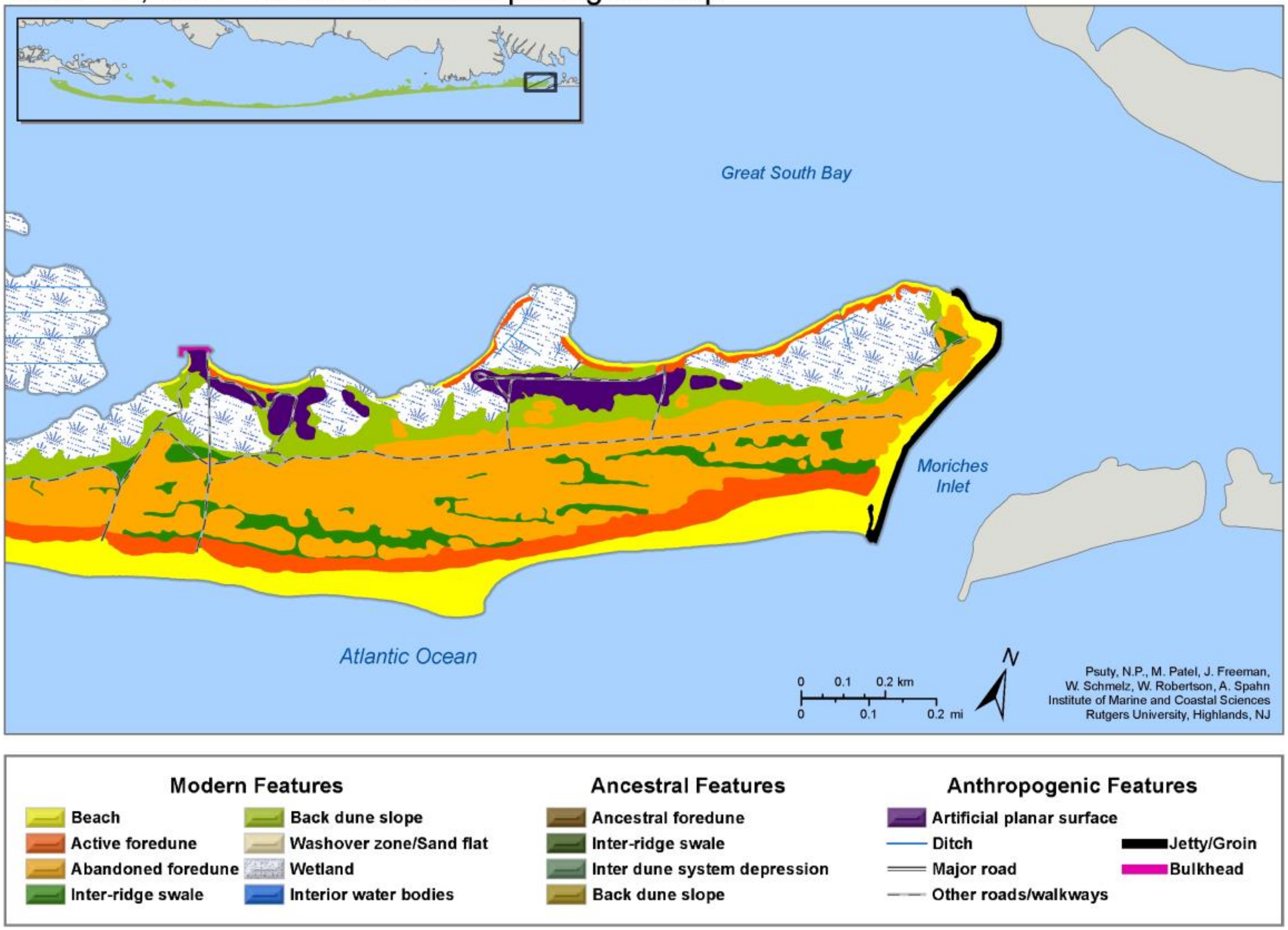
"Area 16", 2011 Fire Island Geomorphological Map



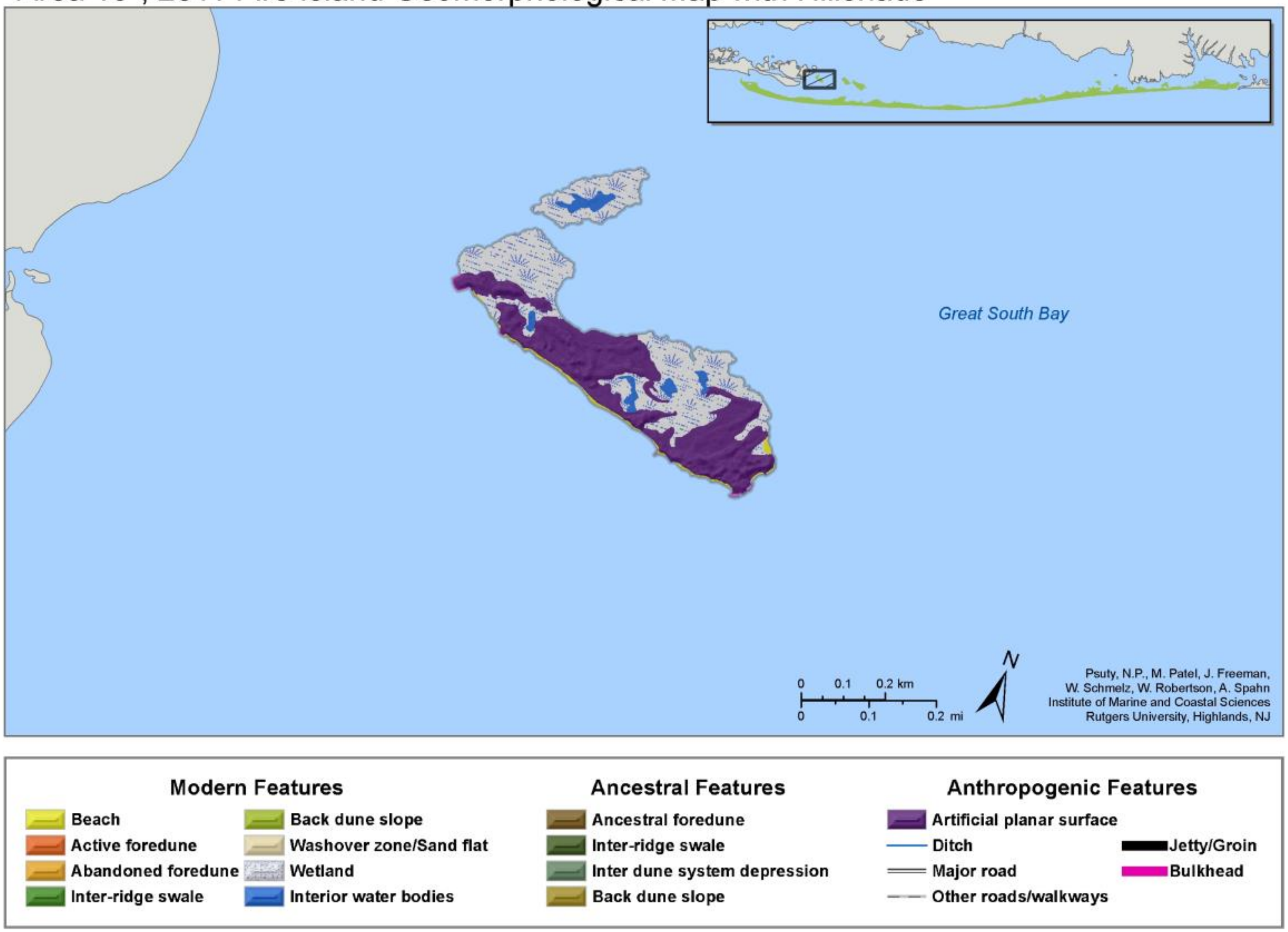
"Area 17", 2011 Fire Island Geomorphological Map with Hillshade



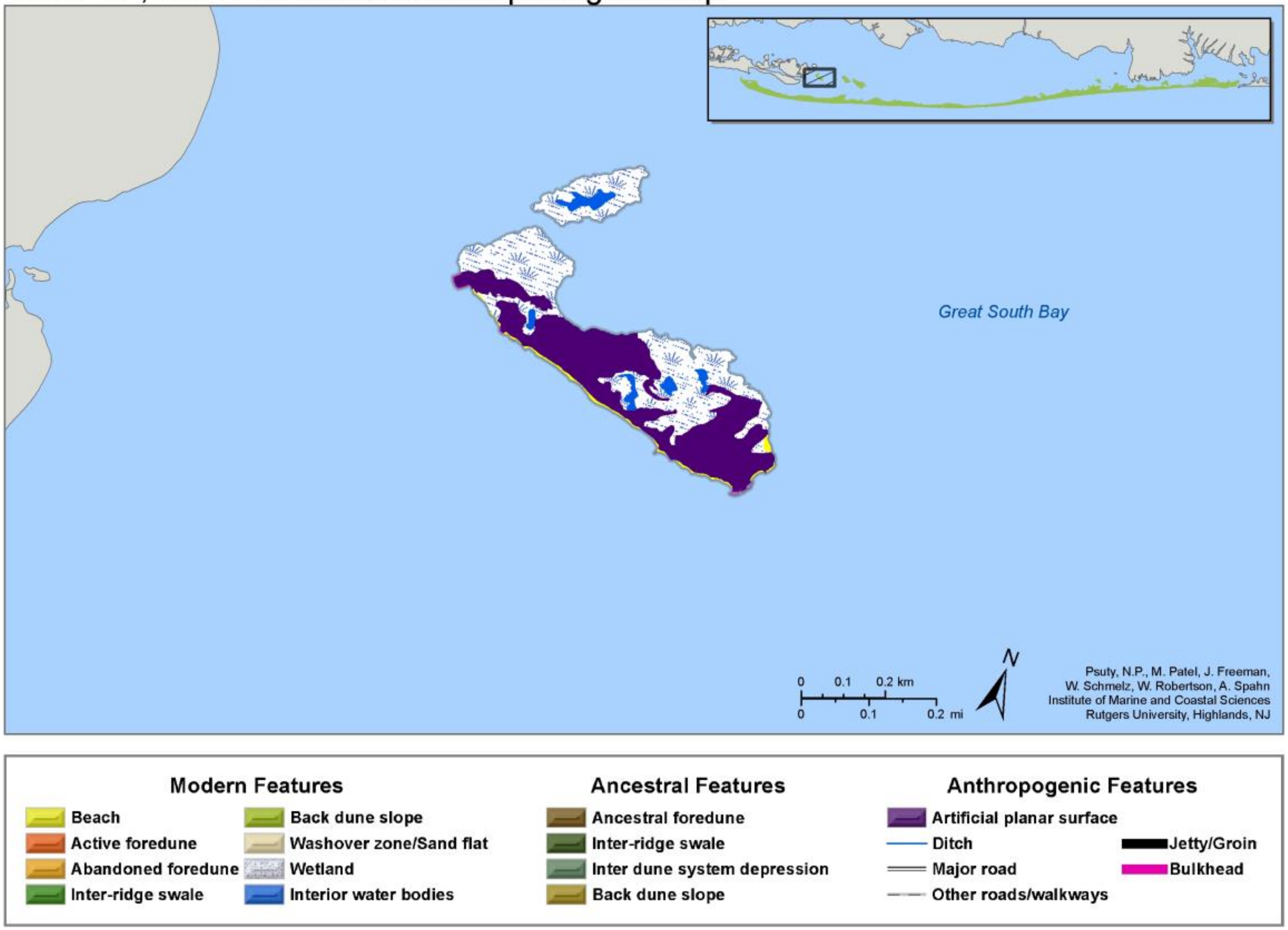
"Area 17", 2011 Fire Island Geomorphological Map



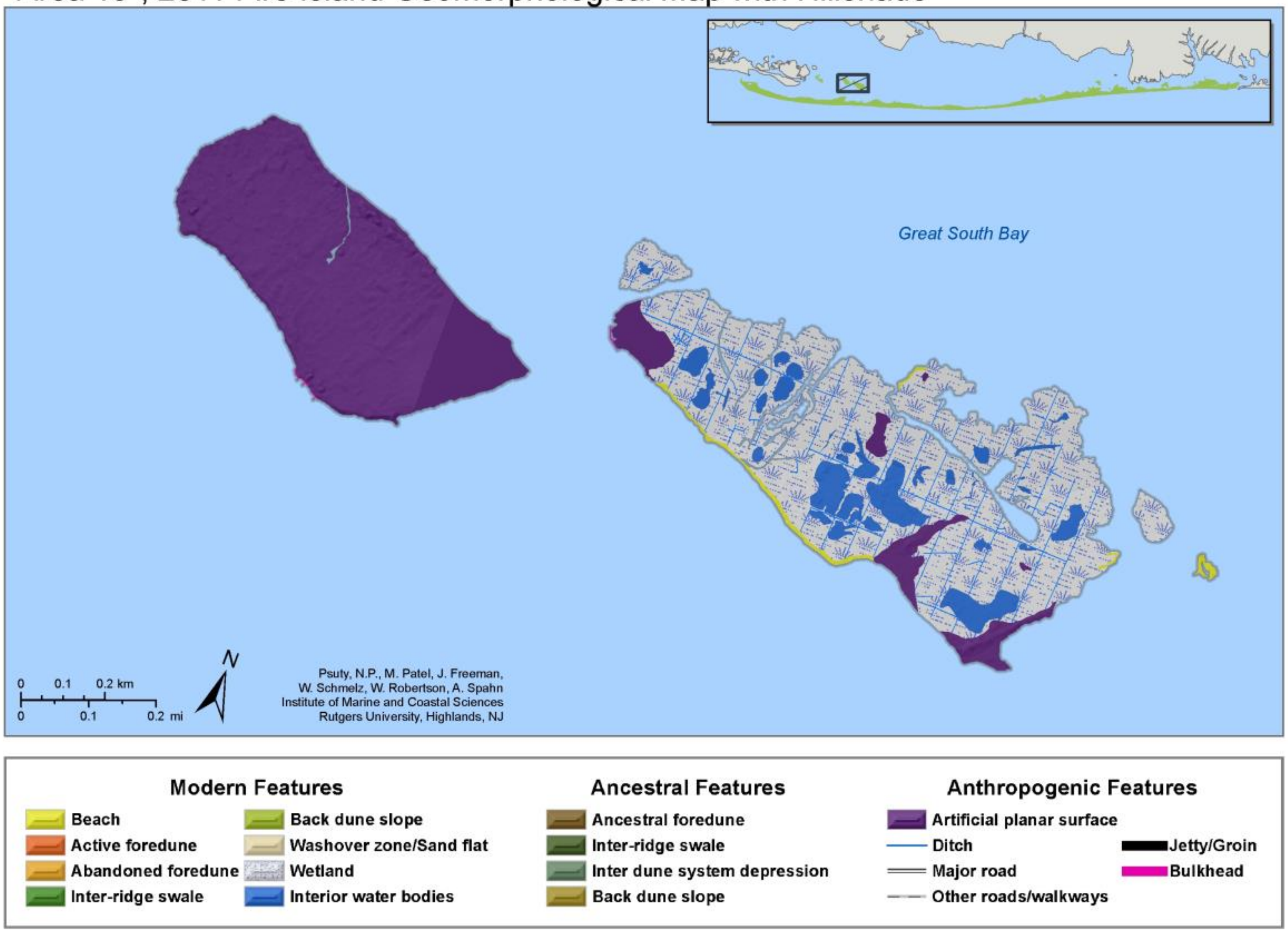
"Area 18", 2011 Fire Island Geomorphological Map with Hillshade



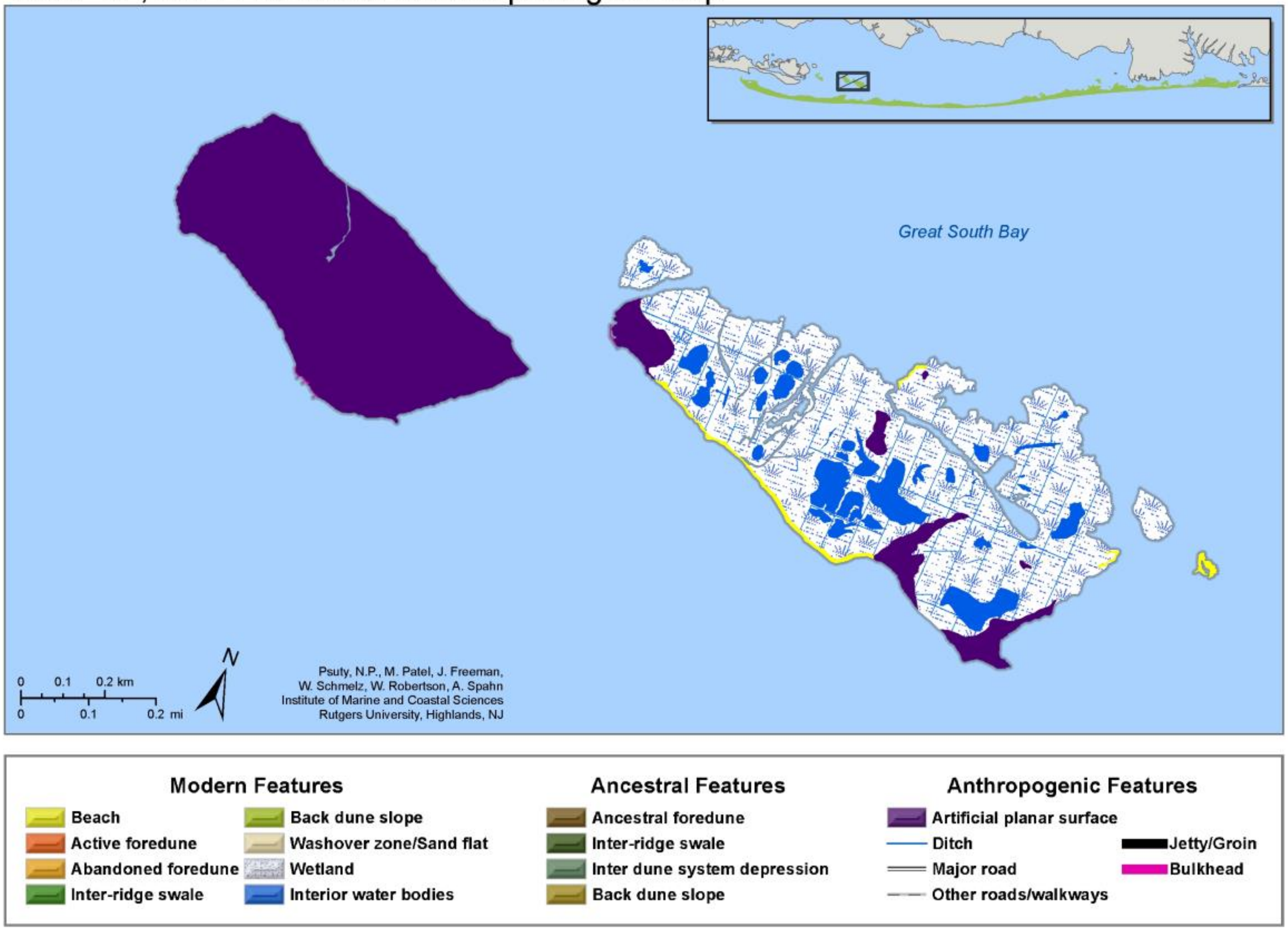
"Area 18", 2011 Fire Island Geomorphological Map



"Area 19", 2011 Fire Island Geomorphological Map with Hillshade



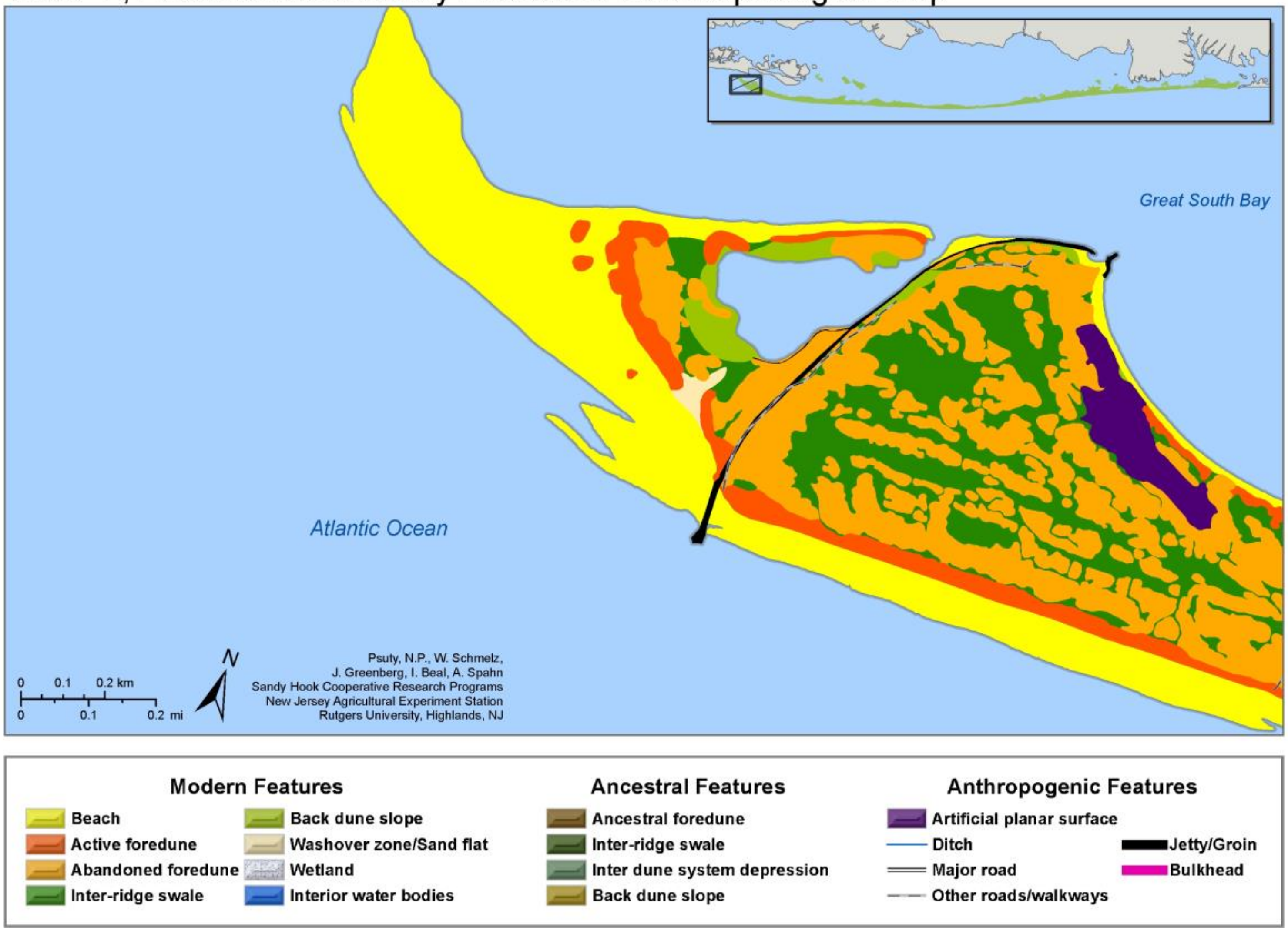
"Area 19", 2011 Fire Island Geomorphological Map



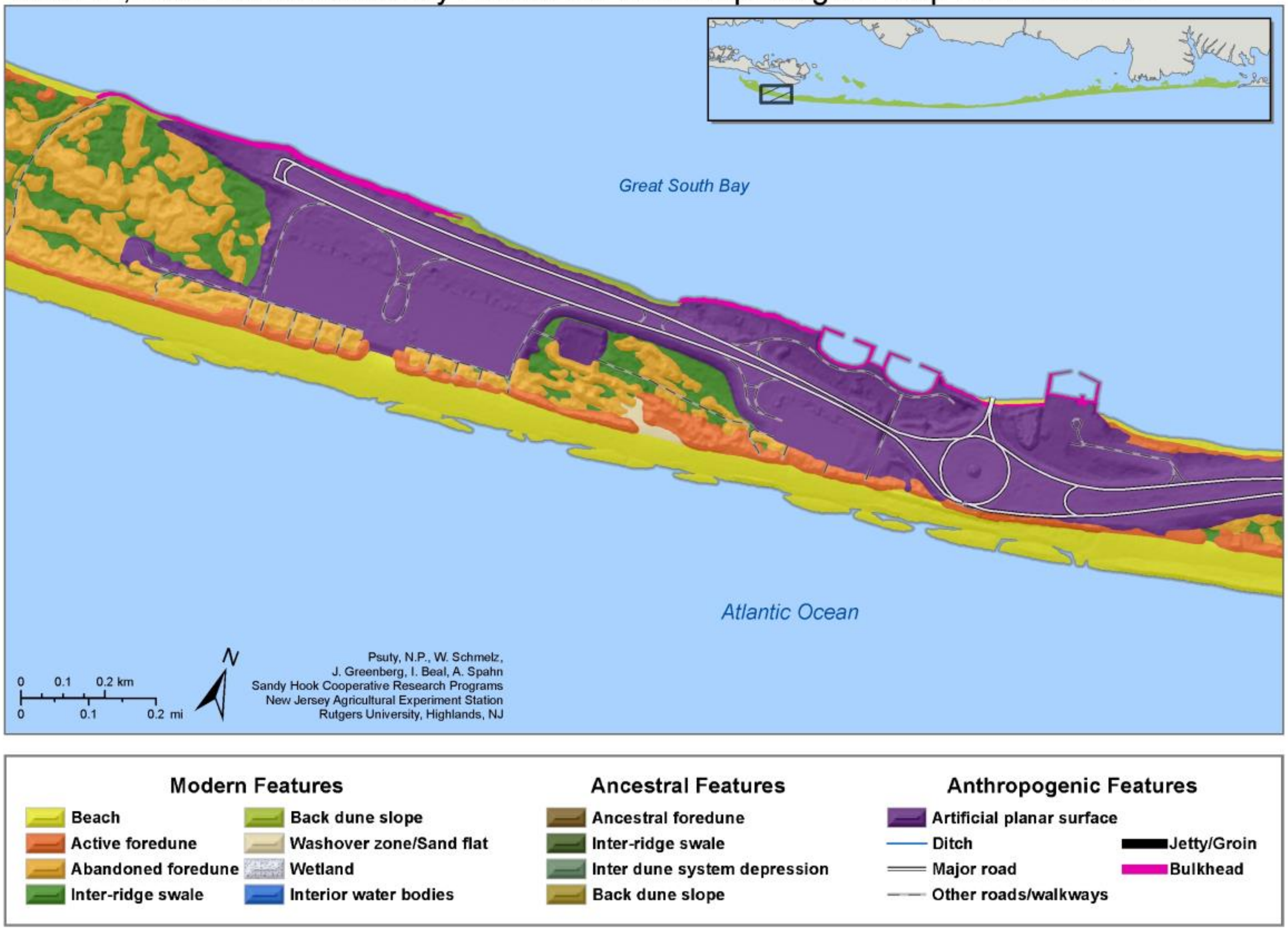
Appendix II: Post-Hurricane Sandy Maps of Fire Island Geomorphology, with and without Hillshade

"Area 1", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade

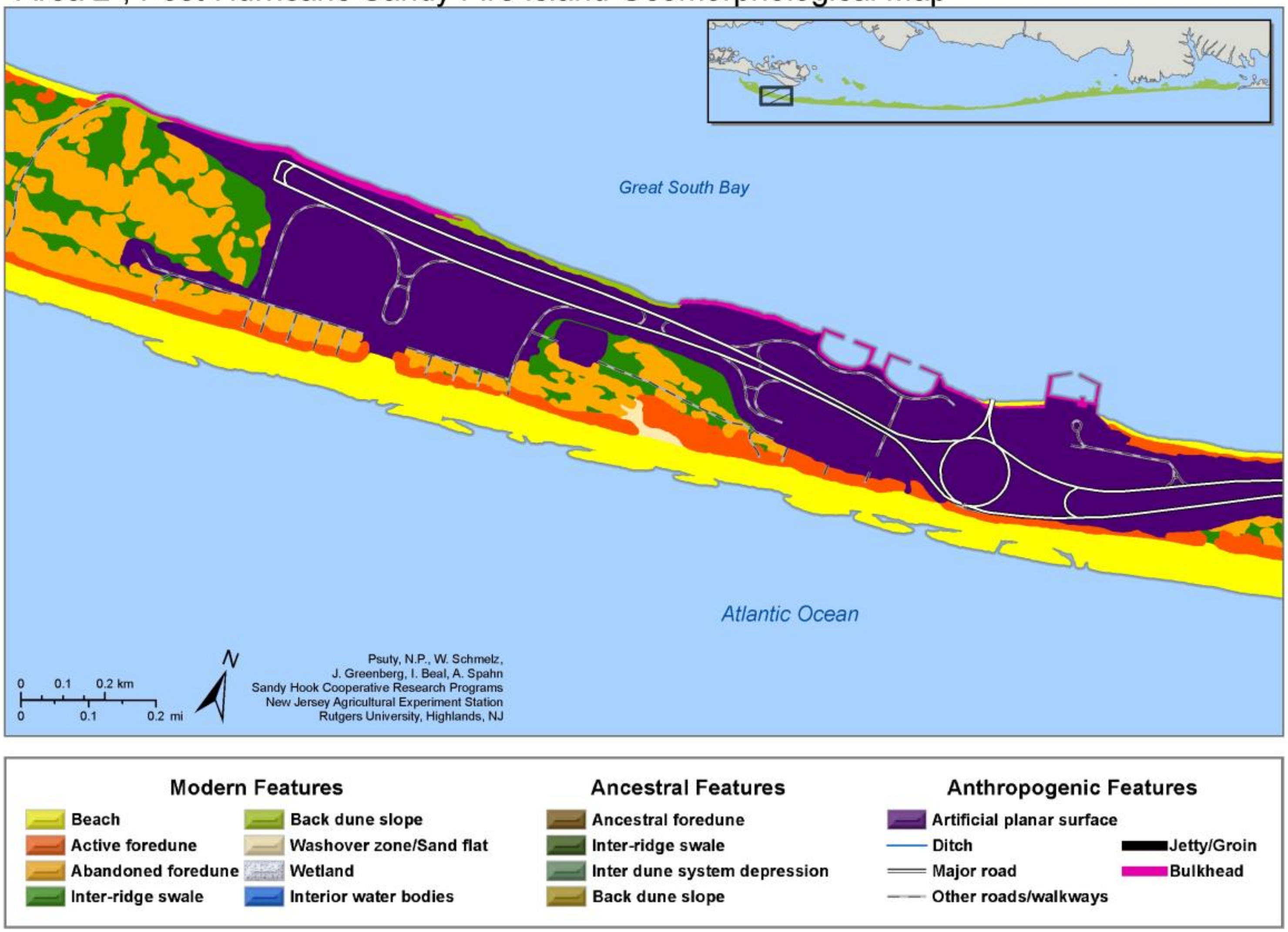
"Area 1", Post-Hurricane Sandy Fire Island Geomorphological Map



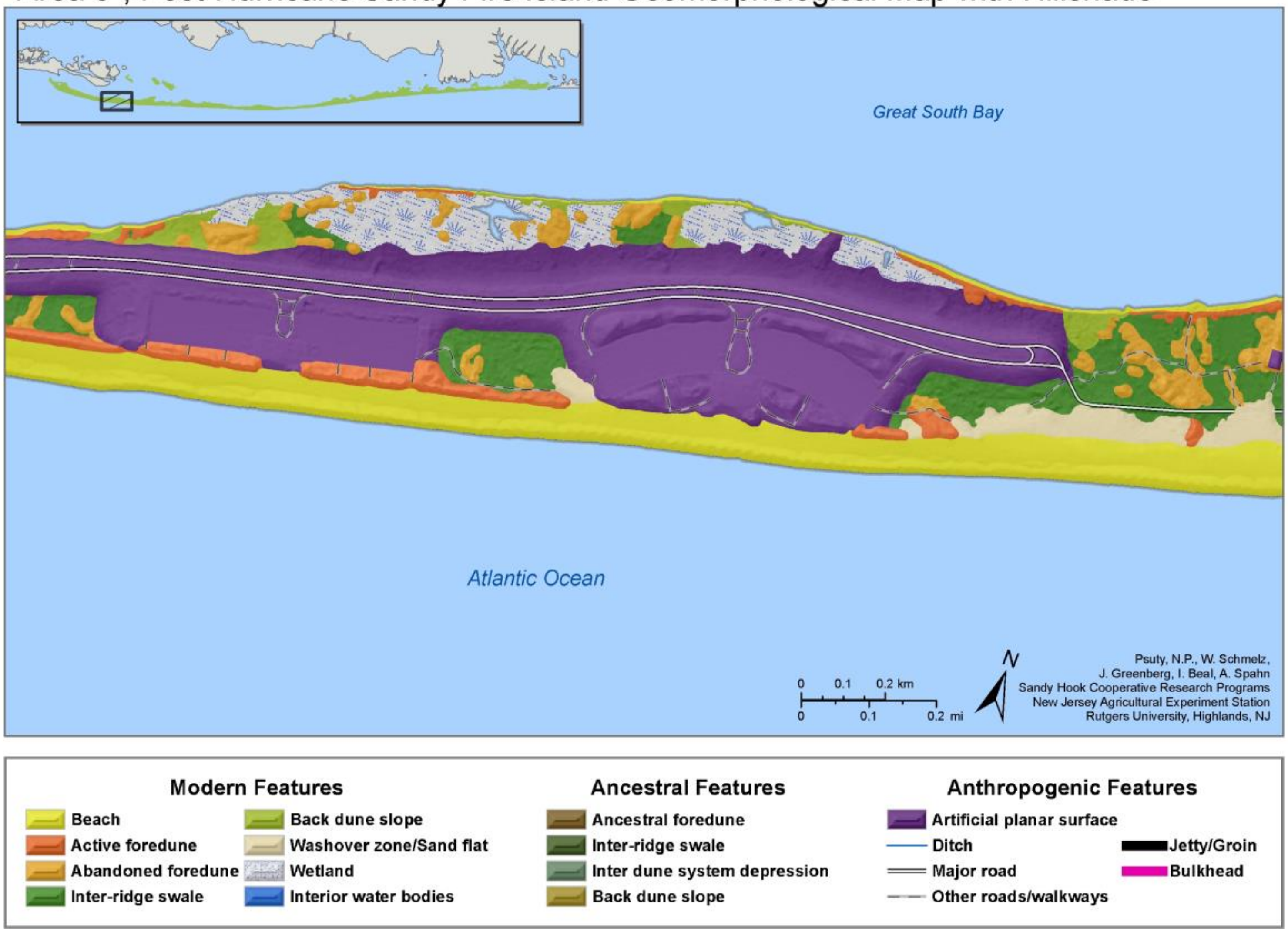
"Area 2", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



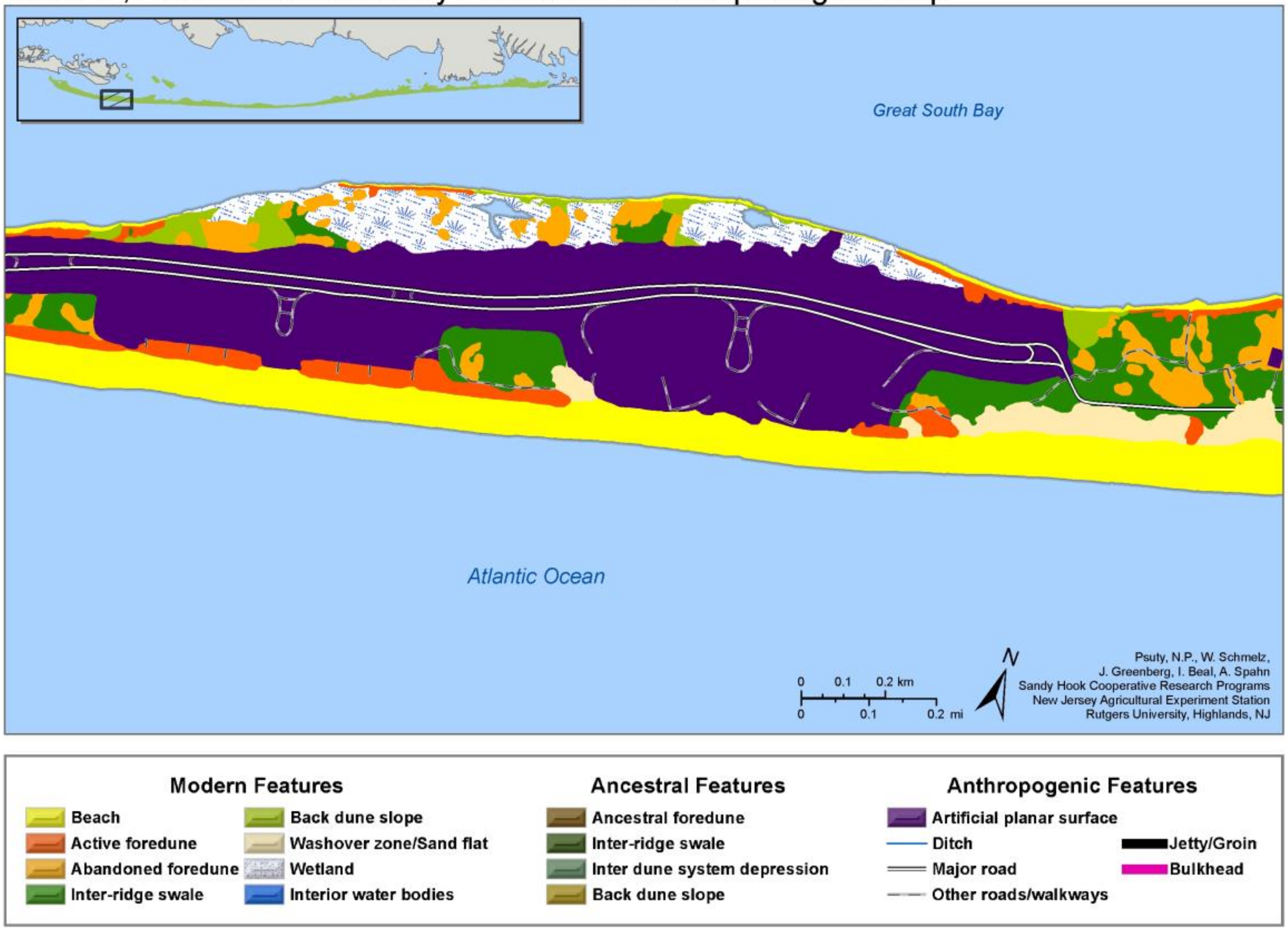
"Area 2", Post-Hurricane Sandy Fire Island Geomorphological Map



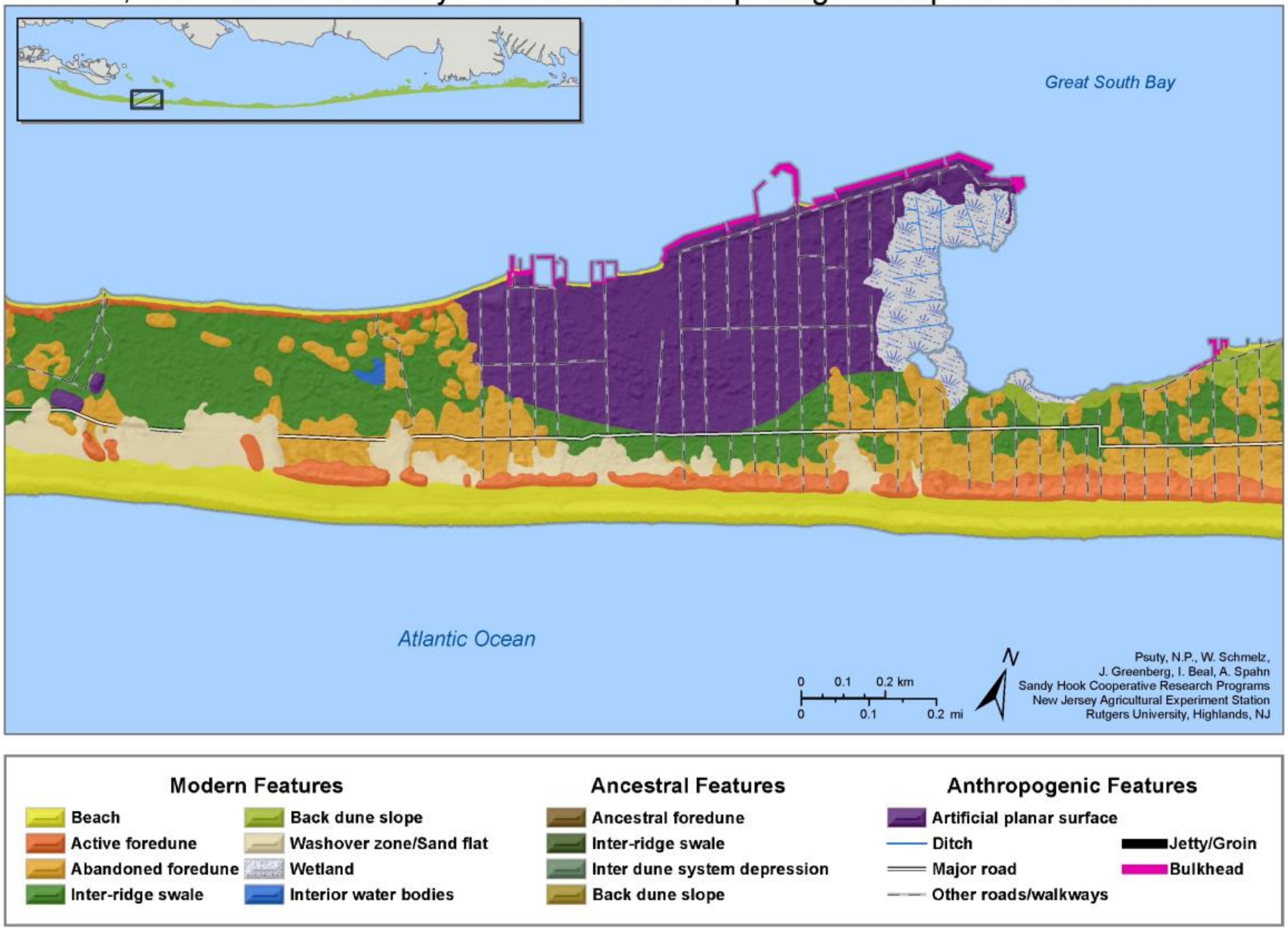
"Area 3", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



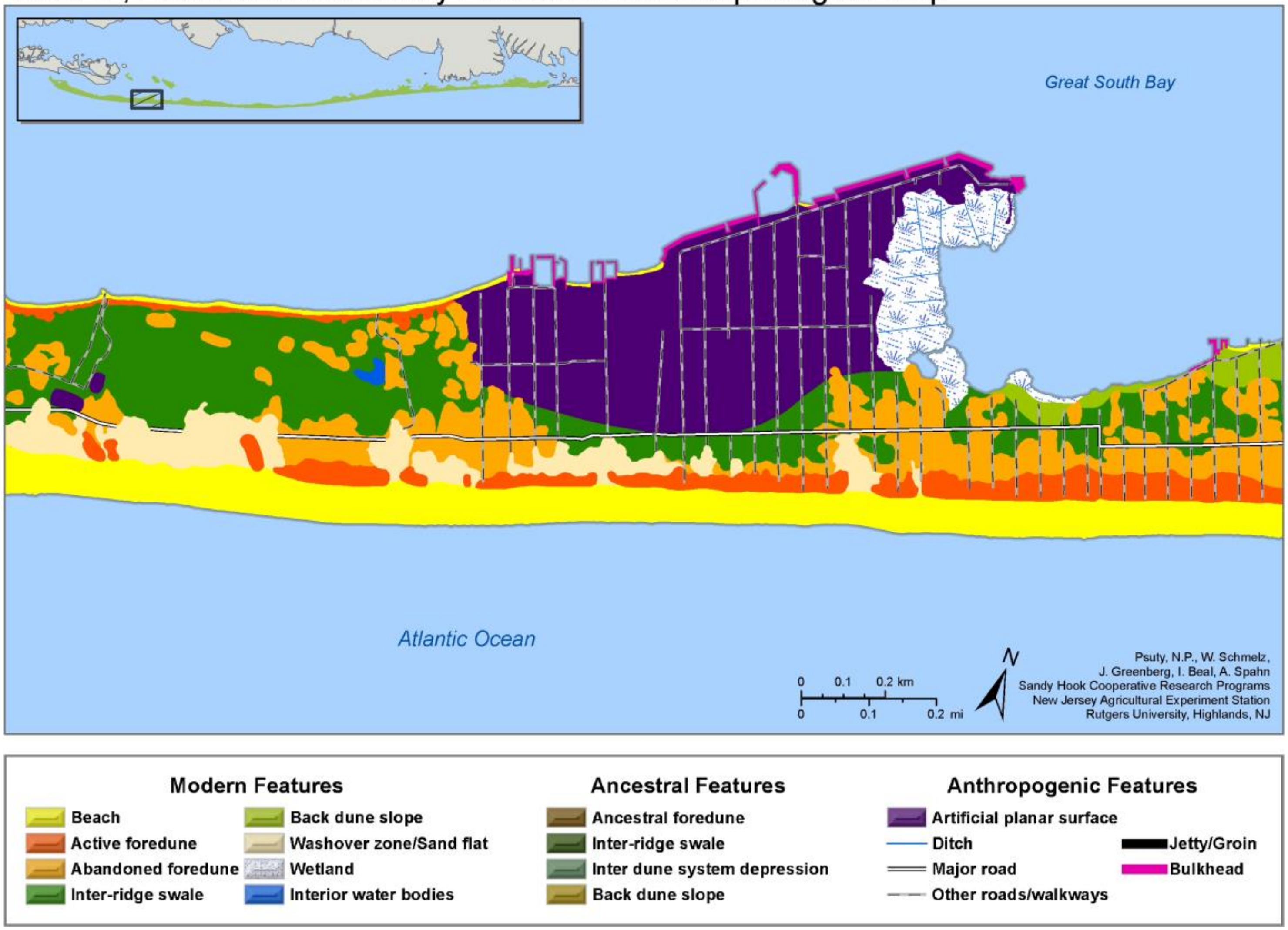
"Area 3", Post-Hurricane Sandy Fire Island Geomorphological Map



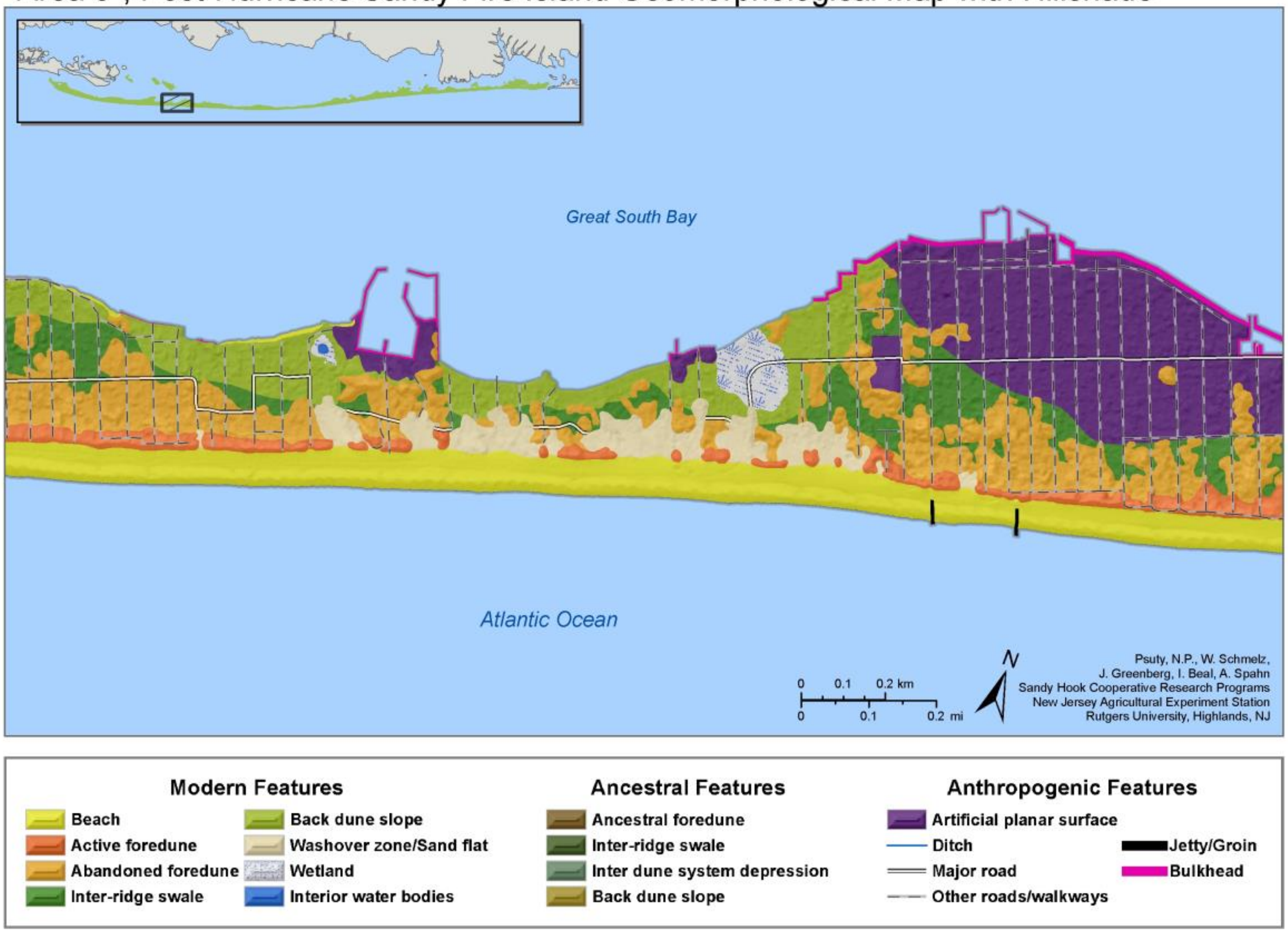
"Area 4", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



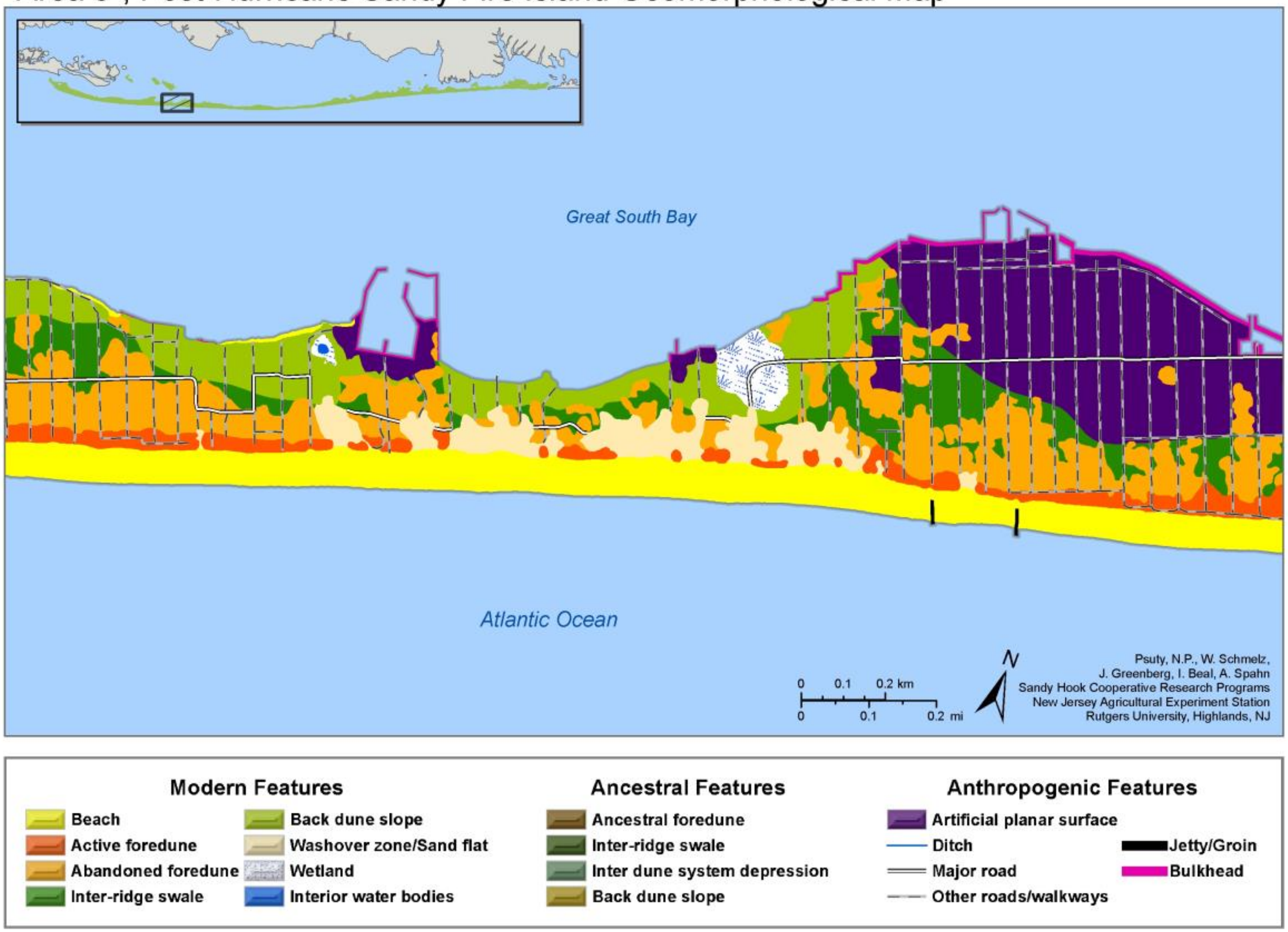
"Area 4", Post-Hurricane Sandy Fire Island Geomorphological Map



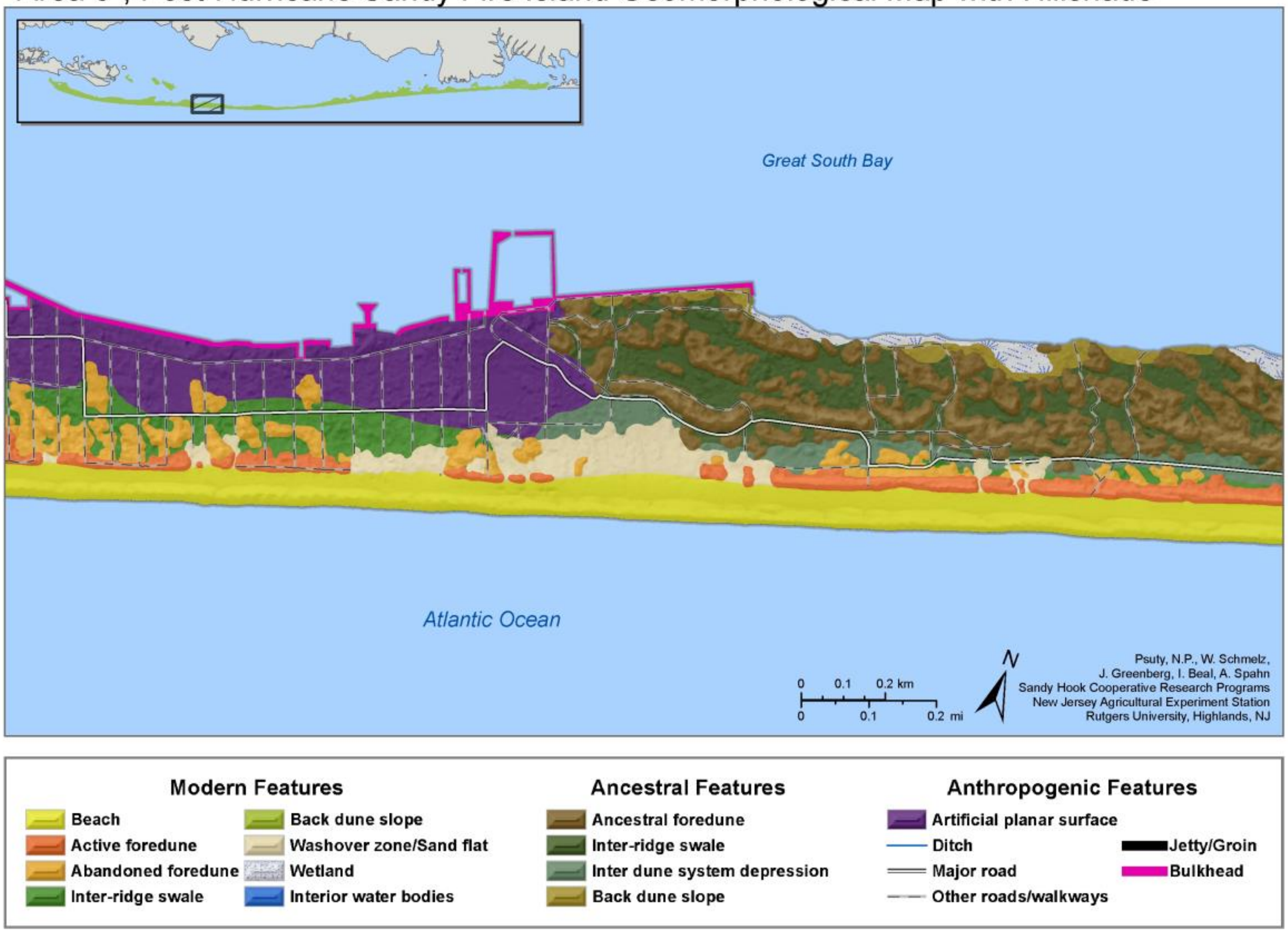
"Area 5", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



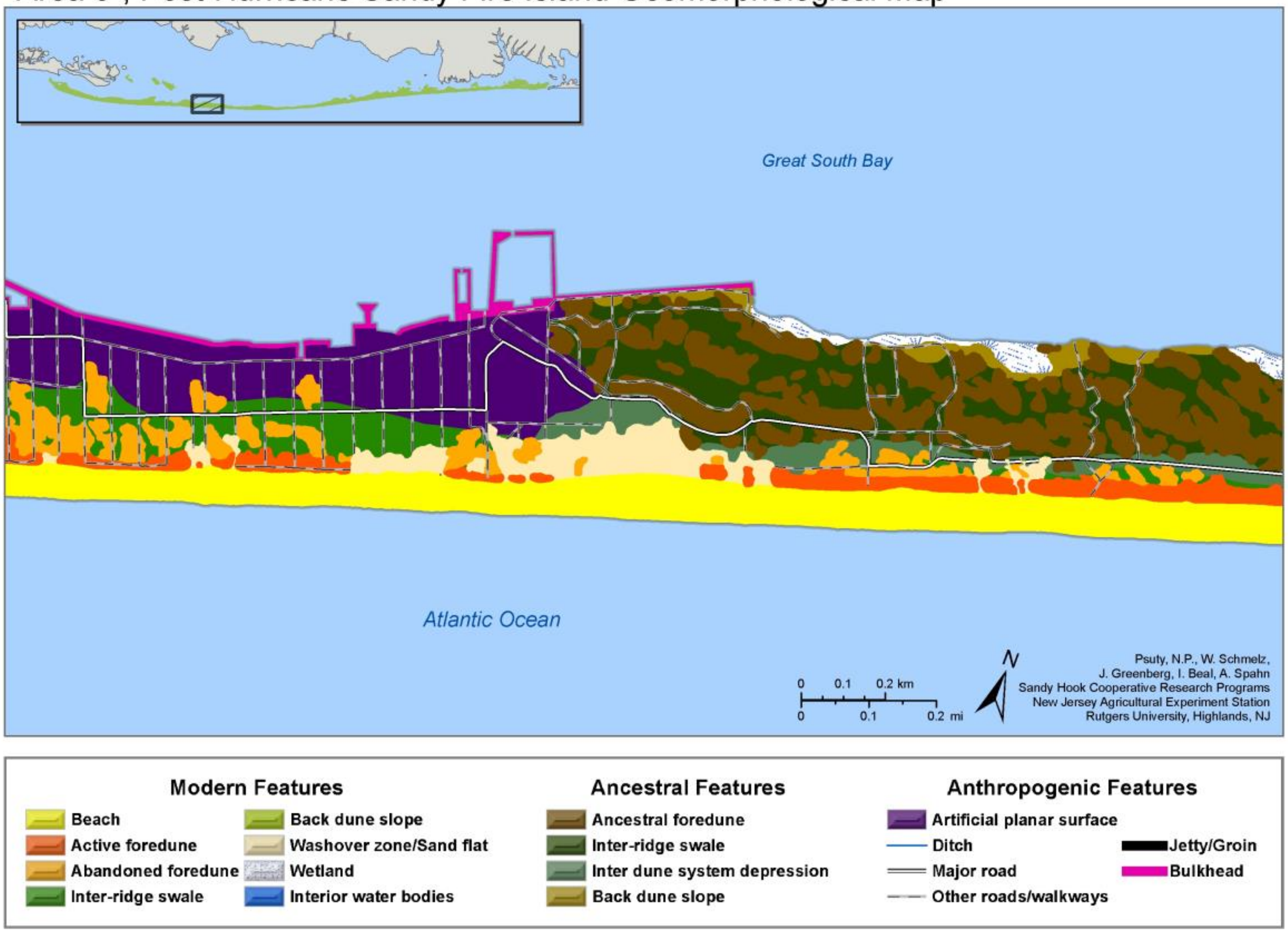
"Area 5", Post-Hurricane Sandy Fire Island Geomorphological Map



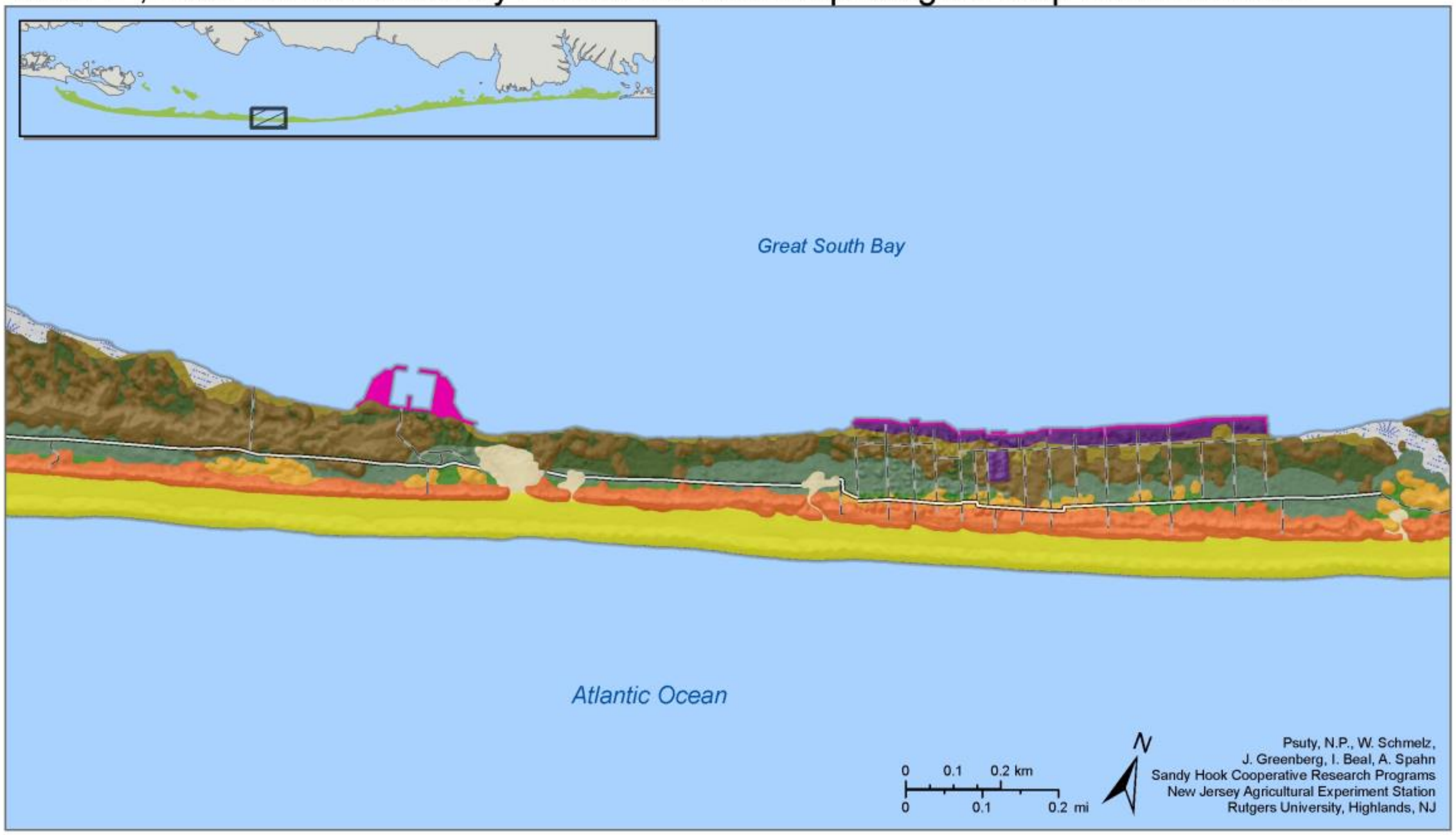
"Area 6", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



"Area 6", Post-Hurricane Sandy Fire Island Geomorphological Map



"Area 7", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



Modern Features

- Beach
- Active foredune
- Abandoned foredune
- Inter-ridge swale
- Back dune slope
- Washover zone/Sand flat
- Wetland
- Interior water bodies

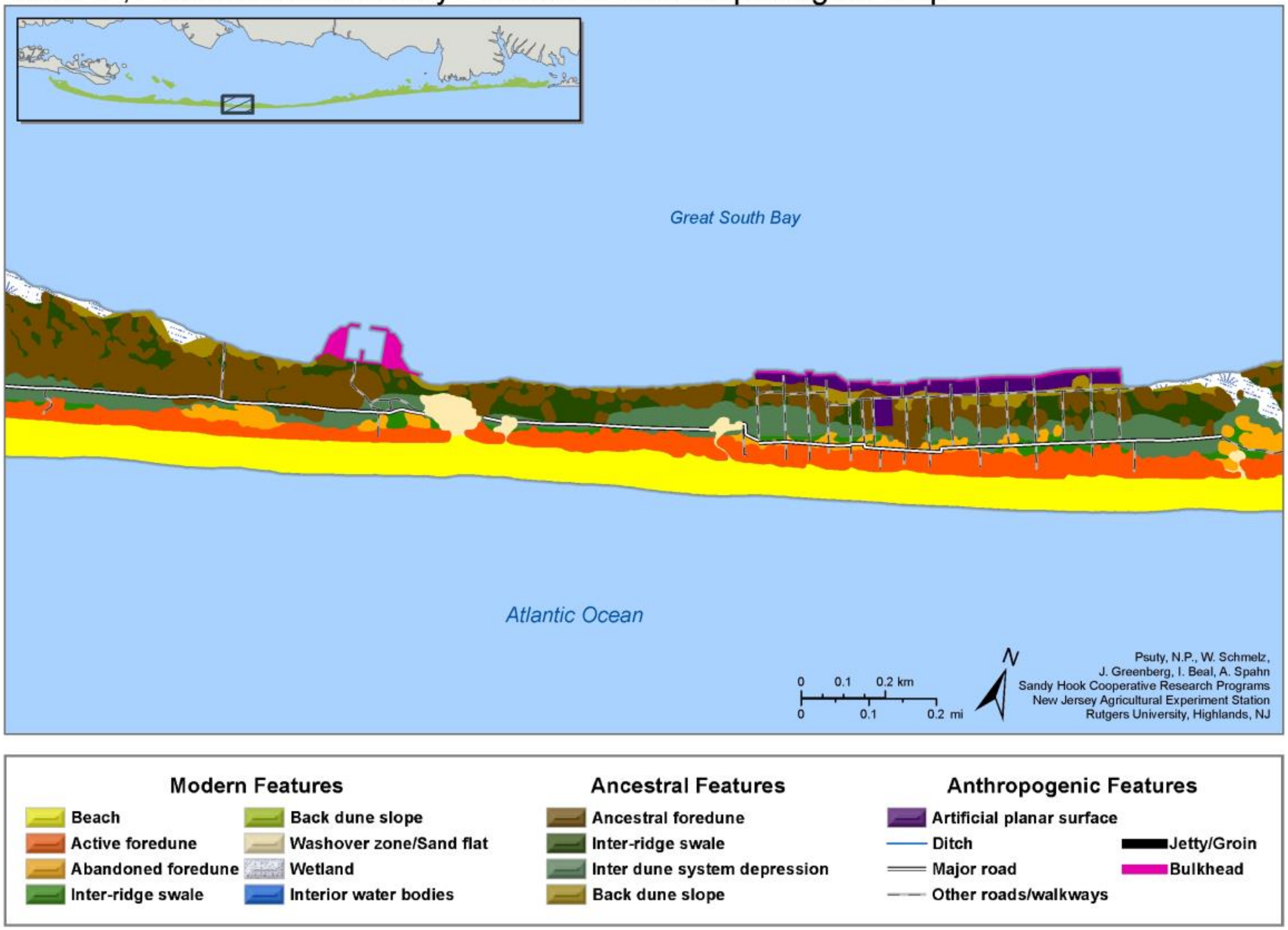
Ancestral Features

- Ancestral foredune
- Inter-ridge swale
- Inter dune system depression
- Back dune slope

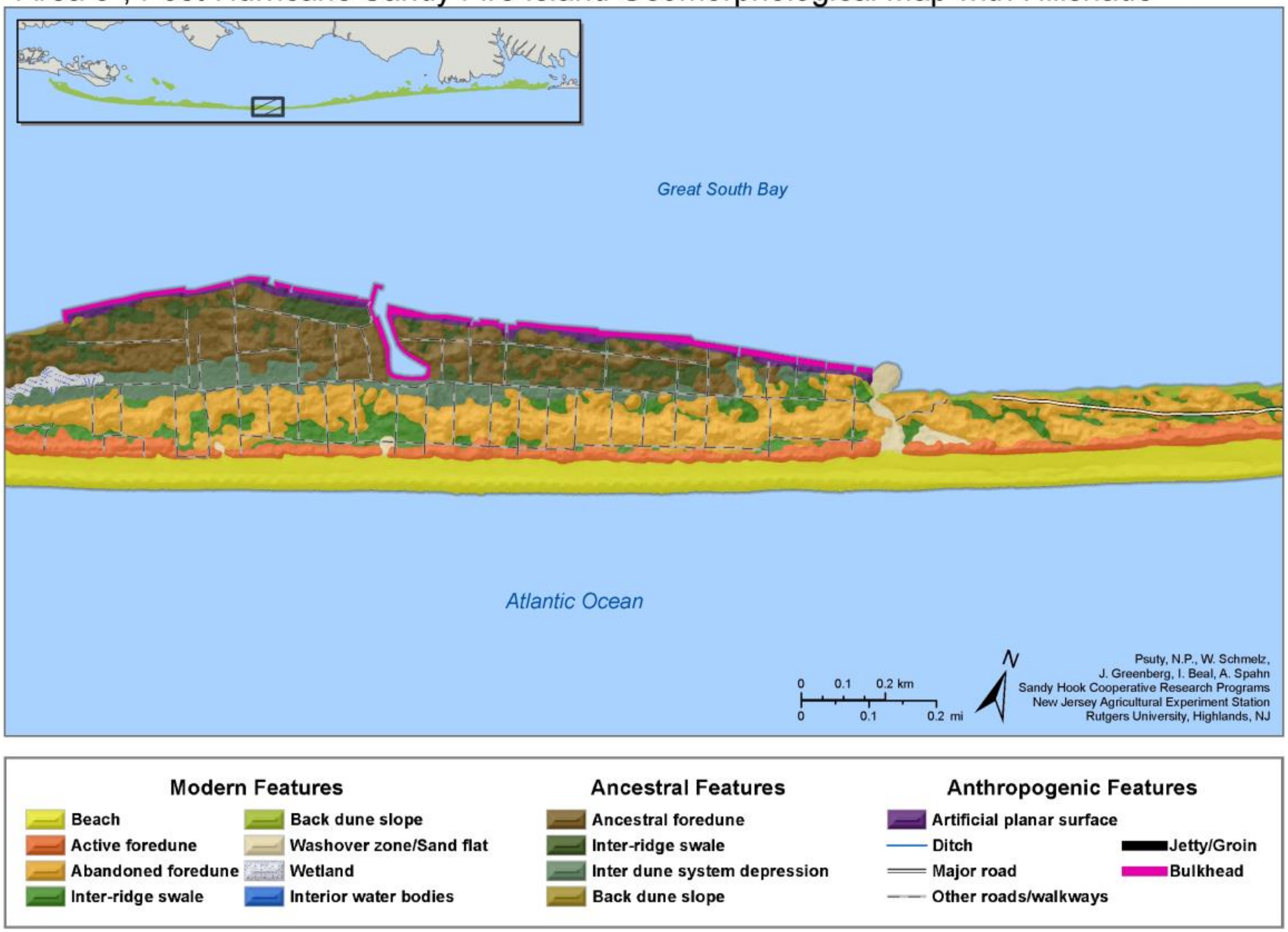
Anthropogenic Features

- Artificial planar surface
- Ditch
- Major road
- Other roads/walkways
- Jetty/Groin
- Bulkhead

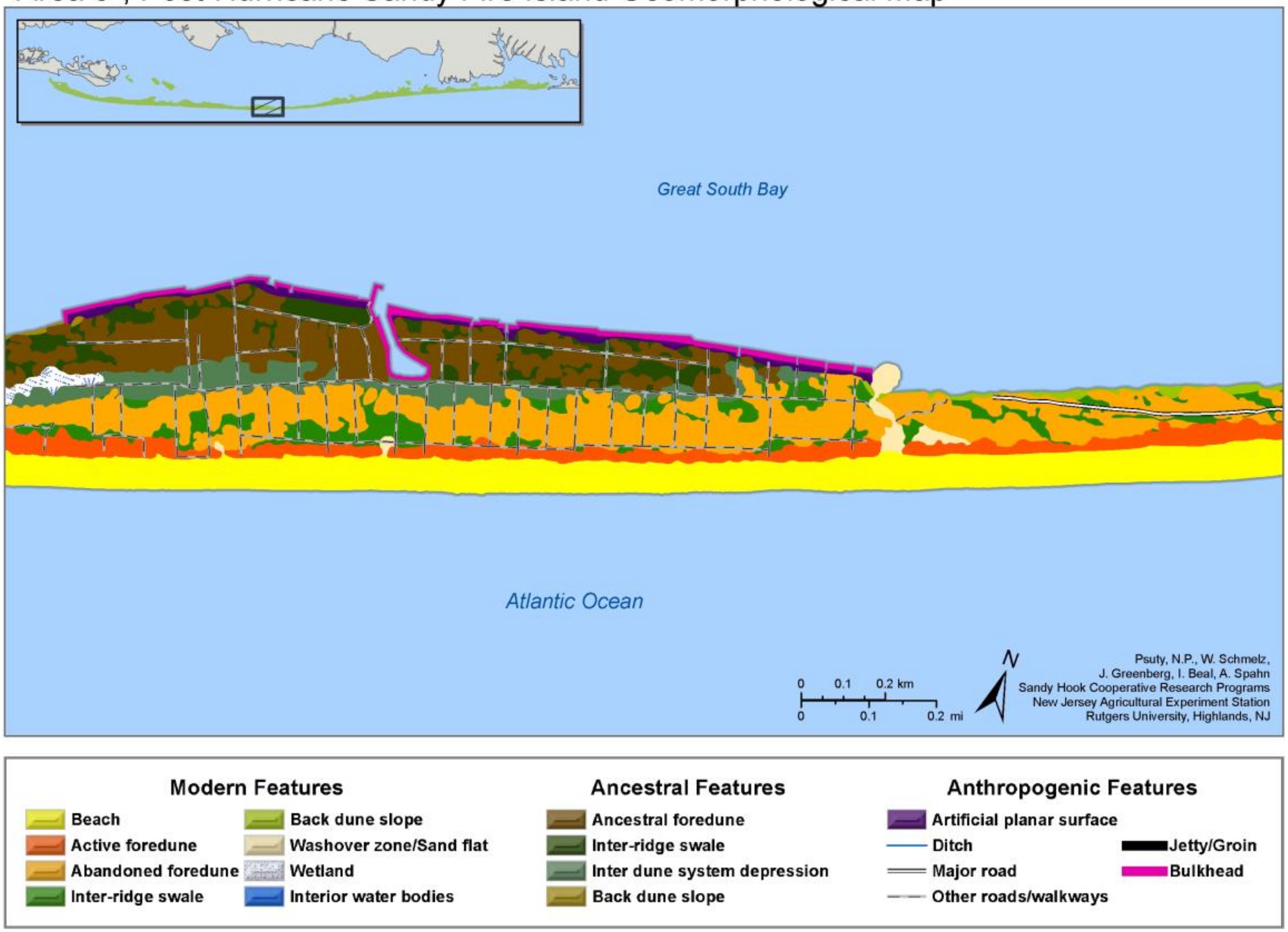
"Area 7", Post-Hurricane Sandy Fire Island Geomorphological Map



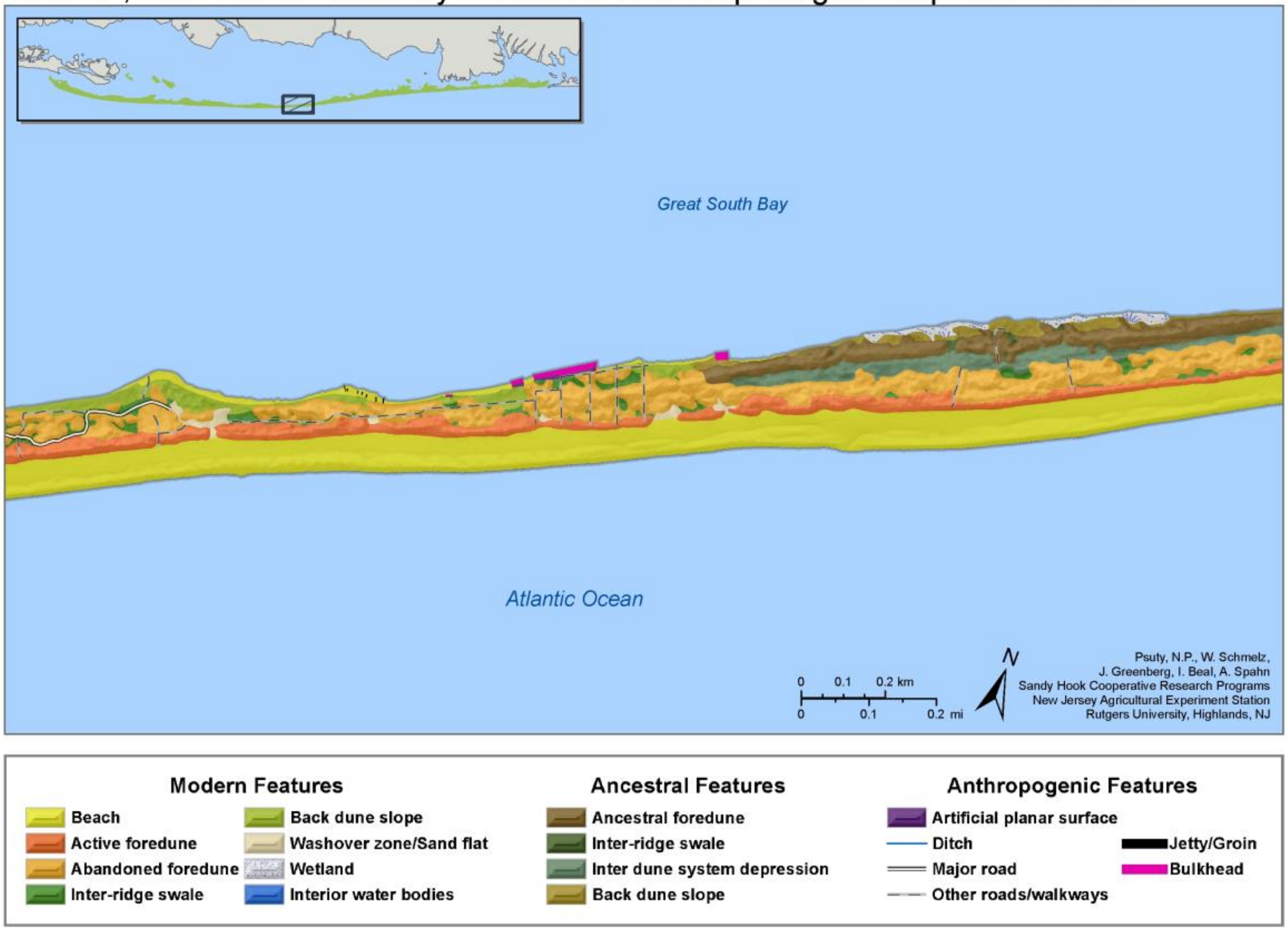
"Area 8", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



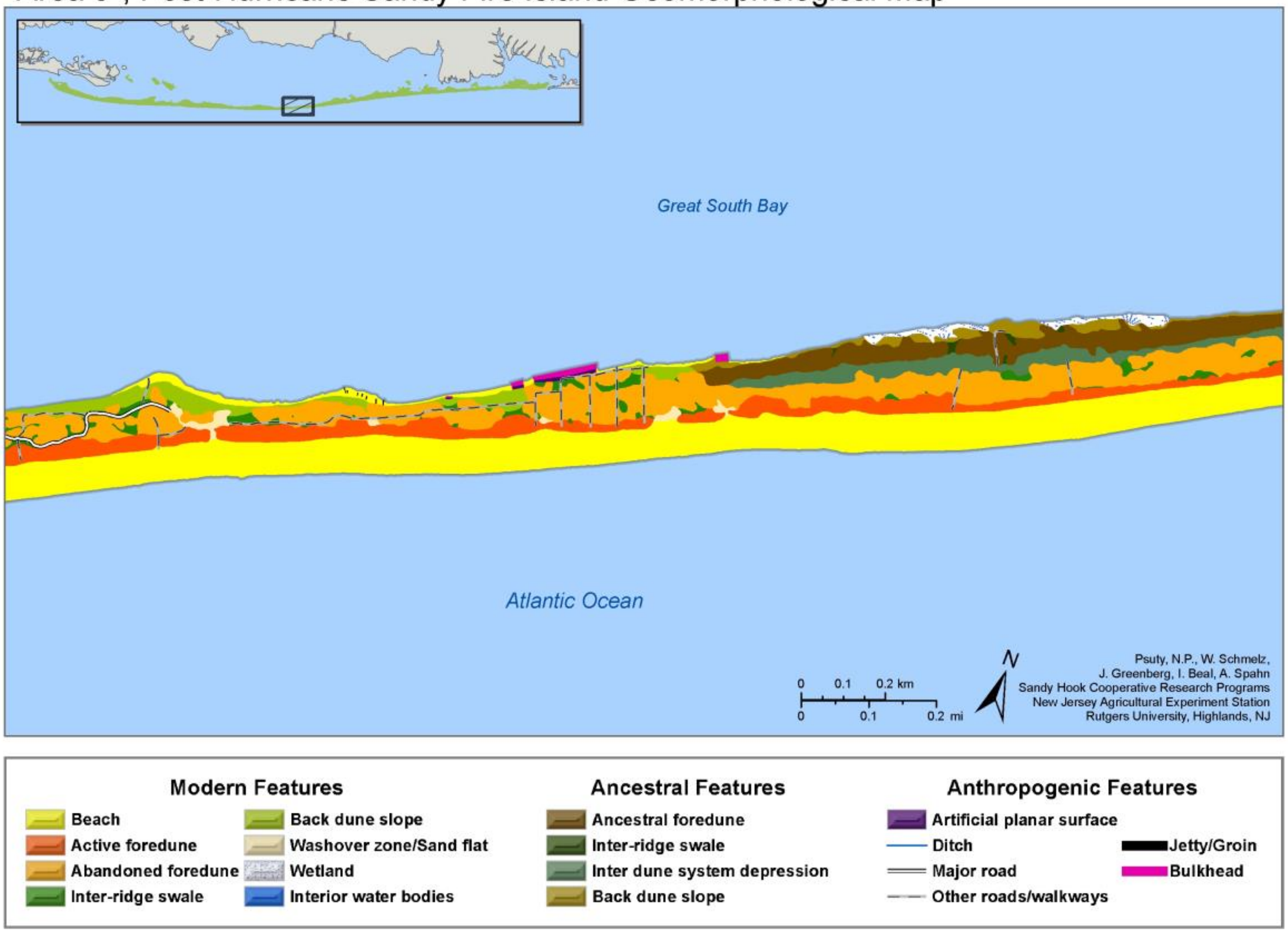
"Area 8", Post-Hurricane Sandy Fire Island Geomorphological Map



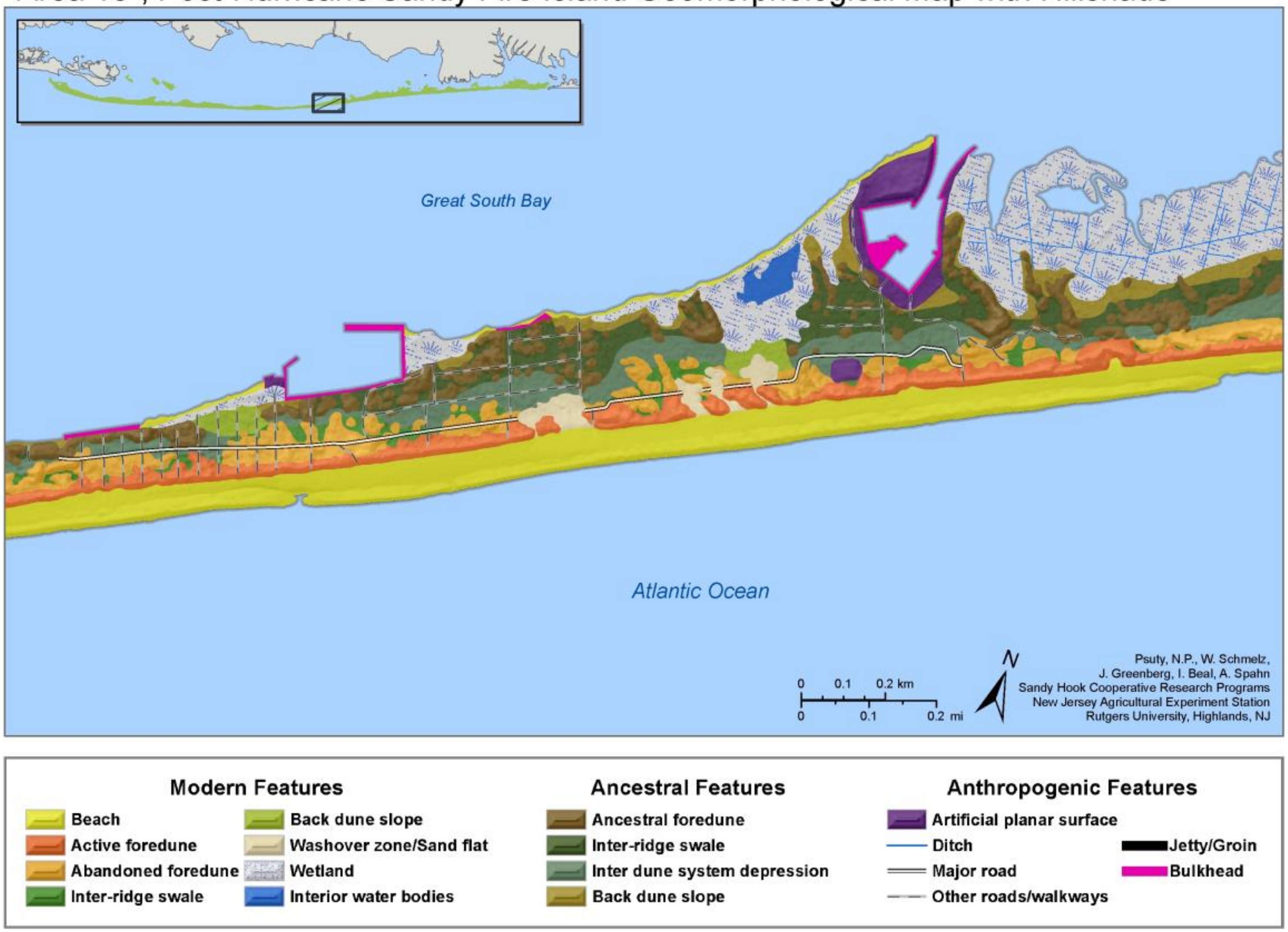
"Area 9", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



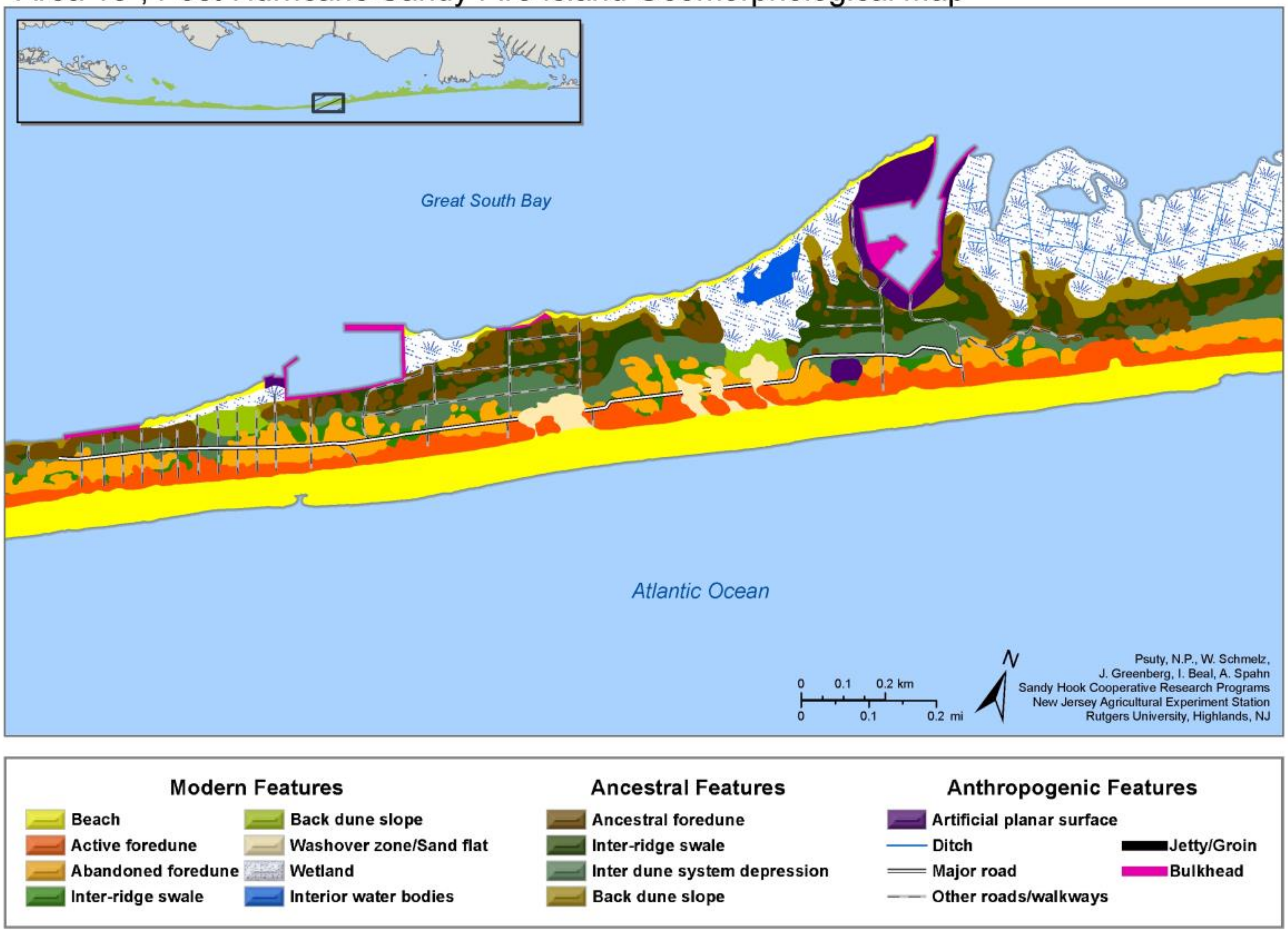
"Area 9", Post-Hurricane Sandy Fire Island Geomorphological Map



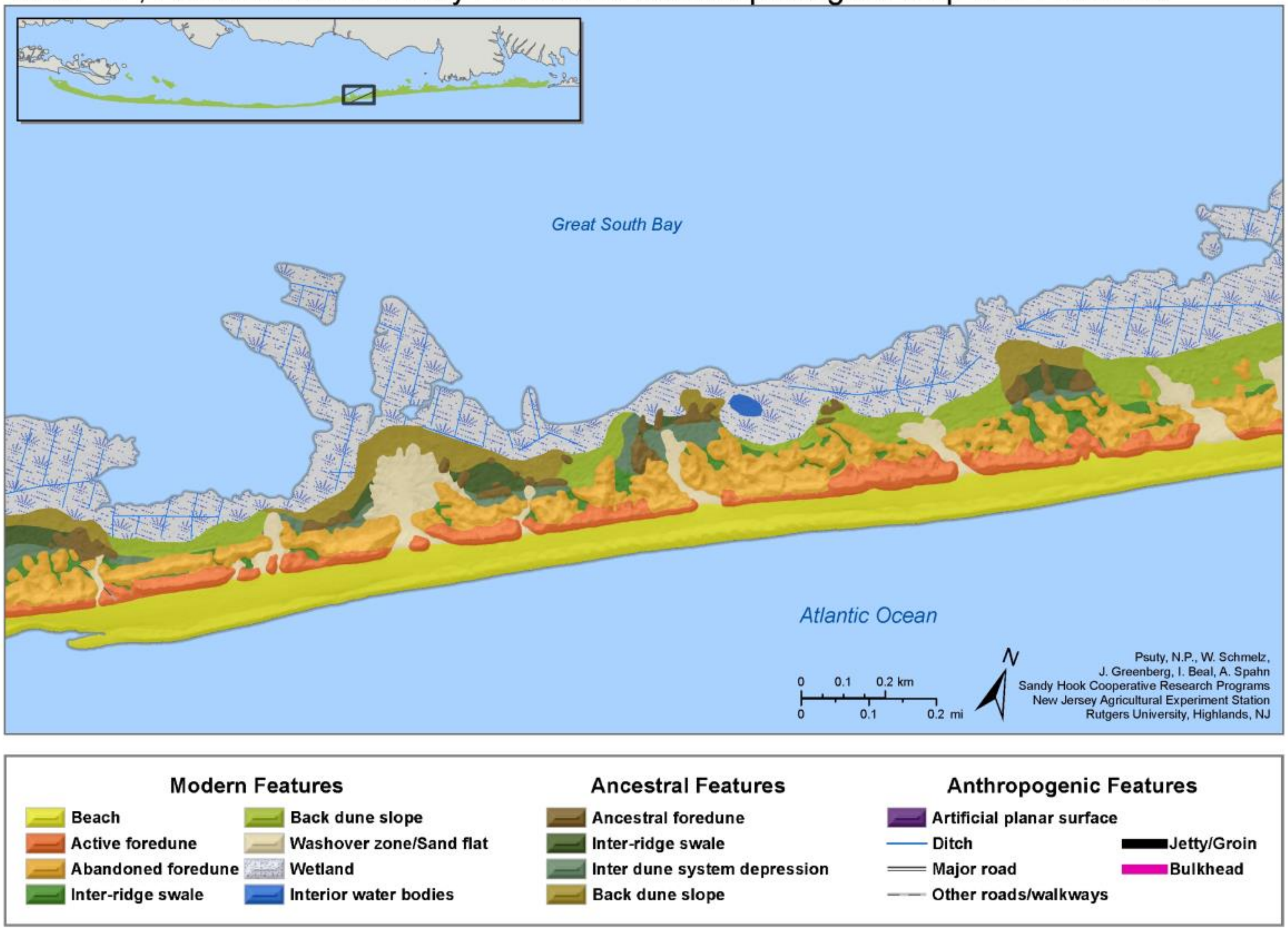
"Area 10", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



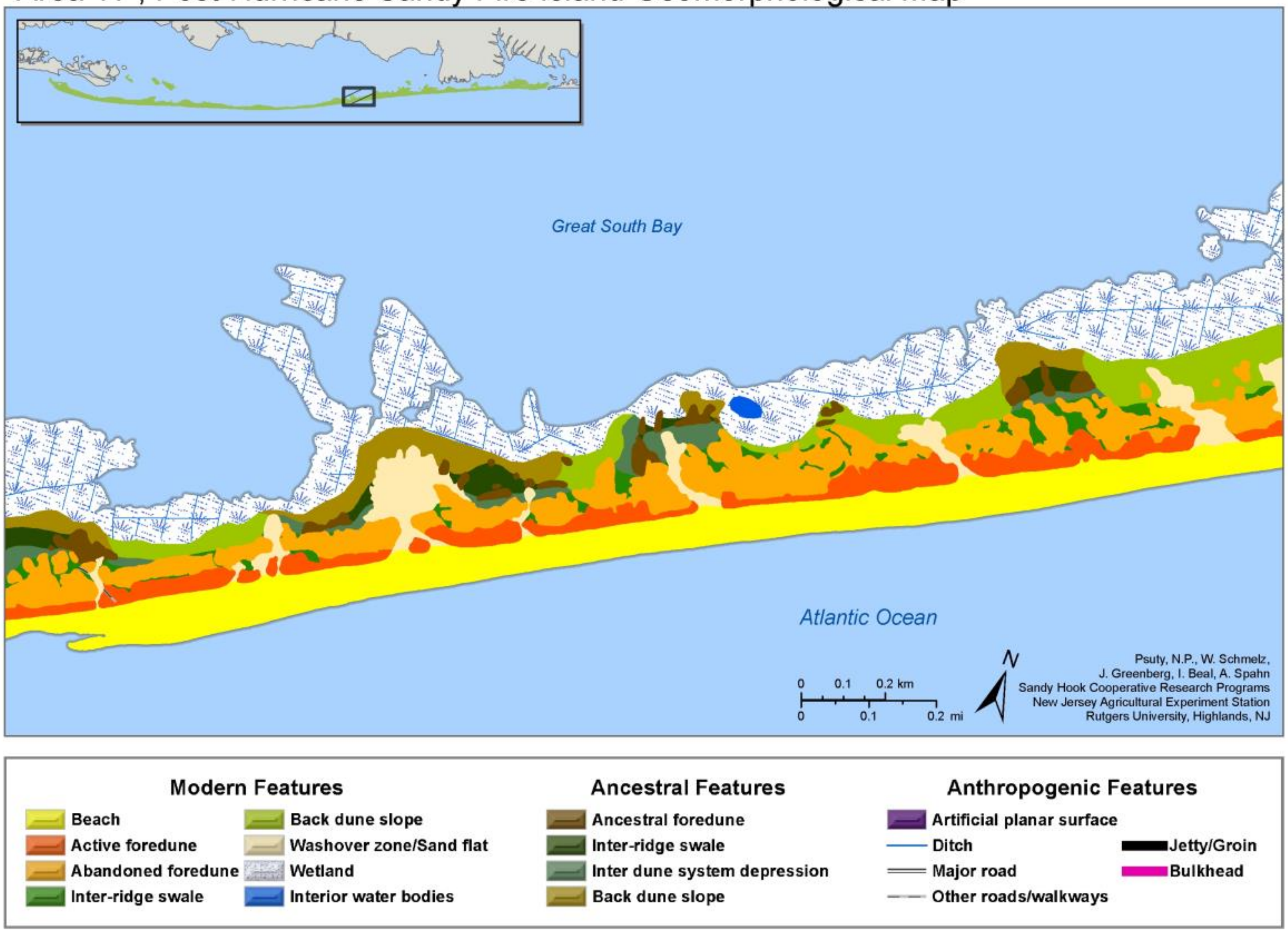
"Area 10", Post-Hurricane Sandy Fire Island Geomorphological Map



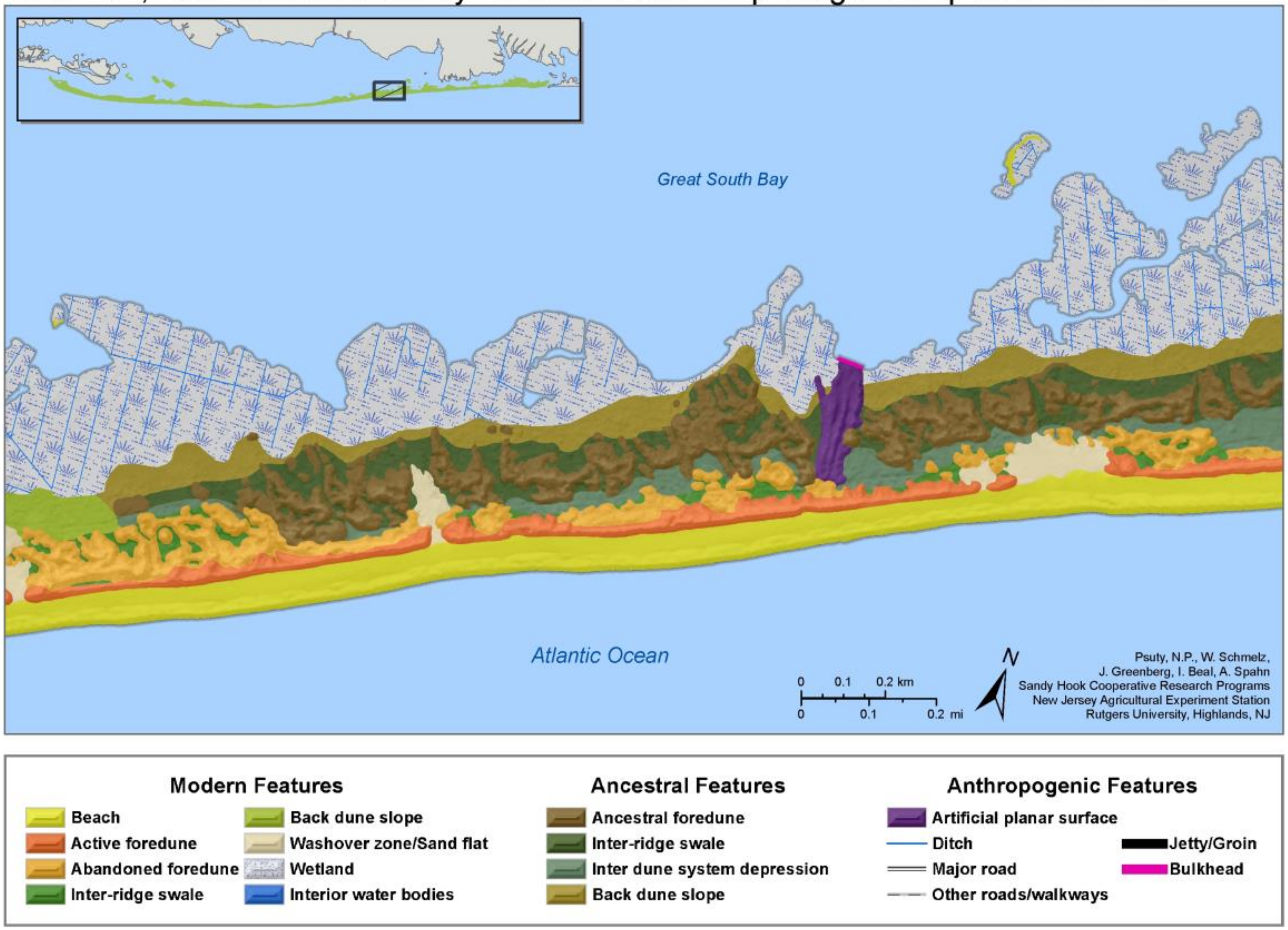
"Area 11", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



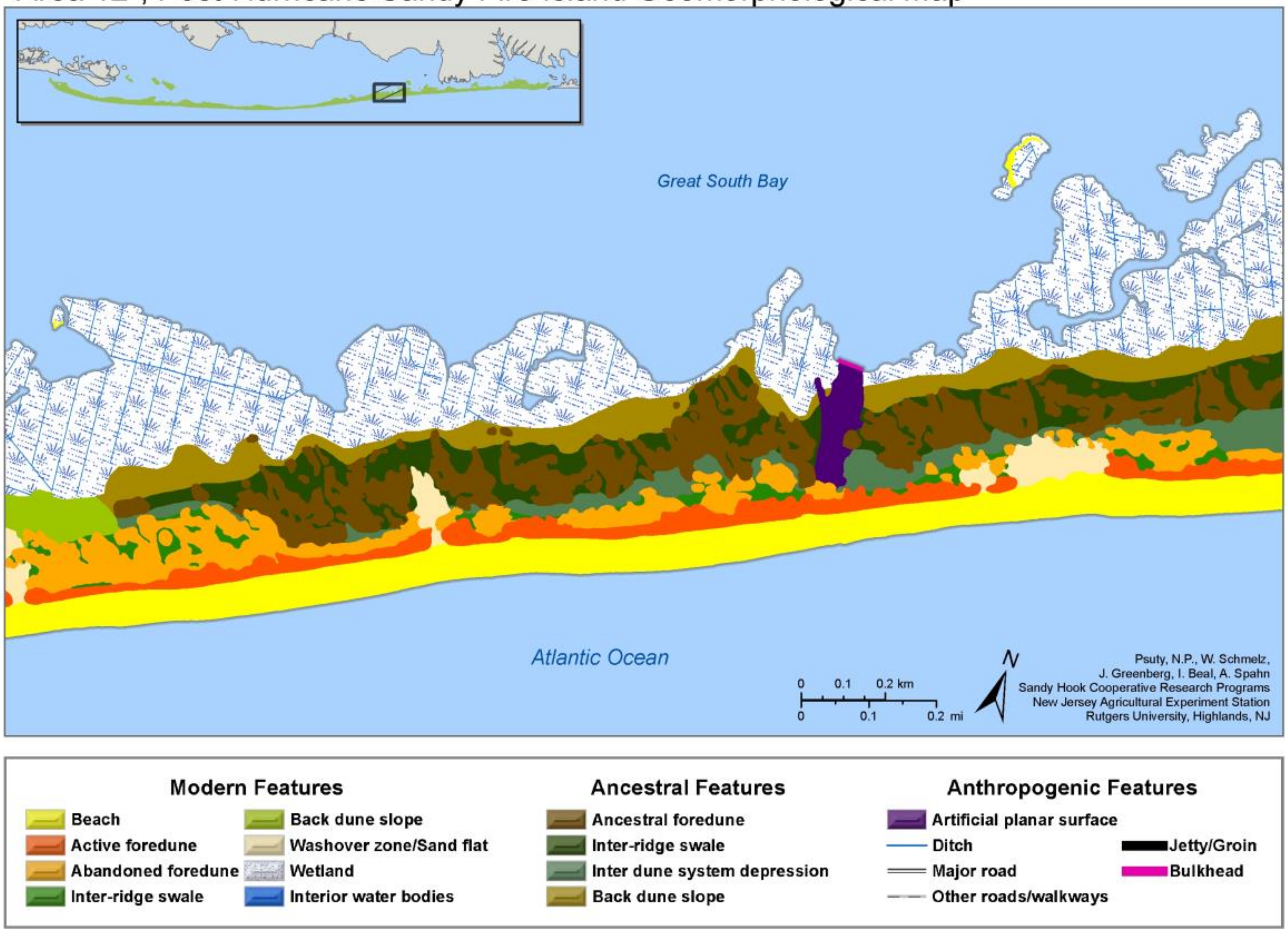
"Area 11", Post-Hurricane Sandy Fire Island Geomorphological Map



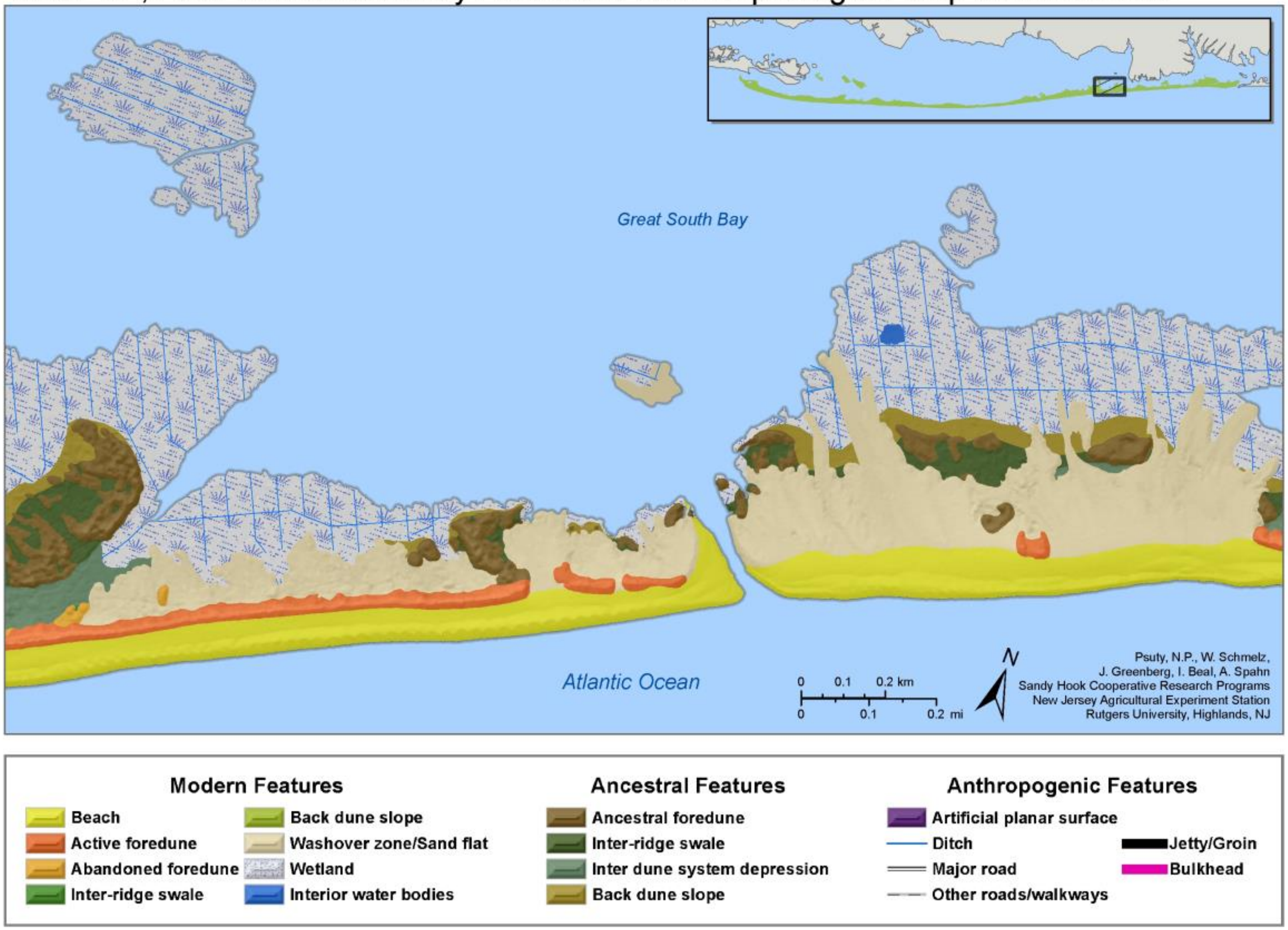
"Area 12", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



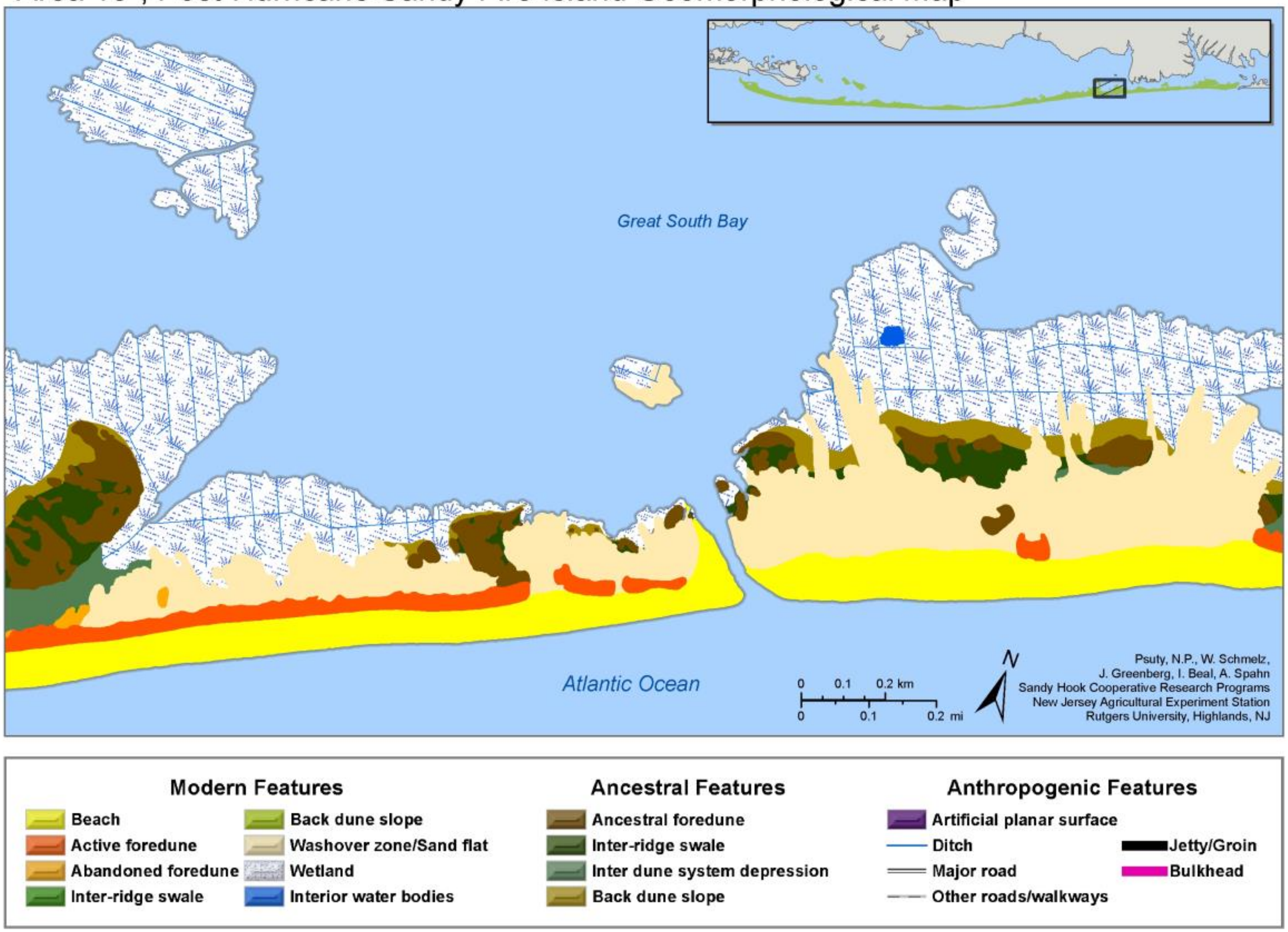
"Area 12", Post-Hurricane Sandy Fire Island Geomorphological Map



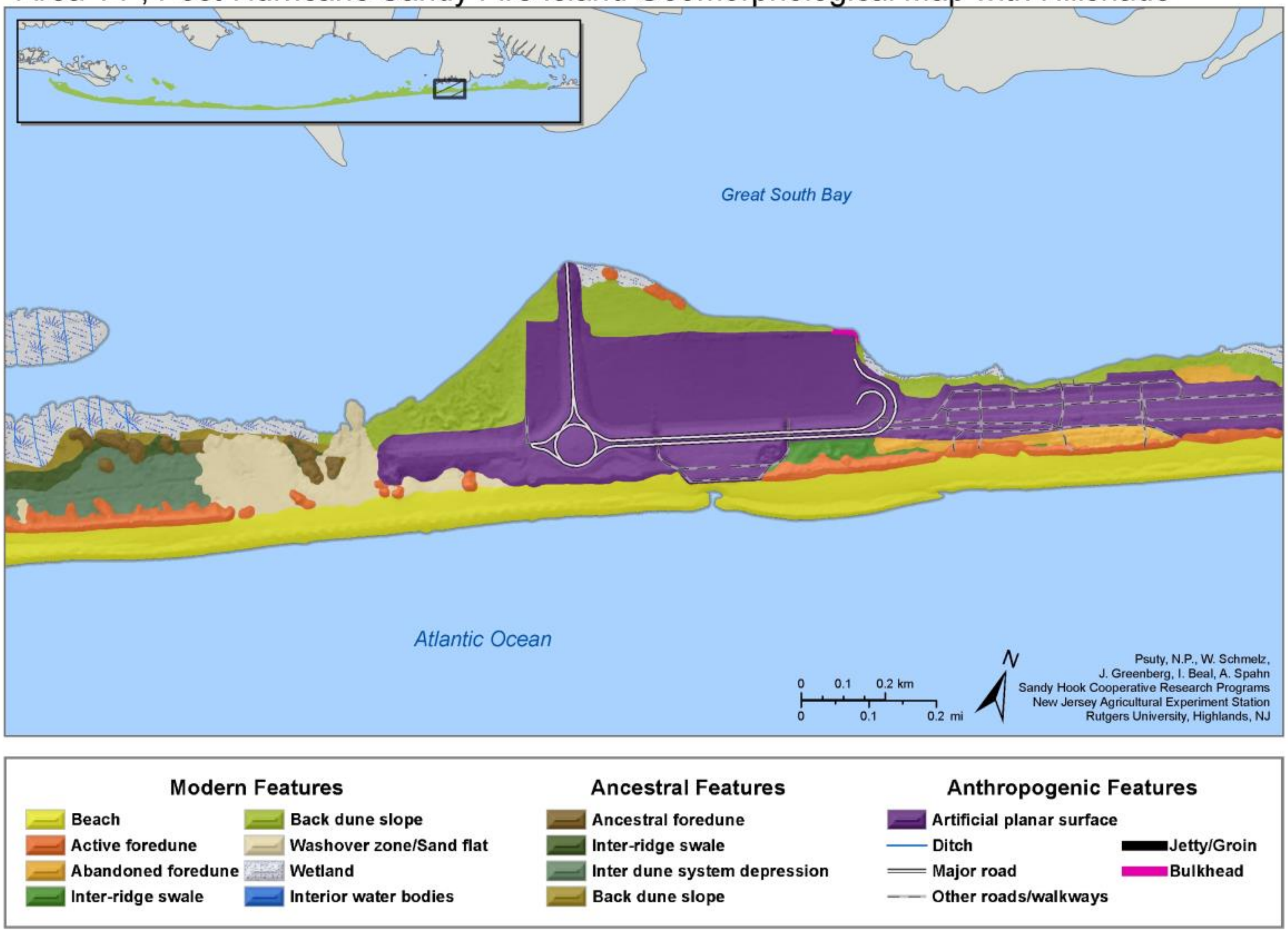
"Area 13", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



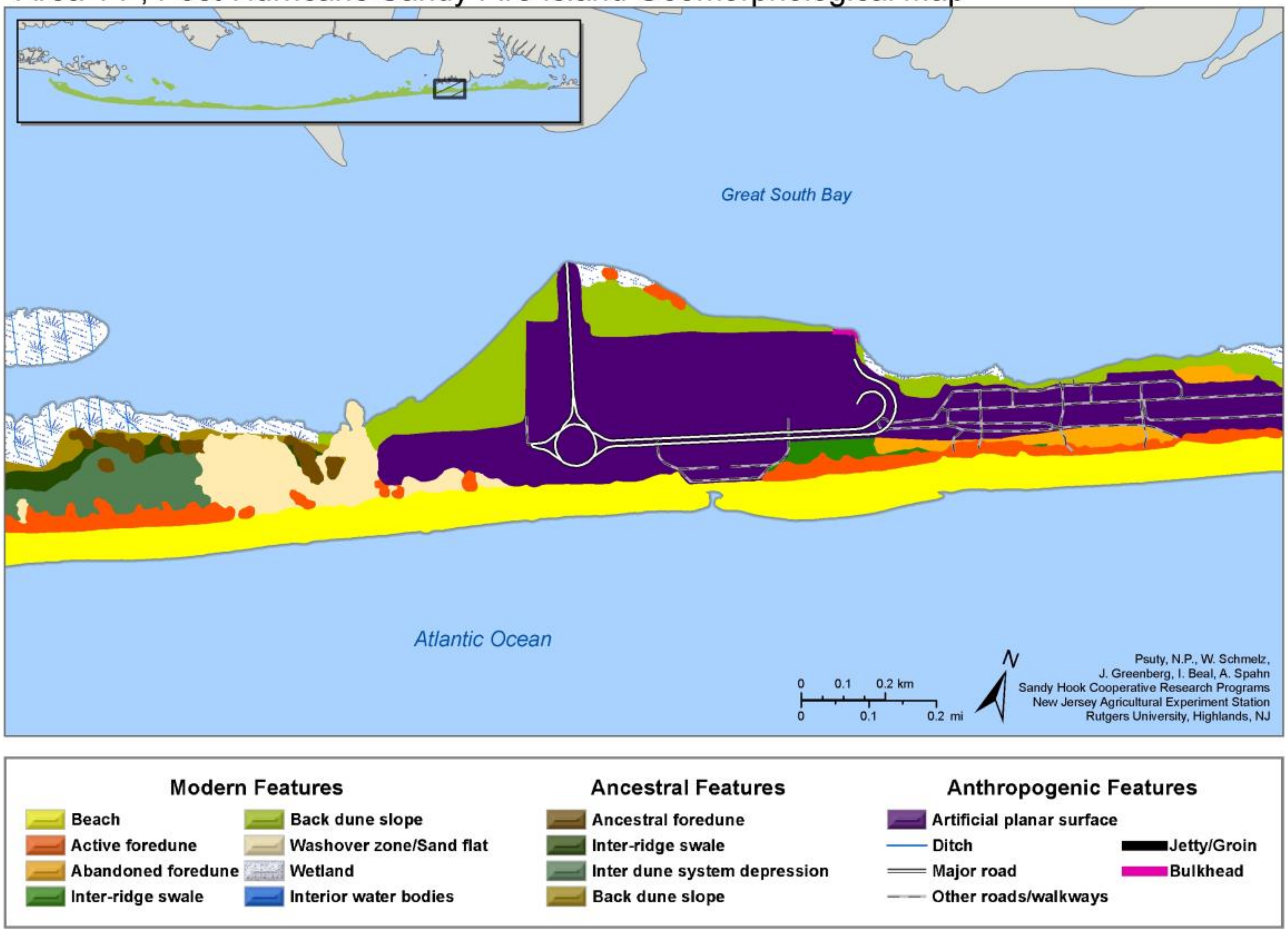
"Area 13", Post-Hurricane Sandy Fire Island Geomorphological Map



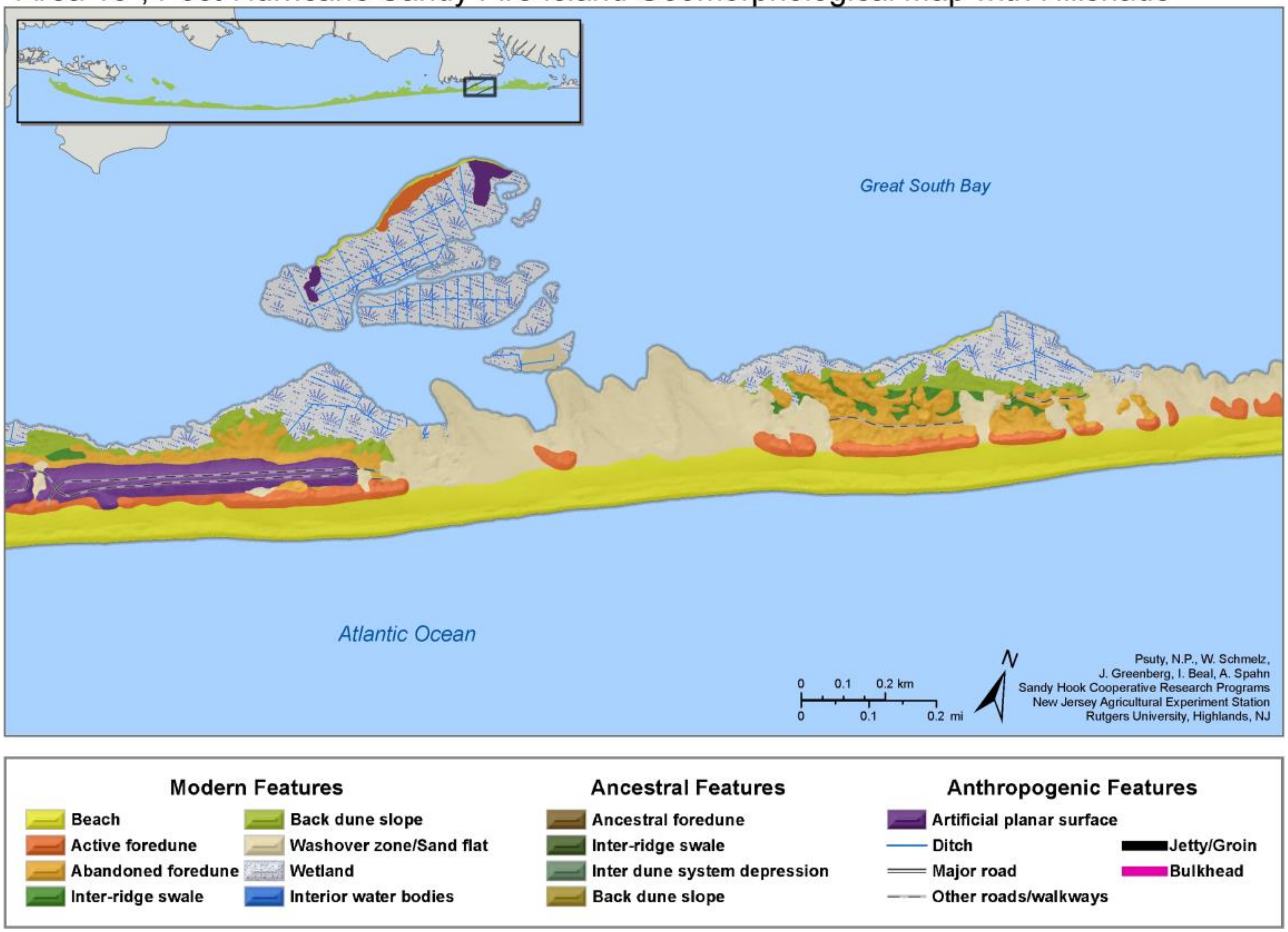
"Area 14", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



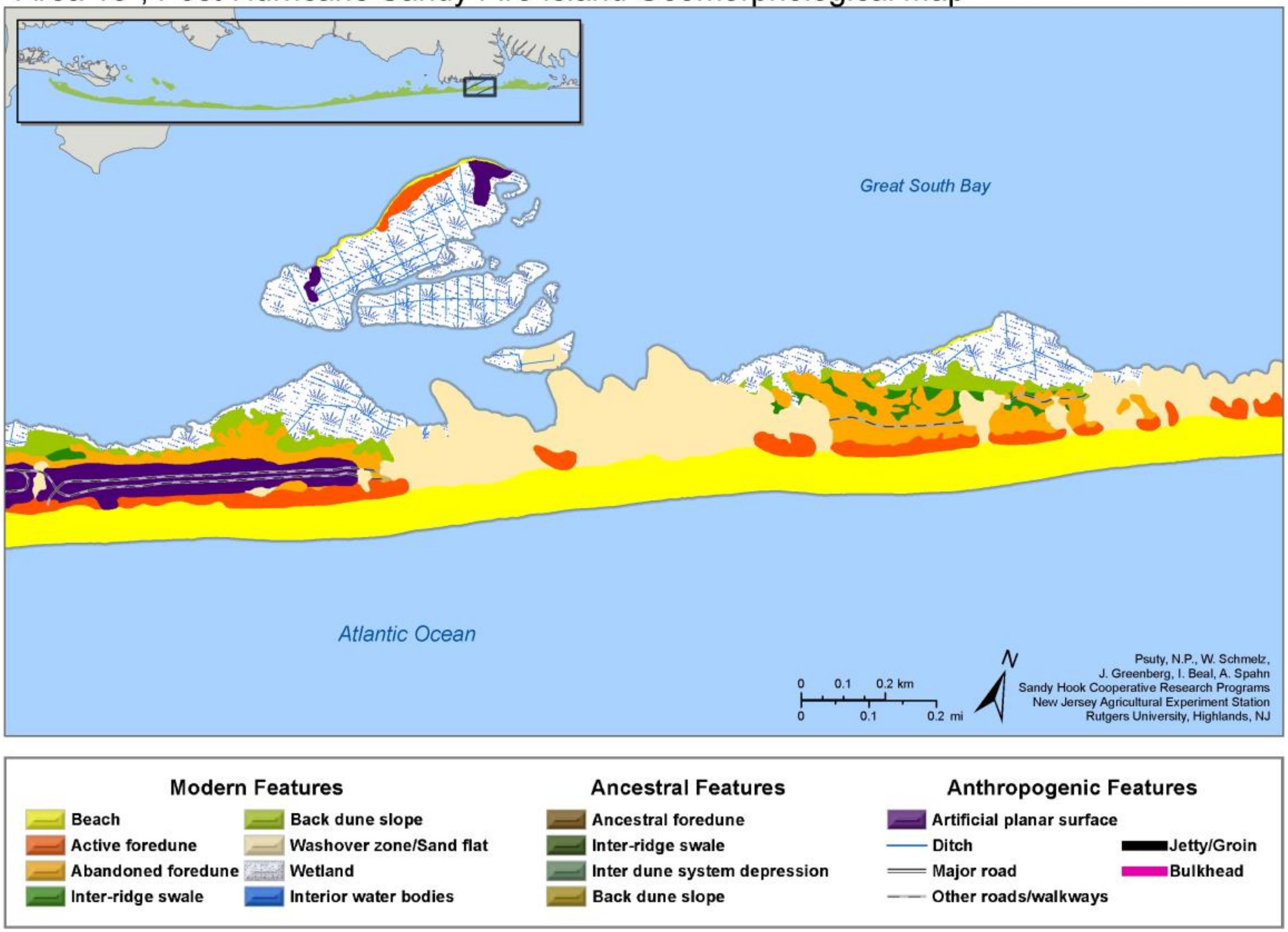
"Area 14", Post-Hurricane Sandy Fire Island Geomorphological Map



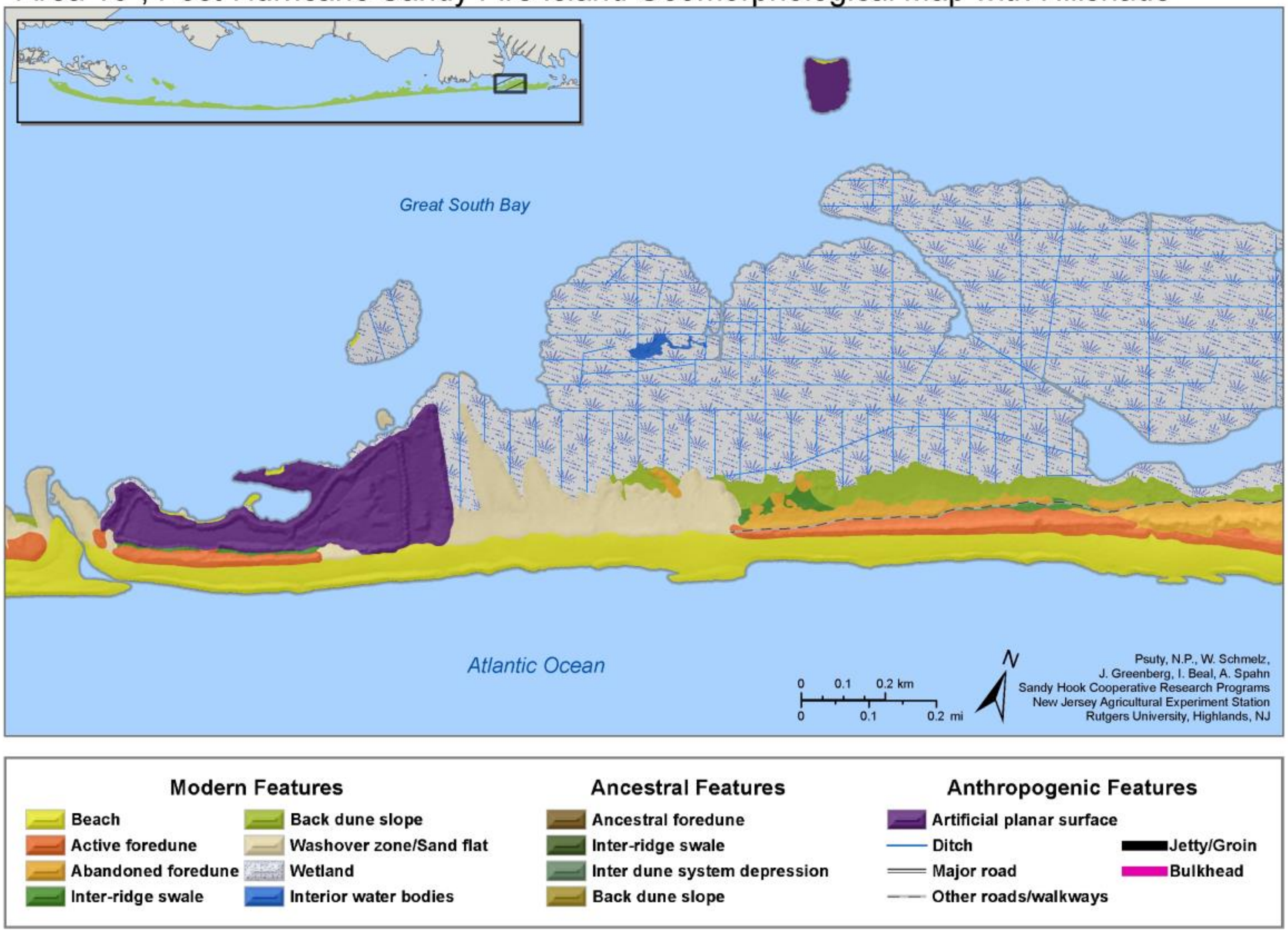
"Area 15", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



"Area 15", Post-Hurricane Sandy Fire Island Geomorphological Map



"Area 16", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



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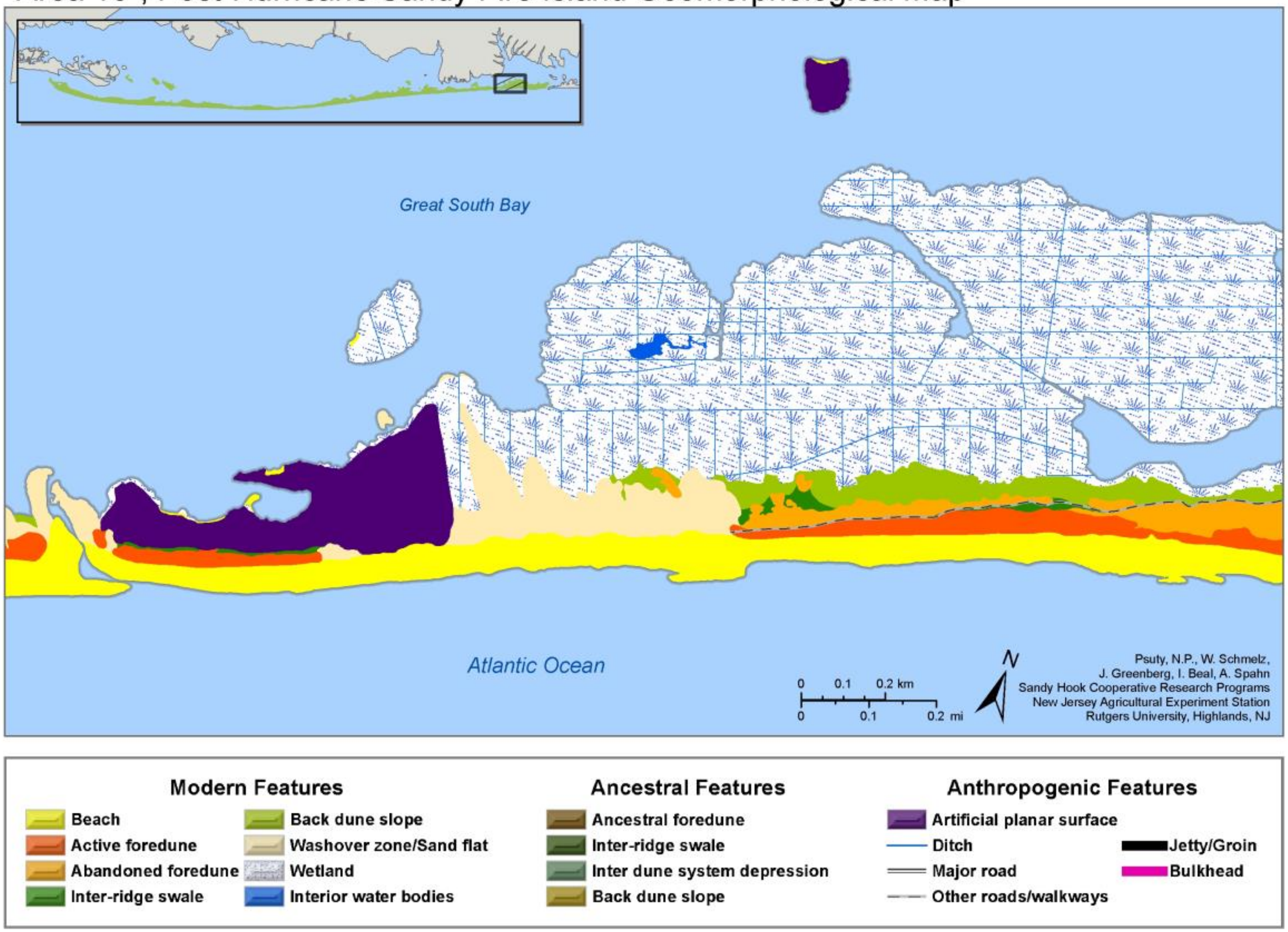
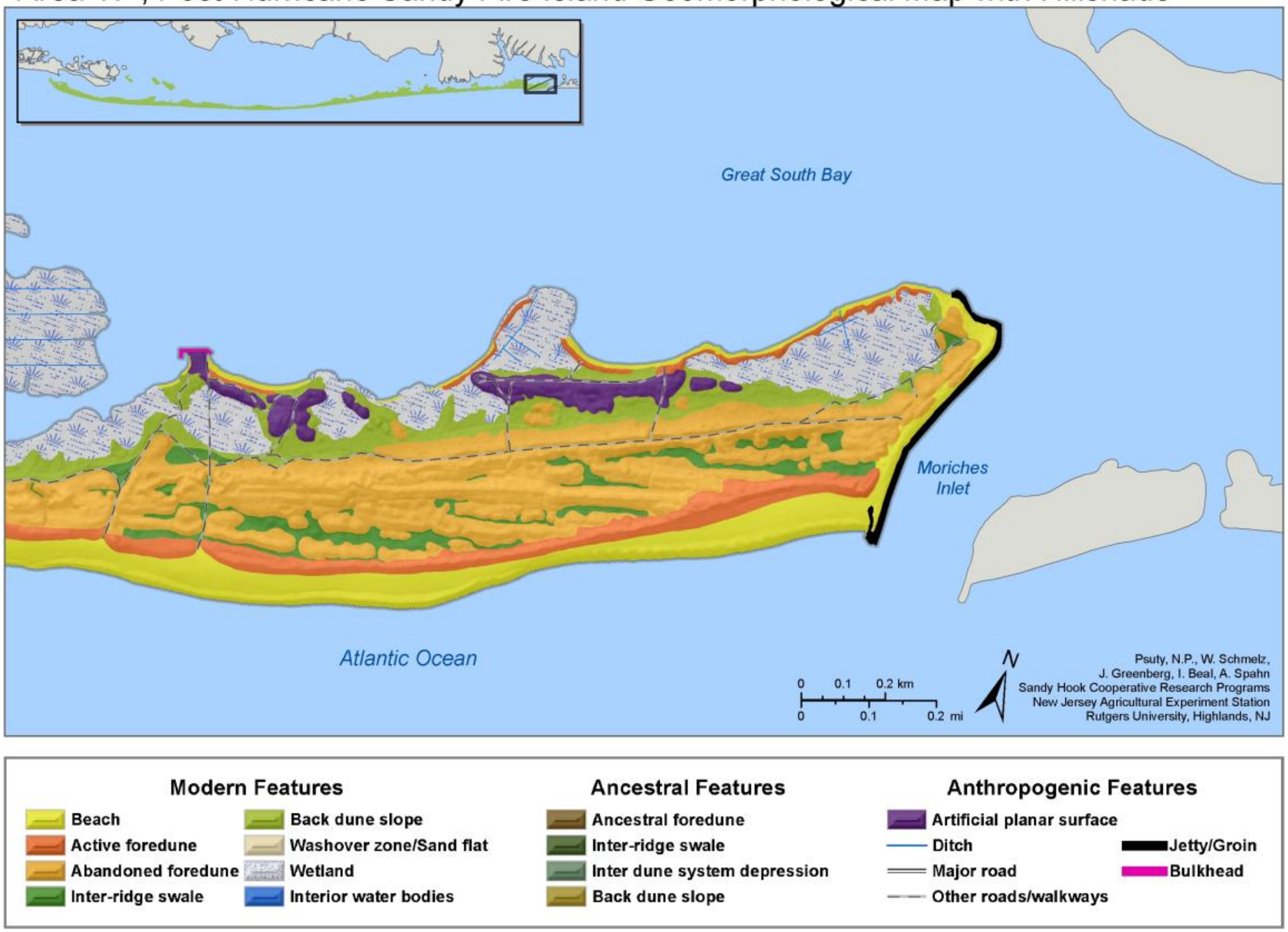


"Area 17", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



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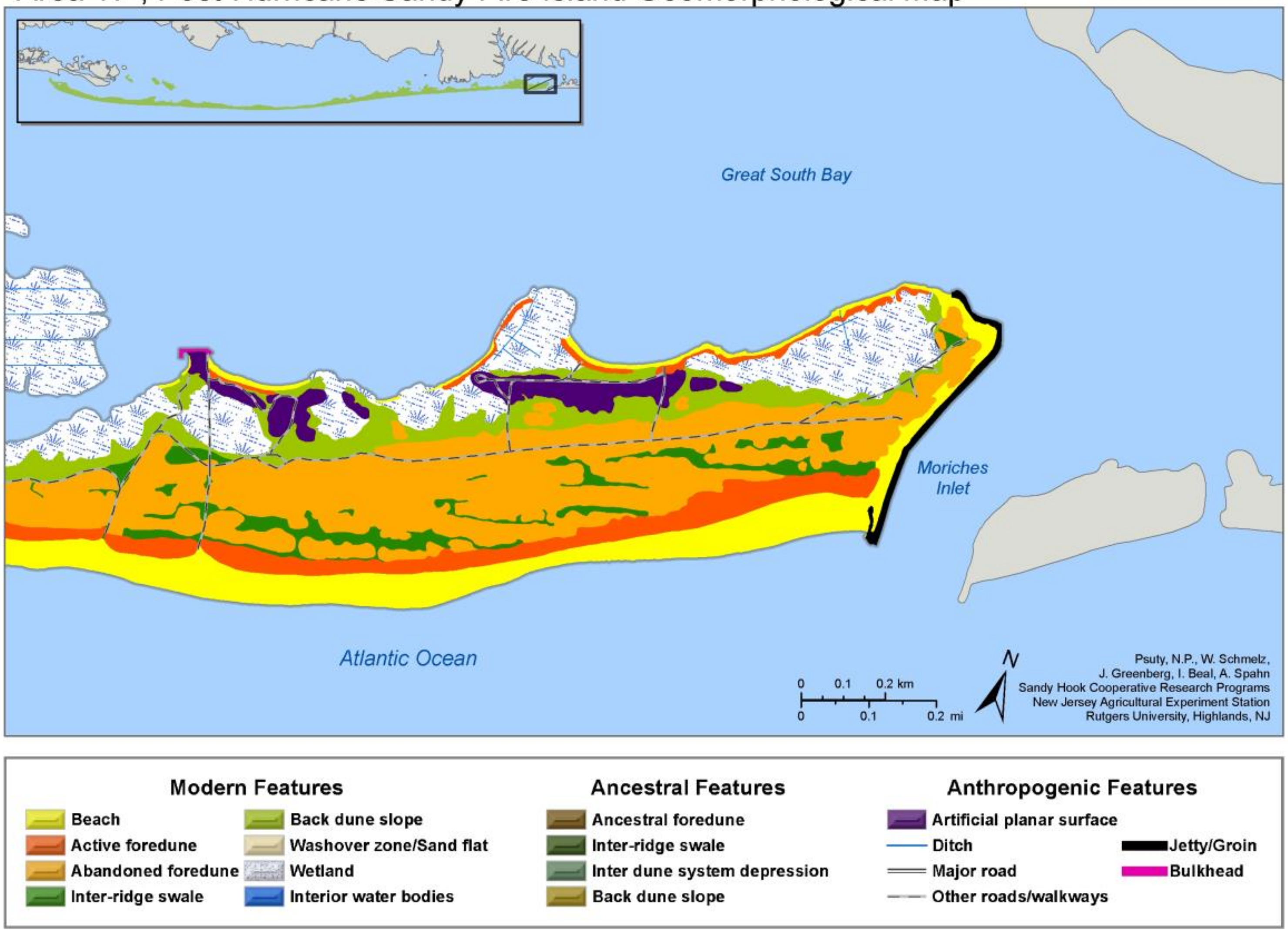
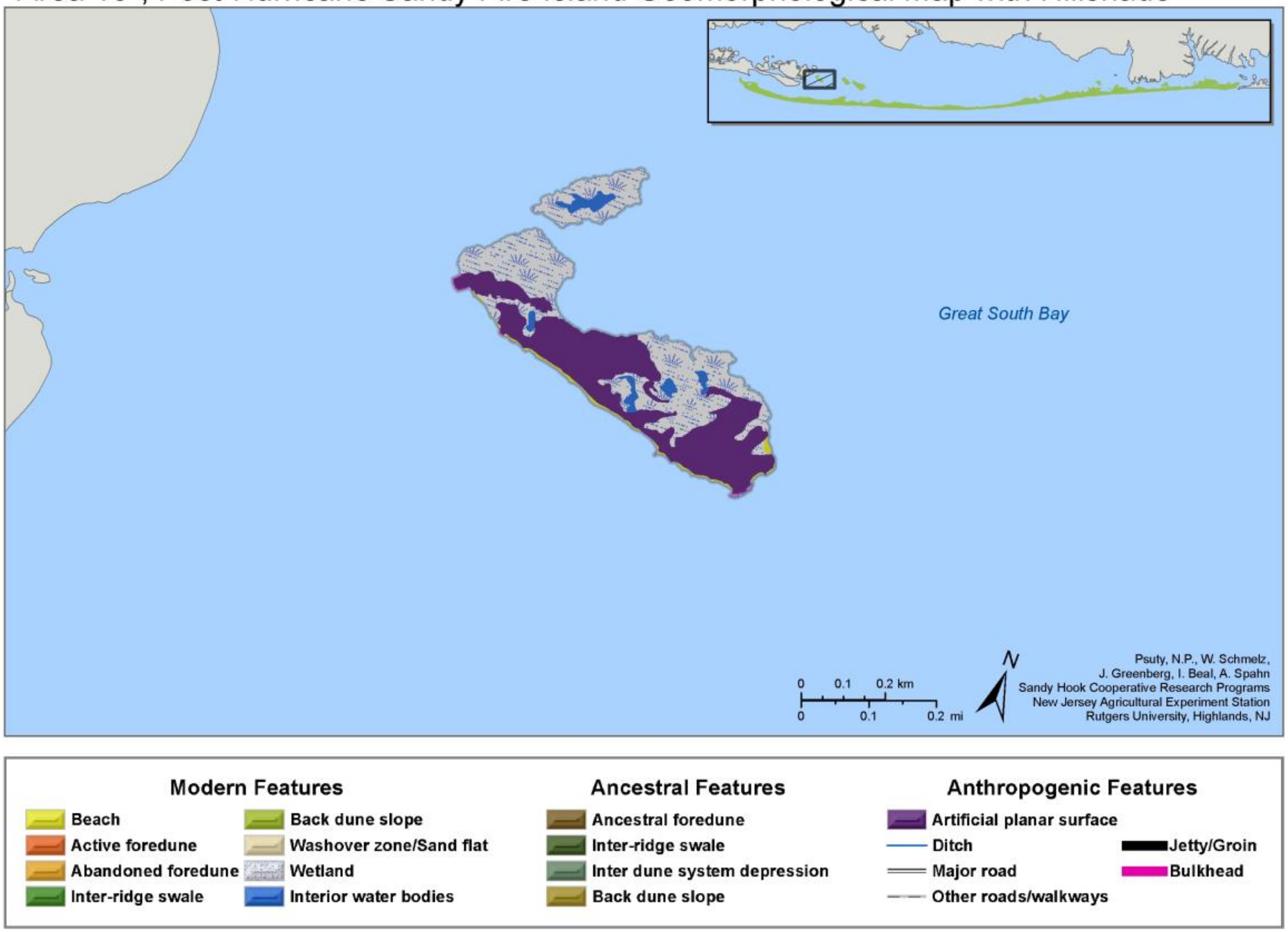


"Area 18", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



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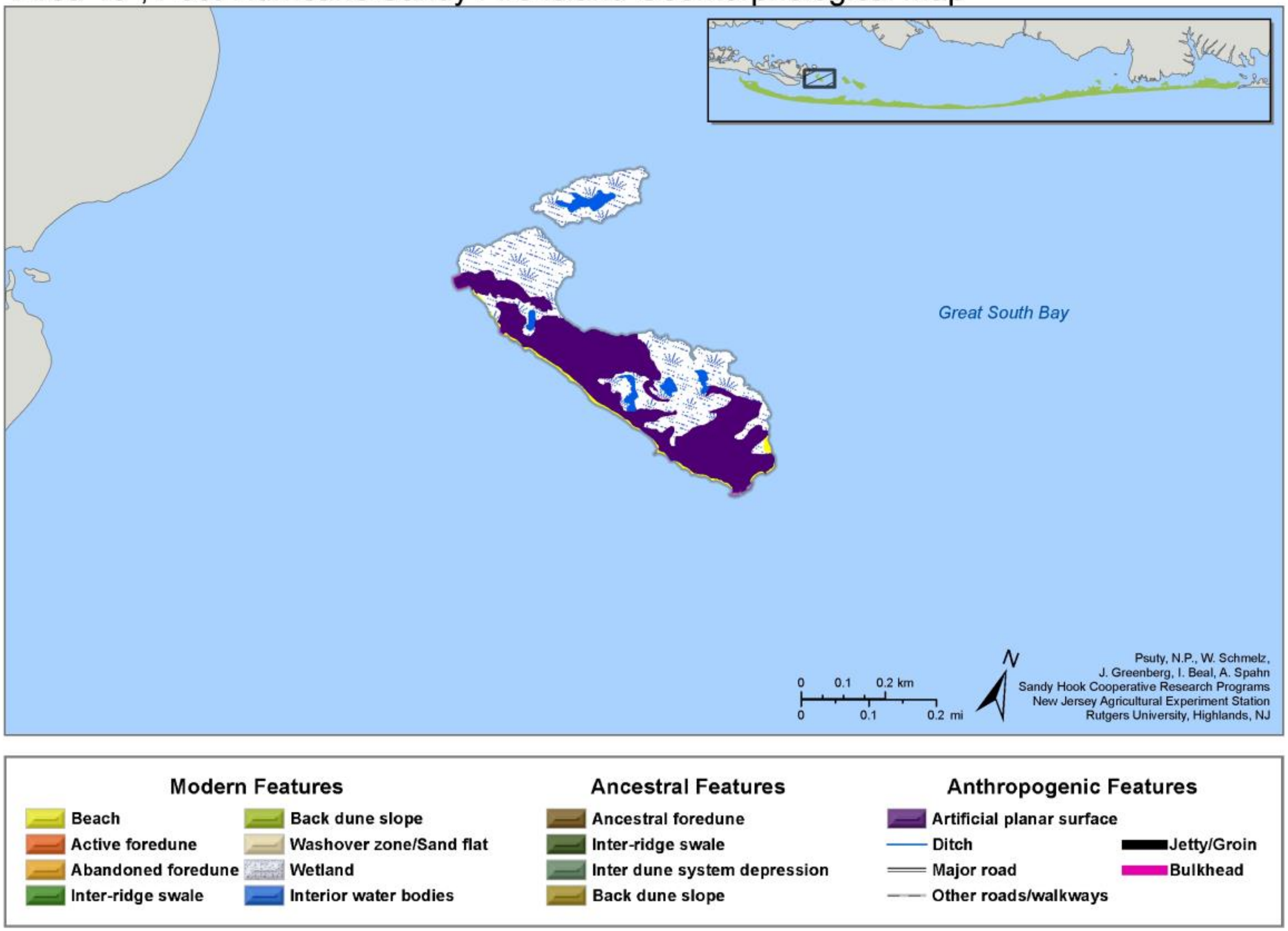
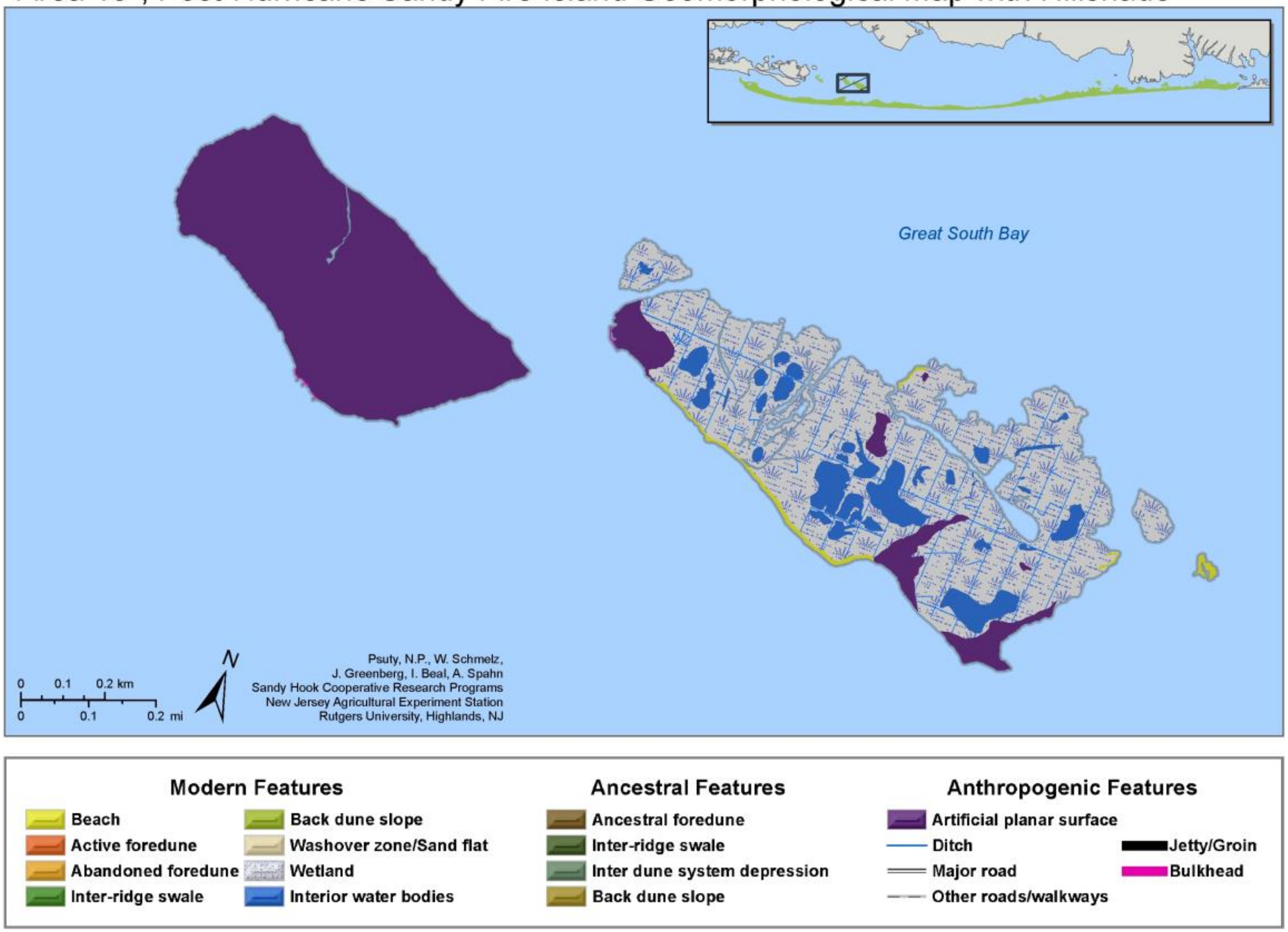
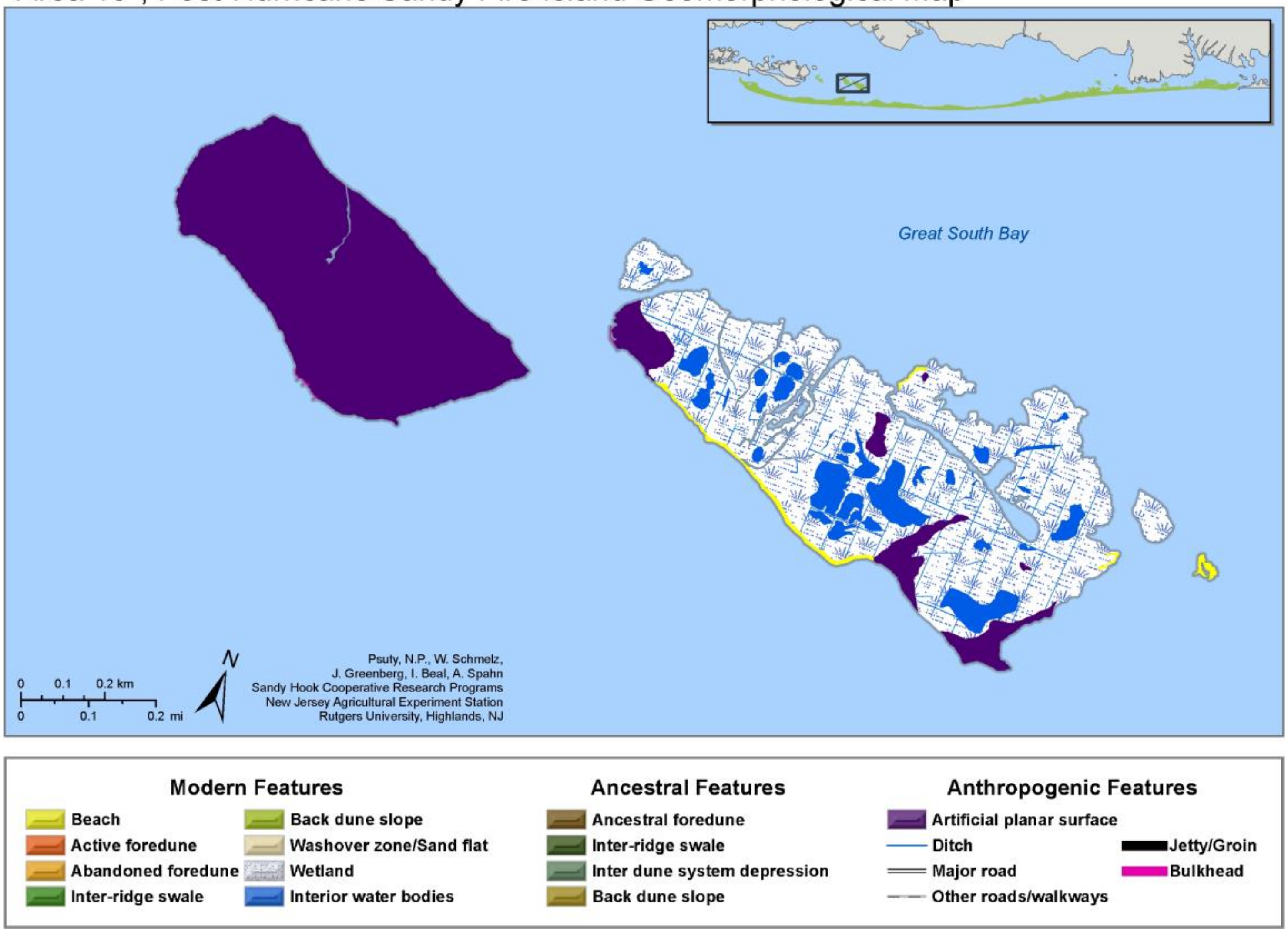


"Area 19", Post-Hurricane Sandy Fire Island Geomorphological Map with Hillshade



"Area 19", Post-Hurricane Sandy Fire Island Geomorphological Map



NPS 615/137696, April 2017

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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