USE OF SPOIL ISLAND AS A SEAGRASS AND MANGROVE MITIGATION SITE

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ABSTRACT

The construction of the Frank A. Wacha Bridge near Jensen Beach Florida and the Ernest Lyons Bridge near Stuart Florida resulted in the destruction of seagrass and mangrove wetlands in the same estuarine system. In 2005, mitigation for these impacted wetlands took place on St. Lucie (SL)-15, a spoil island located in close proximity to both bridges. The mitigation was unique because it consisted of the removal of exotics and excess fill and the reshaping of the island to create habitat suitable for seagrass, mangrove, and transitional and upland hammock species. Success criteria for the planted or recruited mangrove habitat was established as 80% or more survivorship. Seagrass success criterion was established as 3% or more coverage by year three, 6% or greater coverage by year four, and 10% or more coverage by year five. Two different types of environmental monitoring methods were used assess the success of this project. Random transects and quadrats were used to determine permit compliance. Additionally, spatio-temporal monitoring was used to better visualize and identify problem and success areas. After five years of monitoring, permit success requirements were met and management was transferred to the Florida Department of Environmental Protection. Restoration success suggests that spoil islands in the IRL can be utilized for future mitigation sites. Design improvements recommended are to use hummocks and spartina to naturally recruit mangroves and seagrasses. It is anticipated that these design changes could replace planting in future mitigation sites.

Introduction

Pressure from coastal development has caused the destruction of ecologically important mangrove and seagrass habitats. These habitats are vital for coastal wildlife, storm surge protection, economically-important fish and shellfish nurseries, and biogeochemical processes (Alongi 2002; Duarte 2002; Zedler and Kercher 2005). They also play an important role in Florida’s economy. The Florida Department of Environmental Protection (FDEP) estimates Florida’s seagrass and mangroves to provide over 40 billion dollars a year in ecosystem services. These habitats play a vital role in the state’s recreational and commercial fisheries industries. To offset impacts to mangrove and seagrass habitats state and federal law requires mitigation when these habitats are destroyed.

Most restoration projects have been by regulatory agencies, or mitigation projects for wetland fill or excavation allowed by permits (cite: Wetlands Creation and Restoration: The status of the Science 1989). In North America, mangrove restoration often involves re-establishment of natural hydrologic and tidal regimes, planting of mangrove propagules, or planting marsh plants as nurse species (Profit and Devlin 2005). Florida has been the site of numerous coastal restoration or mitigation projects although most have never been assessed for more than a few years after project completion. Some examples of these projects include the Tampa Bay Shoreline Initiative project (Beever et al. 2004), the Marine Resource Council Shoreline Restoration project, and numerous bridge and urban developmental permitted mitigation projects.

The purpose of this manuscript is to explain a unique shoreline mitigation project in St. Lucie County, Florida in which a spoil island was converted into mangrove and seagrass habitat. This is the first time that this type of mitigation project has been attempted. The success of this project may lead to the use of several of Spoil Island as future mitigation sites. The environmental monitoring which was used to monitor this first time mitigation project will be compared and discussed throughout this manuscript.

Background

The Indian River Lagoon (IRL) is a shallow barrier island lagoon which stretches 250 km along the Atlantic coast of Florida with an average depth of 1.7 m and a width of 3 km (Smith 1987). The IRL includes a collection of three estuaries, the Mosquito Lagoon, Banana River, and Indian River, located along Florida's Atlantic coast. The IRL is separated from the Atlantic Ocean by a barrier island system that is interrupted by five inlets (Ponce de Leon, Sebastian, Fort Pierce, St. Lucie, and Jupiter) providing exchange with marine waters. The IRL stabilized over the past 6,000 years during a period of minimal sea level fluctuation, resulting in increased barrier island stability (Davis et al., 1992). All seven subtropical species of seagrass found in the western hemisphere occur in the IRL. In addition, the IRL is home to rich aquatic life including 397 species of fish (Gilmore, 1995). Dredging of the Atlantic Intracoastal Waterway

(ICW) by the U. S. Army Corps of Engineers between 1953 and 1961 resulted in the creation of 137 spoil islands within the IRL. Dredge spoils were typically placed in very shallow seagrass flats near the cuts during a time when wetland impacts were ignored. Over the past decades, some spoil islands have become colonized by native, threatened and endangered species and serve as bird rookeries, adding to the ecological diversity of the IRL. However, colonization by exotic and invasive species has also taken place. Islands dominated by exotic and invasive species are potential locations for mitigation efforts.

The Florida Department of Transportation (FDOT) received permits from the South Florida Water Management District (SFWMD) and the U. S. Army Corps of Engineers for the construction of the Frank A. Wacha Bridge in 2001 and the Ernest Lyons Bridge in 2004 (E Sciences, Inc 2008). Both projects spanned the IRL and resulted in the destruction of sea grass and mangrove habitats, requiring mitigation. St. Lucie (SL)-15 (27° 28’ 40’’ N, 80° 19’ 23” W), a 5.6 ha spoil island in Ft. Pierce, located approximately 27 km north of the Wacha Bridge and 33 km north of the Lyons Bridge, was selected as the mitigation site. This was one of the first mitigation projects to utilize a spoil to offset the destruction of seagrass and mangrove habitats due to coastal development. Prior to mitigation, SL-15 had a maximum elevation of +9 ft (NGVD) and was primarily vegetated in the island’s interior by Australian pine (*Casuarina equisetifolia*) and Brazilian pepper (*Schinus terebinthifolius*), with a fringe dominated by red mangroves (*Rhizophora mangle*), black mangroves (*Avicennia germinans*), and white mangroves (*Laguncularia racemosa*) (figure 1; Marcus et al. 2006). Extensive seagrass covered sub-tidal flats were present surrounding the island and up to the ICW to the west.

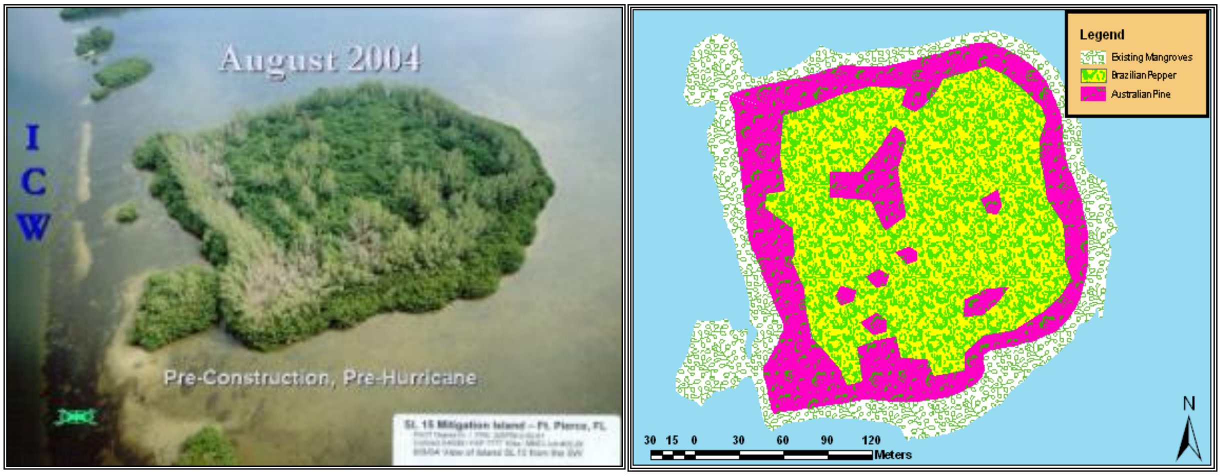

Figure 1. Arial photograph and species map of soil Island SL-15 prior to mitigation (Marcus et al. 2006).

Restoration efforts began in March 2005 contracting firm Misener Marine with the removal of exotic vegetation and excess spoil material, the preservation of the mangrove dominated fringe, and the reshaping of the island to create areas for seagrass and mangrove habitat. In total, the mitigation resulted in the creation of 3.38 acres of seagrass habitat, 4.89 acres of mangrove habitat, and the improvement of 2.43 acres of upland berm or transitional habitat. In order to facilitate restoration of SL-15 a temporary trellis was built on the west side of the island on which a conveyor belt transported material off the island onto a barge. The trellis was constructed to minimize impacts to existing seagrass beds in the area which were known to contain Johnson's seagrass (*Halophila johnsonii*). This trellis remained in place for ten months, during which time approximately 77,000 yd^3 of spoil material were removed. Exotics were removed though clearing and burning. The 1.24 ha island fringe, dominated by red, white, and black mangroves, and the 2.38 acre of uplands forming a berm (+4.0 NGVD) along SL-15's western, northern, and eastern sides were preserved (figure 2).

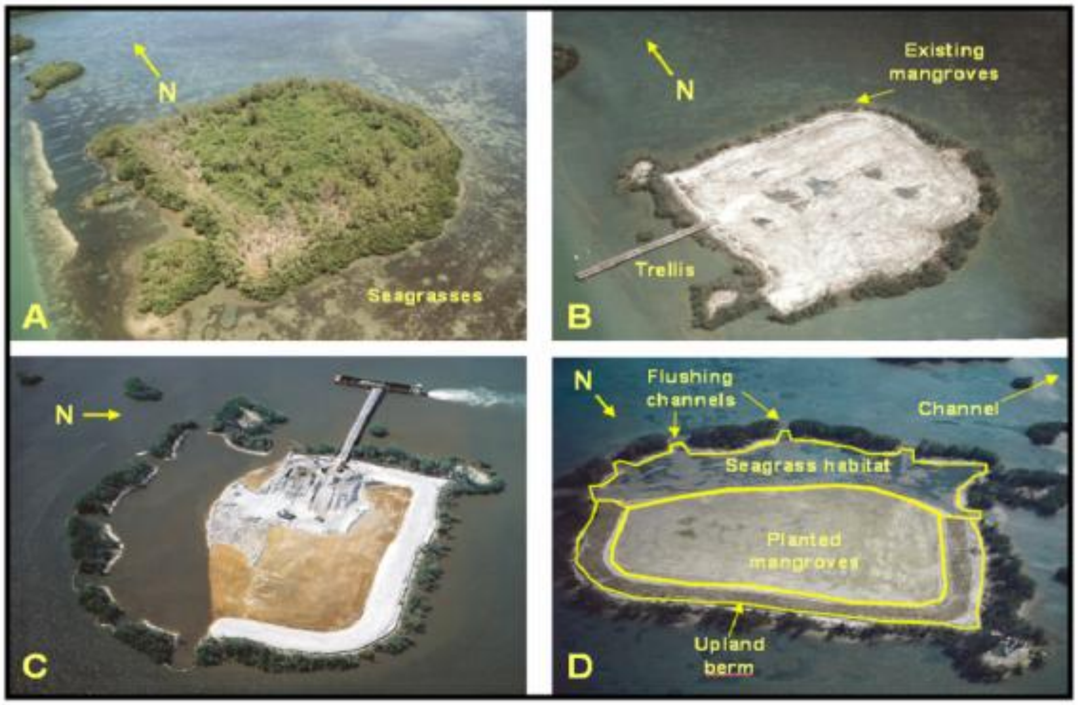

Figure 2. Transformation of SL15. Aerial photos taken in (A) June 2004, (B) May, 2005, (C) November, 2005, and (D) December,2005. The constructed seagrass, mangrove and upland habitats are shown by the yellow polygons (Fischler 2006).

A mangrove planting area within the upland berm was leveled to an elevation of +1.0 NGVD. A seagrass recruitment area was created with a maximum depth of -1.5 NGVD and connected to the IRL via the creation of seven flushing channels separated by six small, islands containing preexisting vegetation including red mangroves (figure 3). Approximately 23,000 red mangrove seedlings were planted in December 2005 within the mangrove planting zone on 1 m centers, while the upland berm, was planted with native vegetation including button woods (*Conocarpus erectus*), sea grapes (*Coccoloba uvifera*), coco plums (*Chrysobalanus icaco*), and myrsines (*Myrsine guianensis*) (Marcus et al. 2006). Bare-root cord grass (*Spartina alternflora*) was planted in the transition zones between the mangrove planting area and seagrass recruitment area, and sea oxeye daisy (*Borrichia arborescens*) and seashore paspalum (*Paspalum distichum*) were planted between the upland berm area and the mangrove planting area (Marcus et al. 2006). The seagrass embayment was not planted, allowing for recruitment by seagrass species from the naturally surrounding IRL. An additional 8,000 red mangrove seedlings were planted in September 2007 (E Sciences, Inc 2008).

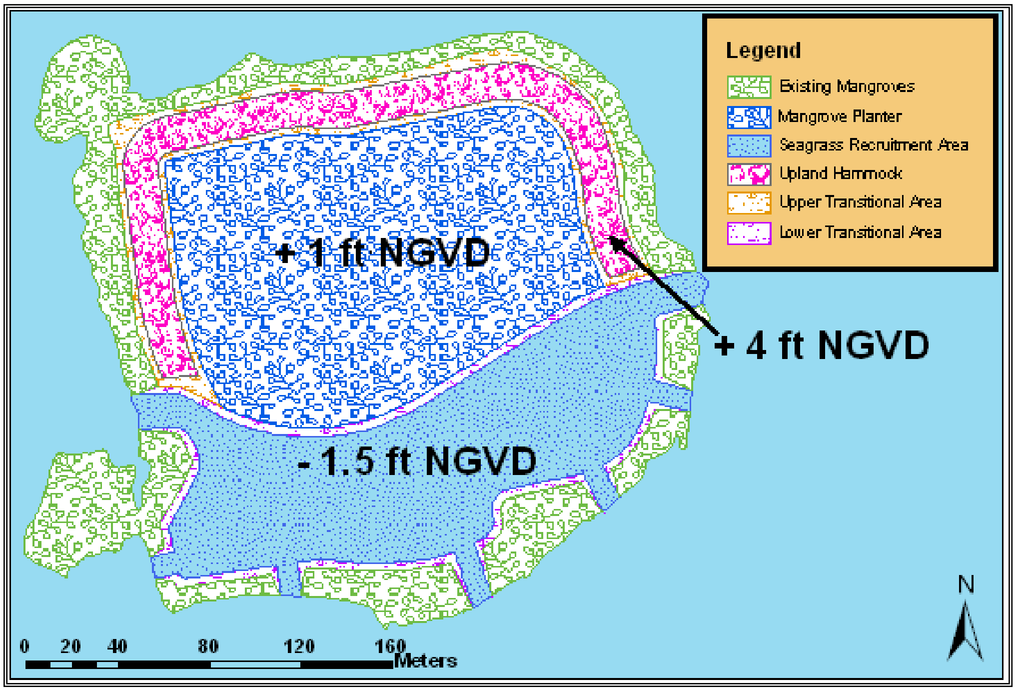

Figure 3. Elevations of the constructed seagrass, mangrove and upland habitats with the flushing channels (Marcus et al. 2006).

Ecological Monitoring Methods

E Sciences, Inc. was contracted to conduct monitoring of the mangrove planting area and seagrass embayment. The schedule for monitoring included a baseline (time zero) event in January 2006 followed by four quarterly events (April, July, October 2006, January 2007) to be followed by two semi-annual monitoring events (July 2007, January 2008) and two annual monitoring events (July 2008, July 2009), as set forth by the permits (Marcus et al. 2006). National Marine Fisheries Service aided in determining the monitoring methodologies for survivorship in the mangrove planter area and recruitment in the seagrass area. Since the upland hammock purpose was to reduce erosion and not required by permit, there was no survivorship requirement. However the upland berm was monitored using three permanent 100 m^2 plots to quantify vegetation coverage by species. The mangrove planting area was monitored on a semiannual basis using four randomly placed transects (50 m x 2 m) to quantify survivorship (figure 4). Success critieria within the mangrove planting area was established as 80% or more survivorship (cover) for planted or recruited mangroves and 5% or less coverage of exotic species. The seagrass embayment was monitored quarterly for the first year after completed construction, semi-annually for the second year after completed construction, and annually for the third, fourth and fifth years after completed construction. Monitoring was carried out by quantifying seagrass shoot counts and coverage using the Braun-Blanquet Classification system within 20 randomly placed paired 1 m^2 quadrates (figure 4). 20 additional randomly placed paired 1 m^2 quadrates were also conducted outside of the seagrass recruitment area within the surrounding IRL. Success criteria in the seagrass embayment were set at 3% (approximate Braun-Blanquet cover class of 0.5) or more coverage by year three, 6% (approximate Braun-Blanquet cover class of 2.0) or greater coverage by year four, and 10% (approximate Braun-Blanquet cover class of 2.0) or more coverage by year five with supplemental plantings required if these criteria were not met by year five. Observations of fauna were quantified within the mangrove planting area and along three randomly established transects within the seagrass embayment. Additionally, fiddler crab burrow counts were conducted in 50 randomly established 1 m^2 quadrates within the mangrove planting area. Permit also required the documentation of any other wildlife such as birds, invertebrates, or fish.

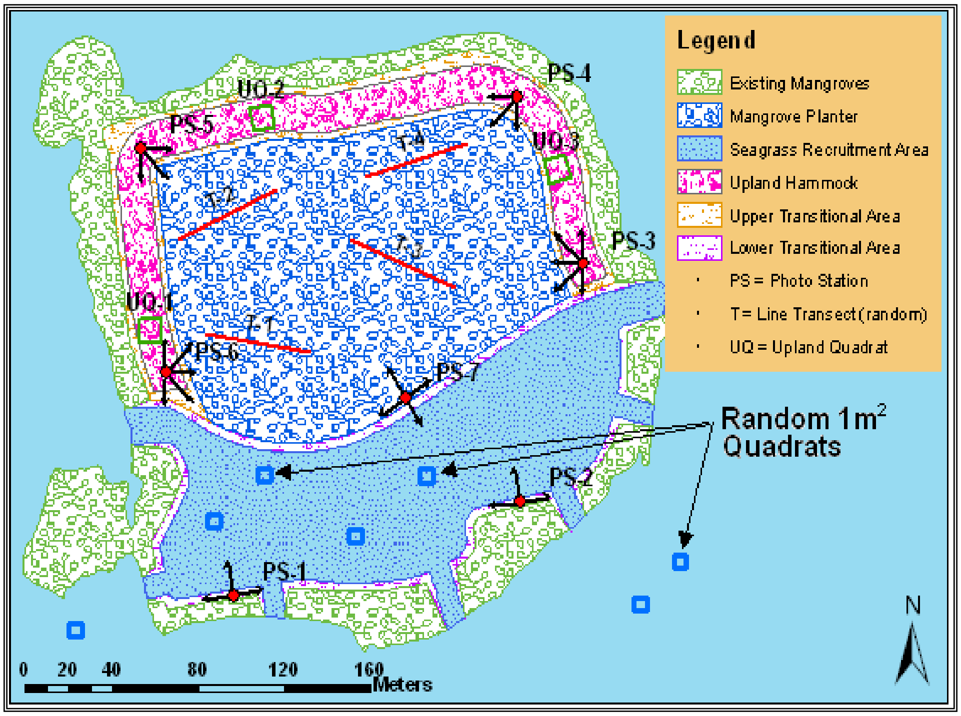

Figure 4. SL-15 post construction mangrove and seagrass monitoring locations (Marcus et al. 2006).

Results

Results reported during by E Sciences during the first year (2006) indicated that the mangrove planting area contained an average mangrove survivorship of 41% (.41 trees/m^2). During this time a supplemental mangrove planting was scheduled in order to facilitate permit requirements. The seagrass embayment was reported to have recruited 1.5% coverage (Braun-Blanquet cover class of 0.2) while the coverage in the control area outside the seagrass recruitment area was to have 56% seagrass coverage. The species composition of year one was determined to be 12% *H. wrightii*, 42.5% *H. Johnsonii*, 5% *S. filiforme*, 10% *H. decpions*, and the remainder being bare substrate.

For year two (2007) results reported by E Sciences indicated that the mangrove planting area contained an average mangrove survivorship of 84% (.84 trees/m^2). During this time the mangrove planting area was in compliance with the required survivorship set forth by the permits. The seagrass embayment was reported to have recruited 1.7% coverage (Braun-Blanquet cover class of 0.3) while the coverage of seagrass outside the embayment was 32%. The species composition of year two was determined to be 5% *H. wrightii*, 35% *H. Johnsonii*, 7.5% *S. filiforme*, and the remainder being bare substrate.

E Sciences year three (2008) results indicated that the mangrove planting area contained an average mangrove survivorship of 108% (1.08 trees/m^2). During this time the mangrove planting area exceeded the permitted required survivorship set forth by the permits and no additional mangroves seedlinds were planted. The seagrass embayment was reported to have recruited 7.5% coverage (Braun-Blanquet cover class of 0.8) while the coverage of seagrass of the control area outside the embayment was 24.5%. The 7.5% seagrass coverage in the seagrass embayment exceeded the permit requirement of 3% coverage after the first three years. The species composition of year three was determined to 25% *H. wrightii*, 67.5% *H. Johnsonii*, 37.5% *S. filiforme*, and the remainder being bare substrate.

Results reported by E Sciences for year four (2009) indicated that the mangrove planting area contained an average mangrove survivorship of 87% (.87 trees/m^2). The seagrass embayment was reported to have recruited 10% coverage (Braun-Blanquet cover class of 1.0) while the coverage of seagrass of the control area outside the embayment was 77.6%. Mangroves did not meet survivorship criteria during this time but percent cover appeared to be adequate (>80%). During this time the seagrass embayment exceeded and met the required mangrove survivorship set forth by the permits. The species composition of year four was determined to 50% *H. wrightii*, 7.5% *T.testudinum*, 20% *H. Johnsonii*, and the remainder being bare substrate.

E Sciences year five (2010) final results indicated that the mangrove planting area contained an average mangrove survivorship of 72% (.72 trees/m^2). The seagrass embayment was reported to have recruited 16.9% coverage (Braun-Blanquet cover class of 1.4) while the coverage of seagrass of the control area outside the embayment was 87.5%. During this time the mangrove planting area and the seagrass embayment exceeded and met the required mangrove survivorship set forth by the permits. The species composition of year five was determined to 5% *H. wrightii*, 2.5% *T.testudinum*, 52.5% *H. Johnsonii*, and the remainder being bare substrate. Once permit requirements were met management of the island was transferred over to the FDEP.

Discussion

Restoration success suggests that spoil islands in the Indian River Lagoon can be utilized for future mitigation sites. The restoration of SL-15 surpassed the required 80% survivorship for mangroves and met the 10% coverage of seagrass for the five year period set forth by the SFWMD. The restored spoil island was also observed to have suitable habitat for fiddler crabs and other marine wildlife including juvenile fish, birds, and insects. Since natural areas with the sufficient conditions to promote seagrass growth are sparse, this mitigation method may serve as a useful way to offset future impacts to seagrass habitats. The success of this project shows that spoil island restoration can be a useful mitigation tool in the IRL, which is considered one of the most diverse estuaries in the United States (Gilmore et al. 1983).

Although this project was deemed a success there can be valuable lessons learned from the results and observations which could be used to improve future similar projects. The random transects utilized to calculated mangrove survivorship and seagrass coverage did not allow for accurate spatial analysis. Spatial analysis can give project managers a better understanding of which areas where successful and unsuccessful, which can lead to more efficient project management. In future projects monitoring transect methods may be altered to give more detailed spatial analysis data. In addition to mangrove and seagrass monitoring other biological and chemical parameters linked to the health of these two key species could have also been monitored, such as soil properties. Since utilizing spoil islands as mitigation sites is a relatively new approach to offset coastal habitat destruction, monitoring efforts continued to ensure the success of this project was ongoing. The second part of this manuscript addresses soil properties, spatial patterns, and post permit monitoring of the mitigation site SL-15.

Introduction

In addition to the required permit monitoring supplementary mangrove and seagrass metrics were taken in the winters and summers from 2008 to 2011. The island was divided into the mangrove planter, planted *S. alterniflora* transition, and seagrass recruitment sampling areas (figure 5). Soil samples were also taken during these sampling events. The additional data was collected to assess mangrove, seagrass, and soil property spatial patterns and relationships. Soil samples were taken to assess particle size, organic matter content, phosphorus, and bulk density. The goal of the Additional and Post Permit monitoring was to establish whether the success criteria set forth by the previous permits continued after post construction monitoring. Since this approach to mitigate for coastal development is relatively new the previous monitoring may not have been long enough to determine whether this project had a long term success and survey techniques may need to be modified. Post monitor sampling methods differed from post construction methods in order to better assess spatial patterns and more intensely survey the study sites. Samples were taken from a total of eighty-three mangrove sites and ten seagrass sites. Soil sample analysis was not a post construction permit requirement however these analysis can be compared to healthy mangrove forest and seagrass bed soil analysis in order to give more detailed perspective to the success of this project.

Methods

Mangroves

From summer 2009 to summer 2011 eighty-three sites within the mangrove planting area were sampled biannually (figure 6). At each site the number of mangroves, species, and height was recorded within a two meter circle. In order to obtain mangroves per square meter the following formula was used:

Observed number of mangroves/(4$*\pi$)=Mangroves/m^2or mangrove density/m^2

For each site average and maximum height was calculated for each species of mangrove. In summer 2011 the shortest canopy diameter length, longest canopy diameter length, and the height to the start of the canopy was recorded (figure 7). Canopy area and volume were calculated using the formulas shown in figure 8 for each tree. These values were then added together to obtain total calculated are and volume for each site. In order to obtain calculated area and volume per square meter the following formulas were used:

Calculated total mangrove area m^2/(4$*\pi$)= Calculated total mangrove area m^2/m^2

Calculated total mangrove volume m^3/(4$*\pi$)= Calculated total mangrove volume m^3/m^2

The spatial data for mangrove density, average height, maximum height, calculated total canopy area, and calculated total canopy volume were analyzed using the Geostatisitcal Analyst extension of ArcGIS 9.3. Ordinary Kriging was used to interpolate the data and estimate measurements and calculations over the mangrove planting area. The resultant models were converted to 1 m raster files in ESRI GRID format for display and spatial analysis.

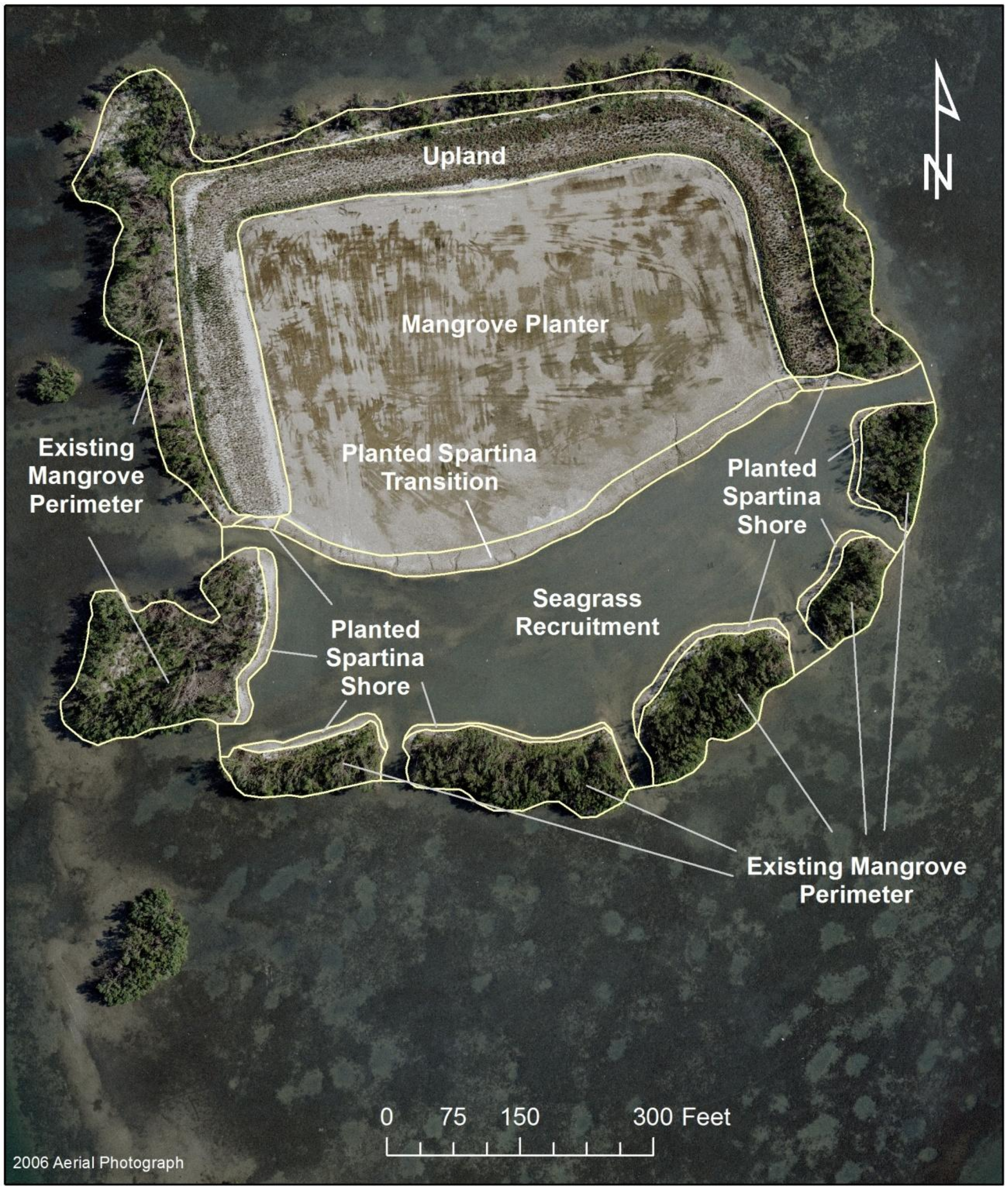

Figure 5. Study areas, existing mangrove perimeter, upland, and planted *S. alterniflora* zones for SL-15 additional and post permit monitoring.

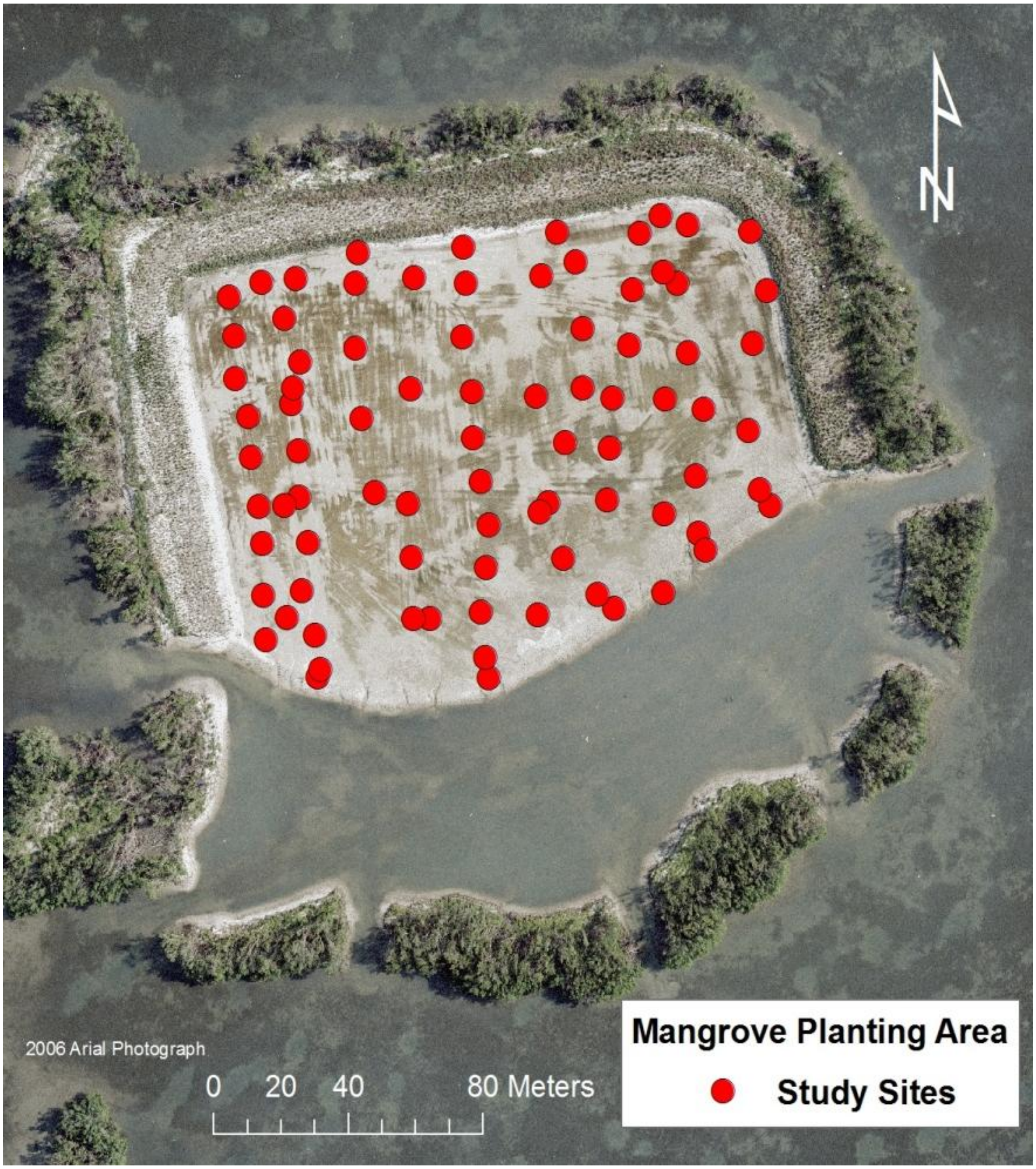

Figure 6. SL-15 post monitoring mangrove planting area study site locations.

Figure 7. Additional mangrove metrics taken in summer 2011.

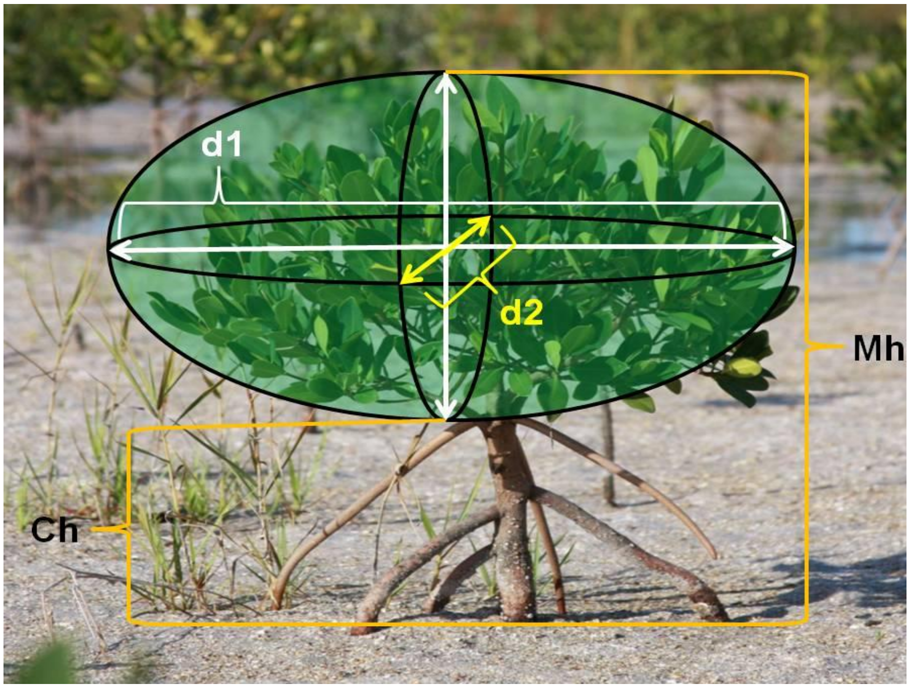

Figure 8. Calculated mangrove canopy area was derived from using the following equation: $Calculated\ Area = \pi * \left(\frac{d1}{2}\right) * \left(\frac{d2}{2}\right)$. Calculated mangrove volume was derived from using the following equation: $Calculated\ Volume = \pi * \left(\frac{d1}{2}\right) * \left(\frac{d2}{2}\right) * \frac{Mh-Ch}{2}$.

Seagrass

From winter 2008 to summer 2011 seagrass coverage, algae coverage, seagrass density, and species composition was recorded biannually for ten study sites within the seagrass embayment (figure 9). From winter 2008 to winter 2010 data was also collected biannually from the three control sites located directly east-northeast of SL-15. Seagrass density was determined by quantifying seagrass shoot counts within the ten study sites and three control sites using one m^2 quadrates. Seagrass coverage was recorded as percent ground cover and using the Braun-Blanquet Classification system in order to compare data to post construction seagrass coverage results. In addition to seagrass coverage algae coverage was also recorded within the one m^2 quadrates. Average seagrass coverage, algae coverage, seagrass density, and species composition was calculated for the seagrass embayment and the control sites.

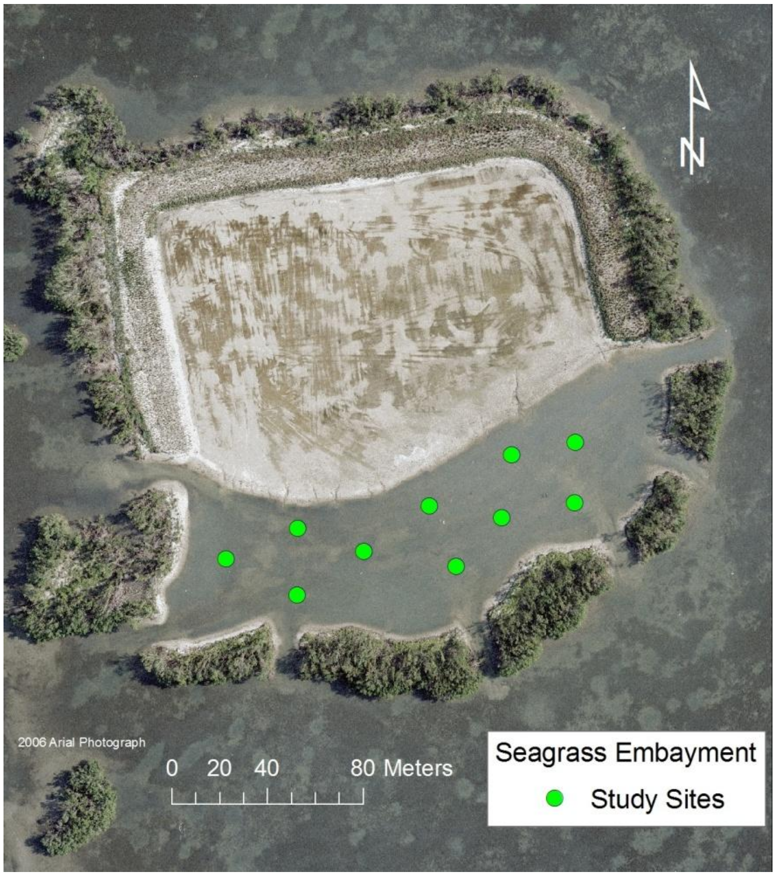

Figure 9. SL-15 post monitoring seagrass study site locations.

The spatial data for seagrass coverage, algae coverage and seagrass density were analyzed using the Geostatisitcal Analyst extension of ArcGIS 9.3. Ordinary Kriging was used to interpolate the data and estimate coverage and density within the seagrass embayment. The resultant models were converted to 1 m raster files in ESRI GRID format for display and spatial analysis.

Soils

From winter 2008 to summer 2011 soil samples were obtain biannually from the mangrove planting area. For comparison soil samples were taken from the upland control biannually from winter 2008 to winter 2010. Within the seagrass embayment and its control sites, soil samples were taken biannually from winter 2008 to winter 2010. The first 0-5 cm portion of the soil at all sites were sampled using polycarbonate core tubes (Figure 10). These soils were characterized by analyzing for particle-size distribution (Day, 1965), bulk density (Blake and Hartage 1986), and organic matter content (Heiri *et. al*, 2001). Total phosphorous within each soil sample was determined by HCl extraction (Reddy et al. 1998).

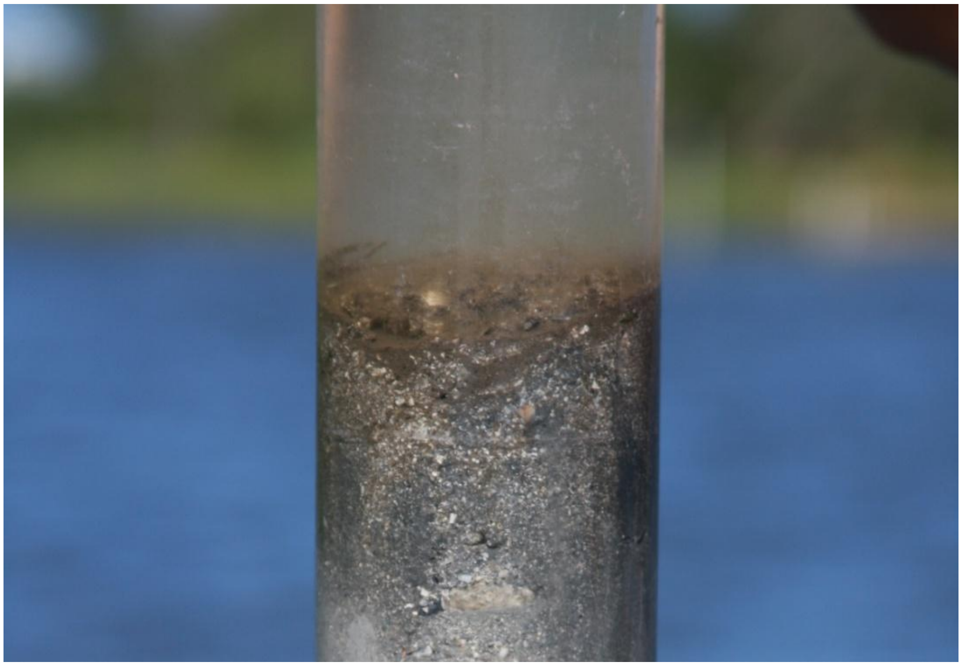

Figure 10. Soil sample obtained from the seagrass embayment area (Ellis 2008)

The spatial data for particle size, orangic matter, and total phosphorus were analyzed using the Geostatisitcal Analyst extension of ArcGIS 9.3. Ordinary Kriging was used to interpolate the data. The resultant models were converted to 1 m raster files in ESRI GRID format for display and spatial analysis.

Results

Mangroves

In summer 2009 the mangrove planting area contained an average *R. mangle* survivorship of 150% or a density of 1.5 trees/m^2 (SD=1.7). During this time the mangrove planting area surpassed the survivorship compliance requirement for *R. mangle* set forth by the previous permits. The average height of *R. mangle* in the planting area was 57.0 cm (SD=29.8). The average maximum height for *R. mangle* in the planting area was 71.0 cm (SD=26.2). The densest places for *R. mangle* were along the transition area and the back north section of planting area. The tallest *R. mangle* trees were concentrated in the northwest corner of the planting are and the southeast corner of the transition area. During this time *A. germinans* had a density of 0.4 trees/m^2 (SD=0.6) in the planting area. The average height within the planting area for *A. germinans* was 37.3 cm (SD=47.8) with an average maximum of 42.1 cm (SD=53.2). The middle of the transition area was where the highest density of *A. germinans* could be found. The tallest *A. germinans* were located on the eastern side of the planting area. During this sampling event *L. racemosa* density was found to be 0.5 trees/m2 (SD=1.3) within the planting area. The average height within the planting area for *L. racemosa* was 30.9 cm (SD=38.1) with an average maximum of 37.2 cm (SD=47.2). The eastern portion of the transition area was where the highest density of *L. racemosa* could be found. The tallest *L. racemosa* were also located in eastern portion of the transition area and the northeast corner of the planting area.

In winter 2009 the mangrove planting area contained an average *R. mangle* survivorship of 150% or a density of 1.5 trees/m^2 (SD=2.5). During this time the mangrove planting area surpassed the survivorship compliance requirement for *R. mangle* set forth by the previous permits. The average height of *R. mangle* in the planting area was 65.6 cm (SD=29.8). The average maximum height for *R. mangle* in the planting area was 84.6 cm (SD=39.2). The densest places for *R. mangle* were along the transition area and the back north section of planting area. The tallest *R. mangle* trees were concentrated in the northwest corner of the planting are and the southeast corner of the transition area. During this time *A. germinans* had a density of 0.5 trees/m^2 (SD=0.7) in the planting area. The average height within the planting area for *A. germinans* was 39.3 cm (SD=47.2) with an average maximum of 48.6 cm (SD=56.3). The middle of the transition area and the northwest corner of the planting area was where the highest density of *A. germinans* could be found. The tallest *A. germinans* were located on the eastern portion of the transition area. During this sampling event *L. racemosa* density was found to be 0.4 trees/m2 (SD=1.1) within the planting area. The average height within the planting area for *L. racemosa* was 39.3 cm (SD=51.3) with an average maximum of 44.3 cm (SD=57.4). The eastern portion of the transition area was where the highest density of *L. racemosa* could be found. The tallest *L. racemosa* were also located in eastern portion of the transition area and the northeast corner of the planting area.

In summer 2010 the mangrove planting area contained an average *R. mangle* survivorship of 170% or a density of 1.7 trees/m^2 (SD=2.8). During this time the mangrove planting area surpassed the survivorship compliance requirement for *R.*

mangle set forth by the previous permits. The average height of *R. mangle* in the planting area was 69.4 cm (SD=24.9). The average maximum height for *R. mangle* in the planting area was 86.6 cm (SD=36.5). The densest places for *R. mangle* were along the transition area, the northwest corner, and the northeast section of planting area. The tallest *R. mangle* trees were concentrated in the northwest corner of the planting are and the southeast corner of the transition area. During this time *A. germinans* had a density of 1.0 trees/m^2 (SD=1.6) in the planting area. The average height within the planting area for *A. germinans* was 32.8 cm (SD=39.2) with an average maximum of 55.2 cm (SD=59.4). The middle of the transition area, the western portion and eastern portion of the planting area was where the highest density of *A. germinans* could be found. The tallest *A. germinans* were located in the transition area, western and eastern corners of the planting area. During this sampling event *L. racemosa* density was found to be 0.8 trees/m2 (SD=1.8) within the planting area. The average height within the planting area for *L. racemosa* was 33.3 cm (SD=42.6) with an average maximum of 50.0 cm (SD=59.2). The eastern portion of the transition area and the northwest corner of the planting area was where the highest density of *L. racemosa* could be found. The tallest *L. racemosa* were also located in transition section of the planting area.

In winter 2010 the mangrove planting area contained an average *R. mangle* survivorship of 140% or a density of 1.4 trees/m^2 (SD=1.3). During this time the mangrove planting area surpassed the survivorship compliance requirement for *R. mangle* set forth by the previous permits. The average height of *R. mangle* in the planting area was 76.9 cm (SD=30.0). The average maximum height for *R. mangle* in the planting area was 97.3 cm (SD=38.0). The densest places for *R. mangle* were along the transition section of planting area. The tallest *R. mangle* trees were concentrated in the transition area and the northwest corner of the planting are. During this time *A. germinans* had a density of 1.0 trees/m^2 (SD=1.8) in the planting area. The average height within the planting area for *A. germinans* was 48.1 cm (SD=41.7) with an average maximum of 71.9 cm (SD=65.9). The northeast corner of the planting area was where the highest density of *A. germinans* could be found. The tallest *A. germinans* were located in the transition section of the planting area. During this sampling event *L. racemosa* density was found to be 0.5 trees/m2 (SD=0.8) within the planting area. The average height within the planting area for *L. racemosa* was 44.5 cm (SD=55.1) with an average maximum of 57.8 cm (SD=74.2). The eastern portion of the transition area was where the highest density of *L. racemosa* could be found. The tallest *L. racemosa* were also located in transition area, northeastern and northwestern corners of the planting area.

In summer 2011 the mangrove planting area contained an average *R. mangle* survivorship of 210% or a density of 2.1 trees/m^2 (SD=4.2). During this time the mangrove planting area surpassed the survivorship compliance requirement for *R. mangle* set forth by the previous permits. The average height of *R. mangle* in the planting area was 73.9 cm (SD=18.7). The average maximum height for *R. mangle* in the planting area was 112.6 cm (SD=32.2). The average canopy area and volume for *R. mangle* within the planting area was 0.3 m^2 leaf area/m^2 (SD=0.2) and 0.1 m^3 of leaf volume/m^2 (SD=0.1), respectively. The average density of *R. mangles* new recruits during this time was 0.5 new recruits/m^2 (SD=1.2). The densest places for *R. mangle* trees were along the transition section of planting area. The tallest *R. mangle* trees were concentrated in the transition area and the northwest corner of the planting area. *R. mangle* canopy area and volume were the highest in the east transition area and in the northwest section of the planting area. *R. mangle* new recruits were most abundant within the eastern portion of the transition section of the planting area. During this time *A. germinans* had a density of 1.6 trees/m^2 (SD=2.1) in the planting area. The average height within the planting area for *A. germinans* was 52.7 cm (SD=36.2) with an average maximum of 112.1 cm (SD=60.6). The average canopy area and volume for *A. germinans* within the planting area was 0.1 m^2 leaf area/m^2 (SD=0.2) and 0.1 m^3 of leaf volume/m^2 (SD=0.2), respectively. The average density of *A. germinans* new recruits during this time was 1.3 new recruits/m^2 (SD=2.0).The northwest and northeast corners of the planting area was where the highest density of *A. germinans* could be found. The tallest *A. germinans* were located in the transition area and northeastern corner of the planting area. *A. germinans* canopy area was greater in the eastern half of the planting area, while canopy volume was the highest in the middle of transition area and in the northeast corner of the planting area. *A. germinans* new recruits were concentrated within the east and west corners the planting area. During this sampling event *L. racemosa* density was found to be 1.2 trees/m2 (SD=3.3) within the planting area. The average height within the planting area for *L. racemosa* was 51.2 cm (SD=45.7) with an average maximum of 84.9 cm (SD=61.2). The average canopy area and volume for *L. racemosa* within the planting area was 0.1 m^2 leaf area/m^2 (SD=0.4) and 0.1 m^3 of leaf volume/m^2 (SD=0.4), respectively. The average density of *L. racemosa* new recruits during this time was 0.7 new recruits/m^2 (SD=2.1).The eastern portion of the transition area, the northeastern and northwestern corners was where the highest density of *L. racemosa* could be found. The tallest *L. racemosa* were also located in transition area and the upper northern portion of the planting area. *L. racemosa* canopy area and canopy volume was greatest in the east part of the transition area and the northeast corner of the planting area. *L. racemosa* new recruits were concentrated within the east and west corners the planting area.

Seagrass

In winter 2008 the seagrass embayment was reported to have 3.5% (SD=6.5) average seagrass ground coverage while the outside seagrass control sites were found to have 54.0% (SD=5.3). Average Braun-Blanquet cover class was found to be 0.6 (SD=0.7) for the seagrass embayment and 4.0 (SD=0.0) for the control sites. Average Braun-Blanquet percent coverage for the study area was found to be 2.5% (SD=5.6) while the control was reported to have 62.5% (SD=0.0) for the control site. Average seagrass density was determined to be 34.4 shoots/m^2 (SD=41.0) for the seagrass embayment and 71.7 shoots/m^2 (SD=25.7) for the outside control sites. The species density within the seagrass embayment during this sampling period was composed of 3.7 shoots/m^2 (SD=7.9) for *H. wrightii*, 30.6 shoots/m^2 (SD=40.8) for *H. Johnsonii*, 0.0 shoots/m^2 (SD=0.0) for *S. filiforme*, and 0.0 shoots/m^2 (SD=0.0) for *T.testudinum*. The species density for the seagrass control sites during this sampling period was composed of 0.0 shoots/m^2 (SD=0.0) for *H. wrightii*, 0.0 shoots/m^2 (SD=0.0) for *H. Johnsonii*, 58.0 shoots/m^2 (SD=20.4) for *S. filiforme*, and 13.7 shoots/m^2 (SD=23.7) for *T.testudinum*.

Average algae coverage during this time for the seagrass embayment was found to be 71.8% (SD=24.4) and 17.3% (SD=14.2) for the seagrass control sites. Seagrass coverage was at the lowest in the middle of the seagrass embayment at this time. Seagrass density was the highest towards the southeastern portion of the seagrass embayment near a flushing channel. Algae coverage was uniform over the study area during this time.

In summer 2009 the seagrass embayment was reported to have 1.0% (SD=1.2) average seagrass ground coverage while the outside seagrass control sites were found to have 73.7% (SD=45.6). Average Braun-Blanquet cover class was found to be 0.2 (SD=0.2) for the seagrass embayment and 4.0 (SD=1.7) for the control sites. Average Braun-Blanquet percent coverage for the study area was found to be 2.0% (SD=1.1) while the control was reported to have 63.3% (SD=41.9) for the control site. Average seagrass density was determined to be 0.0 shoots/m^2 (SD=0.1) for the seagrass embayment and 710.0 shoots/m^2 (SD=255.9) for the outside control sites. The species density within the seagrass embayment during this sampling period was composed of 0.0 shoots/m^2 (SD=0.1) for *H. wrightii*, 0.0 shoots/m^2 (SD=0.1) for *H. Johnsonii*, 0.0 shoots/m^2 (SD=0.0) for *S. filiforme*, and 0.0 shoots/m^2 (SD=0.0) for *T.testudinum*. The species density for the seagrass control sites during this sampling period was composed of 0.0 shoots/m^2 (SD=0.0) for *H. wrightii*, 0.0 shoots/m^2 (SD=0.0) for *H. Johnsonii*, 698.0 shoots/m^2 (SD=203.9) for *S. filiforme*, and 12.0 shoots/m^2 (SD=20.8) for *T.testudinum*. Average algae coverage during this time for the seagrass embayment was found to be 25.7% (SD=11.7) and 0.0% (SD=0.0) for the seagrass control sites. Seagrass coverage was highest in the eastern portion of the seagrass embayment at this time. Seagrass density was the uniform throughout the seagrass embayment. Algae coverage was highest in the western portion of the seagrass embayment during this time.

In winter 2009 the seagrass embayment was reported to have 0.3% (SD=0.5) average seagrass ground coverage while the outside seagrass control sites were found to have 36.7% (SD=23.1). Average Braun-Blanquet cover class was found to be 0.5 (SD=0.2) for the seagrass embayment and 2.7 (SD=0.6) for the control sites. Average Braun-Blanquet percent coverage for the study area was found to be 1.2% (SD=0.8) while the control was reported to have 30.0% (SD=13.0) for the control site.Average seagrass density was determined to be 0.0 shoots/m^2 (SD=0.1) for the seagrass embayment and 24.0 shoots/m^2 (SD=24.8) for the outside control sites. The species density within the seagrass embayment during this sampling period was composed of 0.0 shoots/m^2 (SD=0.1) for *H. wrightii*, 0.0 shoots/m^2 (SD=0.1) for *H. Johnsonii*, 0.0 shoots/m^2 (SD=0.0) for *S. filiforme*, and 0.0 shoots/m^2 (SD=0.0) for *T.testudinum*. The species density for the seagrass control sites during this sampling period was composed of 0.0 shoots/m^2 (SD=0.0) for *H. wrightii*, 0.0 shoots/m^2 (SD=0.0) for *H. Johnsonii*, 15.0 shoots/m^2 (SD=10.0) for *S. filiforme*, and 9.0 shoots/m^2 (SD=15.6) for *T.testudinum*. Average algae coverage during this time for the seagrass embayment was found to be 36.8% (SD=29.5) and 13.3% (SD=23.1) for the seagrass control sites. In winter 2009 seagrass coverage and density were the uniform throughout the seagrass embayment. Algae coverage was concentrated near the west flushing channels of the seagrass embayment during this time.

In summer 2010 the seagrass embayment was reported to have 8.3% (SD=10.7) average seagrass ground coverage while the outside seagrass control sites were found to have 43.3% (SD=49.3). Average Braun-Blanquet cover class was found to be 1.2 (SD=1.1) for the seagrass embayment and 3.0 (SD=1.7) for the control sites. Average Braun-Blanquet percent coverage for the study area was found to be 10.3% (SD=11.9) while the control was reported to have 39.2% (SD=41.9) for the control site. Average seagrass density was determined to be 95.0 shoots/m^2 (SD=144.7) for the seagrass embayment and 483.3 shoots/m^2 (SD=144.3) for the outside control sites. The species density within the seagrass embayment during this sampling period was composed of 7.5 shoots/m^2 (SD=16.9) for *H. wrightii*, 87.5 shoots/m^2 (SD=143.5) for *H. Johnsonii*, 0.0 shoots/m^2 (SD=0.0) for *S. filiforme*, and 0.0 shoots/m^2 (SD=0.0) for *T.testudinum*. The species density for the seagrass control sites during this sampling period was composed of 0.0 shoots/m^2 (SD=0.0) for *H. wrightii*, 0.0 shoots/m^2 (SD=0.0) for *H. Johnsonii*, 450.0 shoots/m^2 (SD=86.6) for *S. filiforme*, and 33.3 shoots/m^2 (SD=57.7) for *T.testudinum*. Average algae coverage during this time for the seagrass embayment was found to be 14.5% (SD=13.0) and 0.0% (SD=0.0) for the seagrass control sites. Seagrass coverage and density were the uniform throughout the seagrass embayment, while algae coverage was concentrated in the west half ofthe seagrass embayment during this time.

In winter 2010 the seagrass embayment was reported to have 0.7% (SD=1.1) average seagrass ground coverage while the outside seagrass control sites were found to have 71.7% (SD=36.2). Average Braun-Blanquet cover class was found to be 0.2 (SD=0.2) for the seagrass embayment and 4.3 (SD=1.2) for the control sites. Average Braun-Blanquet percent coverage for the study area was found to be 1.0% (SD=1.3) while the control was reported to have 70.1% (SD=28.9) for the control site. Average seagrass density was determined to be 10.0 shoots/m^2 (SD=31.6) for the seagrass embayment and 700.0 shoots/m^2 (SD=204.6) for the outside control sites. The species density within the seagrass embayment during this sampling period was composed of 10.0 shoots/m^2 (SD=31.6) for *H. wrightii*, 0.0 shoots/m^2 (SD=0.0) for *H. Johnsonii*, 0.0 shoots/m^2 (SD=0.0) for *S. filiforme*, and 0.0 shoots/m^2 (SD=0.0) for *T.testudinum*. The species density for the seagrass control sites during this sampling period was composed of 0.0 shoots/m^2 (SD=0.0) for *H. wrightii*, 0.0 shoots/m^2 (SD=0.0) for *H. Johnsonii*, 683.3 shoots/m^2 (SD=200.5) for *S. filiforme*, and 16.7 shoots/m^2 (SD=28.9) for *T.testudinum*. Average algae coverage during this time for the seagrass embayment was found to be 70.5% (SD=26.5) and 0.0% (SD=0.0) for the seagrass control sites. In winter 2010 seagrass coverage and density were highest in the eastern half of the seagrass embayment. Algae coverage was concentrated in the western three quarters of the seagrass embayment during this time.

In summer 2011 the seagrass embayment was reported to have 0.5% (SD=1.6) average seagrass ground coverage. Average Braun-Blanquet cover class was found to be 0.1 (SD=0.2) and average Braun-Blanquet percent coverage for the study area was found to be 0.3% (SD=0.8). The outside seagrass control sites were not monitored during this sampling event. During this time the seagrass embayment did not meet the seagrass coverage compliance requirement set forth by the previous permits. Average seagrass density was determined to be 5.0 shoots/m^2 (SD=15.8) for the seagrass embayment. The species density within the seagrass embayment during this sampling period was composed of 5.0 shoots/m^2 (SD=15.8) for *H. wrightii*, 0.0 shoots/m^2 (SD=0.0) for *H. Johnsonii*, 0.0 shoots/m^2 (SD=0.0) for *S. filiforme*, and 0.0 shoots/m^2 (SD=0.0) for *T.testudinum*. Average algae coverage during this time for the seagrass embayment was found to be 68.7% (SD=27.3). Seagrass coverage and density were highest in the eastern half of the seagrass embayment, while algae coverage was uniform throughout the seagrass embayment during this time.

Soils

In winter 2008 the average percent sand and fine soil particles in the mangrove planting area were found to be 87.8% and 12.2% (SD=10.8), respectively, compared to the upland control proportions of 91.8% and 8.2% (SD=2.6). Average percent organic matter was found to be 1.7% (SD=0.5) in the planting area and 3.6% (SD=1.2) in its control. Average bulk density and total phosphorus in the planter soil was found to be 1.1 (SD=0.2) and 247.4 mg P/kg soil (SD=131.9). The upland control was found to have a bulk density of 0.8 (SD=0.0) and 463.7mg P/kg soil (SD=378.4). During this time the average percent sand and fine particles in the seagrass embayment was found to be 80.4% and 19.6% (SD=7.8), respectively, compared to the seagrass control proportions of 77.1% and 22.9% (SD=9.8). Average percent organic matter was found to be 2.6% (SD=0.7) in the seagrass embayment and 2.7% (SD=1.4) in its control. Average bulk density and total phosphorus in the seagrass embayment soil was found to be 0.8 (SD=0.2) and 503.3 mg P/kg soil (SD=128.7). The segarss control was found to have a bulk density of 0.6 (SD=0.2) and 560.6 mg P/kg soil (SD=172.6).). Percent fine particles in the soil were higher in the seagrass embayment than in the mangrove planting area and were relatively uniform in the seagrass embayment. Within the planting area fine particles were the highest on the east side. Organic matter was higher in the seagrass embayment and uniform. There were low percentages of organic matter in the northern border of the mangrove planting area during this time. There was more phosphorus in the soil in the seagrass embayment which was concentrated near the western flushing channels. Phosphorus in the mangrove planting area was concentrated in the middle portion of the planting area.

In summer 2009 the average percent sand and fine soil particles in the mangrove planting area were found to be 89.1% and 10.9% (SD=4.1), respectively, compared to the upland control proportions of 84.5% and 15.5% (SD=10.5). Average percent organic matter was found to be 1.4% (SD=0.5) in the planting area and 5.3% (SD=2.9) in its control. Average bulk density and total phosphorus in the planter soil was found to be 1.3 (SD=0.2) and 418.0 mg P/kg soil (SD=74.3). The upland control was found to have a bulk density of 1.1 (SD=0.1) and 636.0 mg P/kg soil (SD=98.4). During this time the average percent sand and fine particles in the seagrass embayment was found to be 77.9% and 22.1% (SD=6.1), respectively, compared to the seagrass control proportions of 86.2% and 13.8% (SD=6.1). Average percent organic matter was found to be 2.6% (SD=0.8) in the seagrass embayment and 2.2% (SD=1.0) in its control. Average bulk density and total phosphorus in the seagrass embayment soil was found to be 1.1 (SD=0.5) and 619.8 mg P/kg soil (SD=52.7). The segarss control was found to have a bulk density of 1.0 (SD=0.1) and 706.7 mg P/kg soil (SD=25.9).). Percent fine particles in the soil were higher in the seagrass embayment than in the mangrove planting area and were relatively uniform in the seagrass embayment. Within the planting area fine particles were the highest on the east side during this sampling period. Organic matter was higher in the seagrass embayment and uniform. Organic matter was higher on the east half of the mangrove planting area. There was more phosphorus in the soil in the seagrass embayment which was relatively uniform. Phosphorus in the mangrove planting area did not show a distinct spatial pattern.

In winter 2009 the average percent sand and fine soil particles in the mangrove planting area were found to be 92.2% and 7.8% (SD=3.5), respectively, compared to the upland control proportions of 93.3% and 6.7% (SD=4.6). Average percent organic matter was found to be 1.2% (SD=0.3) in the planting area and 3.5% (SD=3.4) in its control. Average bulk density and total phosphorus in the planter soil was found to be 1.6 (SD=0.1) and 348.7 mg P/kg soil (SD=137.6). The upland control was found to have a bulk density of 1.0 (SD=0.5) and 644.3 mg P/kg soil (SD=61.1). During this time the average percent sand and fine particles in the seagrass embayment was found to be 85.4% and 14.6% (SD=5.2), respectively, compared to the seagrass control proportions of 78.2% and 21.8% (SD=9.8). Average percent organic matter was found to be 1.6% (SD=0.5) in the seagrass embayment and 2.0% (SD=0.8) in its control. Average bulk density and total phosphorus in the seagrass embayment soil was found to be 1.3 (SD=0.3) and 572.2 mg P/kg soil (SD=52.8). The segarss control was found to have a bulk density of 1.0 (SD=0.3) and 655.8 mg P/kg soil (SD=9.5). Percent fine particles in the soil were higher in the seagrass embayment than in the mangrove planting area and were relatively uniform in the seagrass embayment. During this time fine particles were the highest in the southern half of the planting area. Organic matter was higher in the seagrass embayment the highest percentage in the western middle part of the embayment. Organic matter was relatively uniform in the mangrove planting area. There was more phosphorus in the soil in the seagrass embayment which did not exhibit any spatial pattern. Phosphorus in the mangrove planting area was highest in the southeast corner.

In summer 2010 the average percent sand and fine soil particles in the mangrove planting area were found to be 92.1% and 7.9% (SD=3.2), respectively, compared to the upland control proportions of 66.0% and 34.0% (SD=10.5). Average percent organic matter was found to be 1.0% (SD=0.2) in the planting area and 3.1% (SD=1.5) in its control. Average bulk density and total phosphorus in the planter soil was found to be 1.6 (SD=0.2) and 356.1 mg P/kg soil (SD=123.9). The upland control was found to have a bulk density of 0.4 (SD=0.2) and 519.3 mg P/kg soil (SD=261.8). During this time the average percent sand and fine particles in the seagrass embayment was found to be 82.7% and 17.3% (SD=6.3), respectively, compared to the seagrass control proportions of 82.1% and 17.9% (SD=1.5). Average percent organic matter was found to be 2.7% (SD=4.1) in the seagrass embayment and 1.0% (SD=0.3) in its control. Average bulk density and total phosphorus in the seagrass embayment soil was found to be 1.2 (SD=0.3) and 443.6 mg P/kg soil (SD=93.2). The segarss control was found to have a bulk density of 1.2 (SD=0.2) and 496.2 mg P/kg soil (SD=175.9). Percent fine particles in the soil were higher in the seagrass embayment than in the mangrove planting area and were relatively uniform in the seagrass embayment. During this time fine particles were the highest in the southeastern corner of the planting area. Organic matter was higher in the seagrass embayment the highest percentage in the western quarter of the embayment. Organic matter was relatively uniform in the mangrove planting area. Phosphorus was the highest in the middle of the seagrass embayment and eastern half of the mangrove planting area.

In winter 2010 the average percent sand and fine soil particles in the mangrove planting area were found to be 94.0% and 6.0% (SD=3.0), respectively, compared to the upland control proportions of 93.8% and 6.2% (SD=1.7). Average percent organic matter was found to be 1.2% (SD=0.3) in the planting area and 2.0% (SD=1.2) in its control. Average bulk density and total phosphorus in the planter soil was found to be 1.4 (SD=0.2) and 463.4 mg P/kg soil (SD=117.4). The upland control was found to have a bulk density of 1.7 (SD=0.0) and 807.1 mg P/kg soil (SD=250.5). During this time the average percent sand and fine particles in the seagrass embayment was found to be 86.7% and 13.3% (SD=7.3), respectively, compared to the seagrass control proportions of 85.5% and 14.5% (SD=4.3). Average percent organic matter was found to be 1.8% (SD=0.7) in the seagrass embayment and 1.6% (SD=0.2) in its control. Average bulk density and total phosphorus in the seagrass embayment soil was found to be 1.2 (SD=0.3) and 649.9 mg P/kg soil (SD=128.7). The segarss control was found to have a bulk density of 1.2 (SD=0.1) and 666.8 mg P/kg soil (SD=8.5). Percent fine particles in the soil were higher in the seagrass embayment than in the mangrove planting area. Fine particle were highest in the western edge and the middle section of the seagrass embayment. During this time fine particles were the lowestest in the western edge of the planting area. Organic matter was higher in the seagrass embayment than in the mangrove planting area and relatively uniform in both areas. Phosphorus was the highest in the seagrass embayment and relatively uniform in both areas.

In summer 2011 control samples were taken only for the seagrass embayment and phosphorus analysis was not preformed during this time. The seagrass embayment was only sampled for organic matter and bulk density during this sampling period. The average percent sand and fine soil particles in the mangrove planting area were found to be 95.3% and 4.7% (SD=3.5), respectively. Average percent organic matter and bulk density was found to be 1.8% (SD=0.8) and 1.5 (SD=.1), respectively in the planting area. Average percent organic matter was found to be 1.8% (SD=0.7) in the seagrass embayment and 1.4% (SD=0.1) in its control. Average bulk density in the seagrass embayment soil was found to be 1.4 (SD=0.1). Percent fine particles in the soil were highest in the transition section of the mangrove planting area. Organic matter was also highest in the transition section of the mangrove planting area.

Discussion

Mangroves

R. mangle trees exceeded permit expectations for the entire additional and post monitoring period with a maximum survivorship of 210% (including natural recruitment) in summer 2011. Spatial patterns produced in ArcGIS suggest the densest areas within the mangrove planting area occur in the transitional zone and along the borders of the planting area (figure 11). In these areas mangrove density was observed to be larger than original planting density, which would imply natural recruitment. The transitional zone was found to have the most natural recruitment. The 2011 *R. mangle* new recruit interpolation (figure A23) confirms this. Note in winter 2009 and summer 2010 there were large zones in the center of the planter with low *R. mangle* densities, less than permit requirements. However in winter 2010 *R. mangle* density within the center of the mangrove planting area increased to meet permit requirements, which again suggests natural recruitment. Average height and maximum height increased steadily through time. Spatial analysis of height can be found in the appendix of this manuscript. Incidental observations showed that recruitment seemed to be the highest in areas of *S. alterniflora* (figure 12).

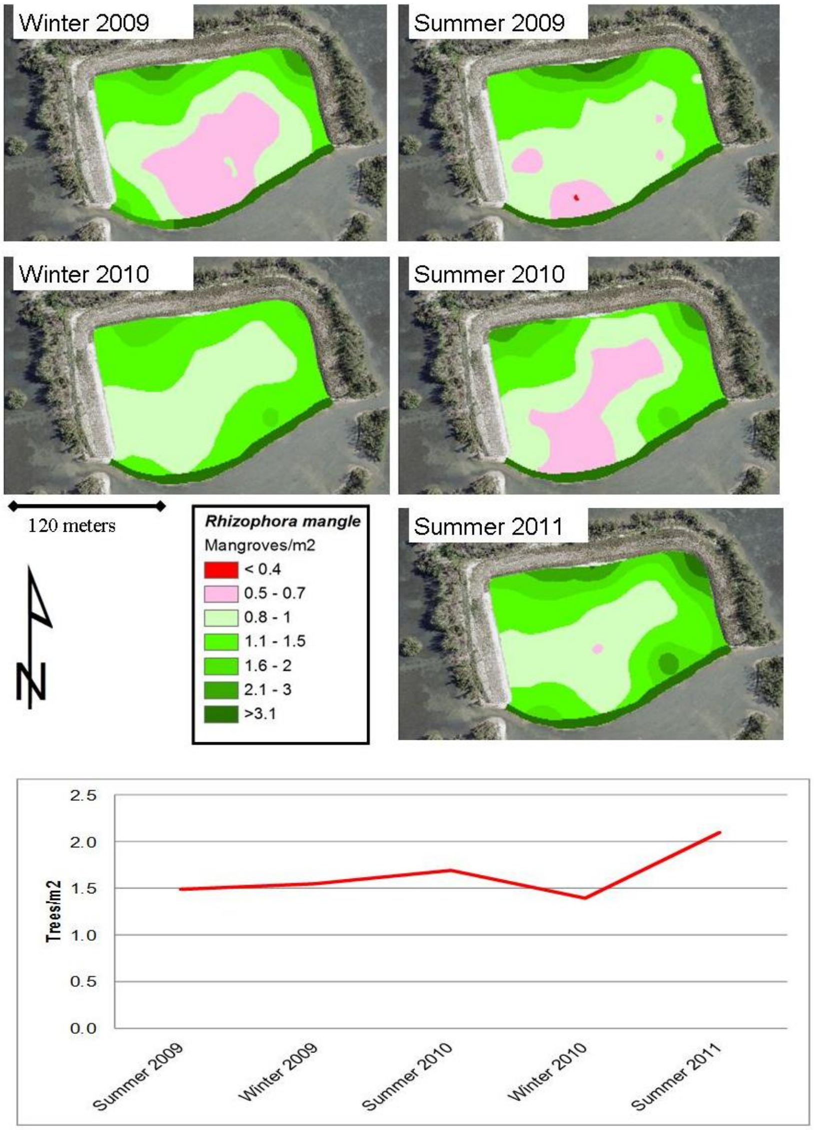

Figure 11. *R. mangle* density from summer 2009 to summer 2011.

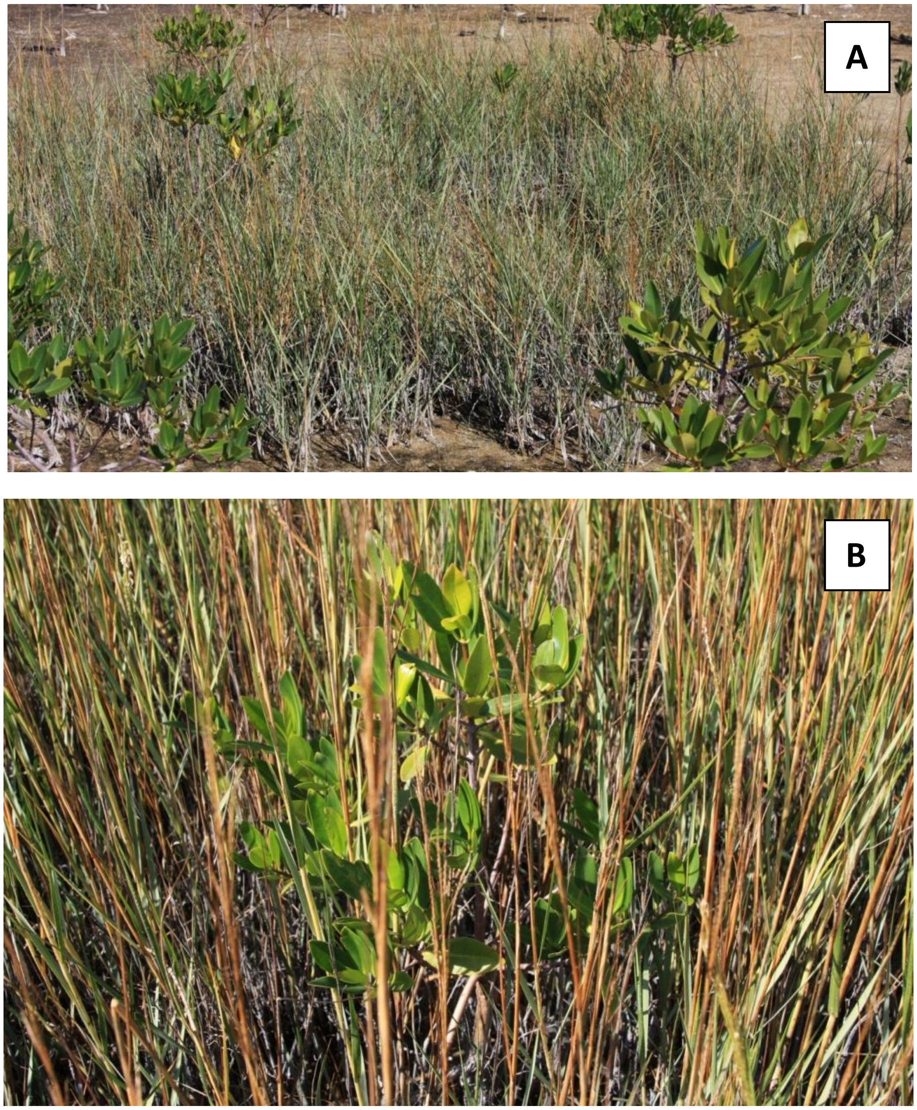

Figure 12. Patch of *Spartina alterniflora* (A) with a close-up view of *R. mangle* recruit within that patch (B).

Post construction monitoring of the mangrove planter showed densities less than the calculated densities using the additional and post permit monitoring methods. Possible reasons for the difference may be due to the amount and location of study sites used in the two different sampling methods. Post construction monitoring and the additional and post permit monitoring results both illustrated that the mangrove planting area met and exceeded the permit requirements for survival. Additional and post permit monitoring methods were more adapted for spatial analysis and were more precise due to the larger number of sample sizes. If mangrove survivorship is the main metric to judge the success of a mitigated spoil island than post construction monitoring methods may be sufficient in evaluating success. However it may be useful to use information from a combination of both methods to improve the success of the island and help project managers more efficiently make additional planting decisions. Utilizing spatial data for the beginning years can help project managers decide where to plant additional mangroves if a success criterion is not met.

This project not only met success criteria for *R. mangle* but also recruited other mangrove species, A. germinans and *L. racemosa*, as well. By summer 2011 both of these species exceeded one tree per square meter, 1.6 trees/m^2 and 1.2 trees/m^2 for A. germinans and *L. racemosa* respectively. Spatial analysis of density, average height, and maximum height can be found in the appendix section of the manuscript. These two species of mangroves were not planted within the mangrove planting area and were all considered to be recruited to the island after construction. R. mangle recruitment is unknown because original planted mangroves were unmarked and recruitment was not able to be determined. Mangrove recruitment may play an important role in the mangrove survivorship metrics and should be further examined in future projects.

Seagrass

Seagrasses coverage within the seagrass embayment did not meet permit requirements for all years using additional and post permit monitoring methods. Seagrass coverage did meet permit requirements using the post construction methods for all years. Both methods did show that *H. johnsonii* was the dominate seagrass and that control sites had larger percent seagrass coverage. The differences in percent coverage of the study sites are largely attributed to sampling locations and methods. Spatial analysis of the seagrass embayment did not show a strong spatial pattern and seemed to be variable throughout the years (figure 13). Algae coverage was variable as well and did not appear to affect seagrass coverage. Shoot density and percent algae coverage interpolations can be found for the additional and post permit monitoring in the appendix of this manuscript.

The random post construction monitoring sites may have included more of the seagrass beds than the additional and post permit montoring sites. The additional and post permit monitoring sites were positioned in order for best spatial analysis. By positioning the study sites for ideal spatial analysis small seagrass beds along the shallower shoreline may have been missed. Silt and turbidity in the deeper areas of the seagrass embayment made it more difficult to obtain shoot count and percent coverage which also may account for the difference in percent seagrass coverage. Methods utilized in the additional and post permit monitoring also recorded percent ground coverage for seagrass. This percent coverage was lower than that of the coverage calculated by the Braun-Blanquet classification system.

Post construction monitoring appeared to capture more of the seagrass than additional and post permit monitoring. In order to account a more accurate spatial analysis of seagrass coverage study sites would need to be equally distributed between depth and area. This data does show how variable seagrass recruitment can be in relationship to depth, possibly due to light attenuation.

This project was deemed a success however due to the inconsistencies from the two monitoring methods additional monitoring may better illustrate continued successful seagrass mitigation. By using a combination of the two survey methods, a better spatial analysis can be done. It is recommended that the Braun-Blanquet classification system for coverage be used since this is the proffered method to assess seagrass density in previous studies.

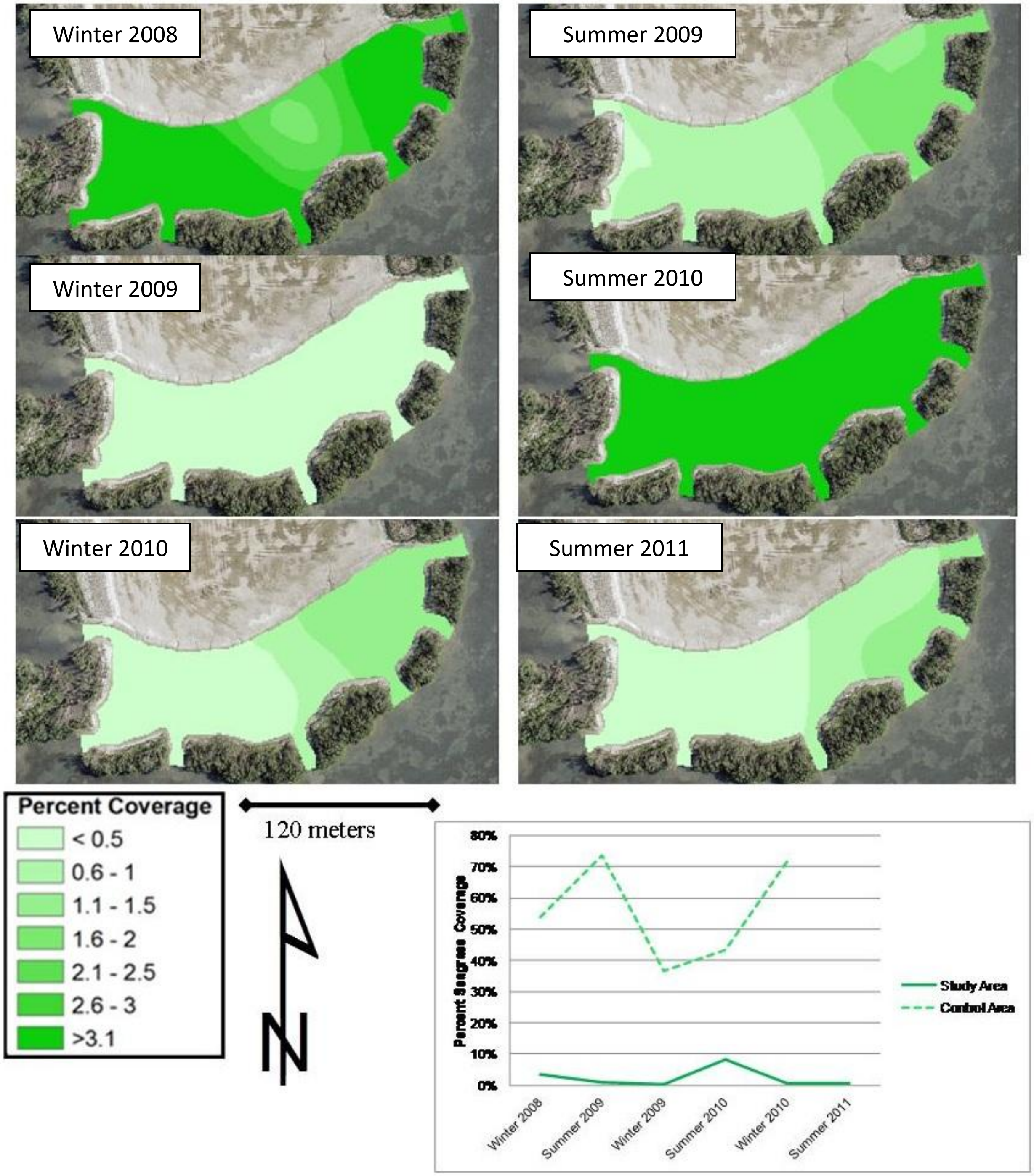

Figure 13. Seagrass ground coverage from winter 2008 to summer 2011.

Soils

Percent fine particles of the soil samples within the mangrove planter and upland control both decreased over time. The mangrove planting area had decreased by 61.5% relatively steady over time. The upland control decreased by 25.4% but, was much more variable over time. Healthy mangrove forests normally have a large percentage of fine particles (Boto and Wellington 1984). In general the fine particles seemed to decrease from the back of the mangrove planter towards the seagrass embayment (figure 14).

Percent fine particles within the seagrass embayment and its study sites also decreased slightly, however with much more variability. Soils within healthy seagrass beds are typically fine in texture (Ellis 2006).

Organic matter content within the mangrove planting area did not seem to change with respect to time. Organic matter averaged 1.4% (SD=0.3) between winter 2008 and summer 2011. At the upland control sites the organic matter content was approximately twice as much at any given sampling period. There did not seem to be any clear spatial pattern to organic matter content within the mangrove planting area (figure 15). The percentage of organic matter within the mangrove planting area was found to be less than that of a healthy mangrove forest (Boto 1984). The mangroves at SL-15 are relatively new and organic matter content may continue to rise as time goes on. The organic matter content found within the seagrass embayment was closely related to the organic matter content found at the seagrass control sites at approximately 2%. A previous study showed that organic matter content of vegetated subaqueous soils is less than 5% (Koch 2001). Soils found within the seagrass embayment meet this criterion. Organic matter content should not inhibit seagrass recruitment.

Total phosphorus increased both within the mangrove planting area, the seagrass embayment, and their respective controls. Both control sites had slightly higher total phosphorus within the soil samples than their respective study sites. There is not a clear overall spatial pattern however, looking at individual sampling events some spatial patterns do immerge (figure 16). In the winter 2008, total phosphorus is highest in seagrass embayment near the west flushing channels. The higher amounts of phosphorus in the middle of the mangrove planter appear to follow the middle flushing channel and some of the observed ponding patterns on high tide (figure 17). These patterns are amplified in the mangrove planter in summer 2009. The total phosphorus values found within the mangrove planting area were similar to values for from Chamber’s and Pederson’s 2006 study of soil properties in mangrove ecotones in the Shark River Slough basin.

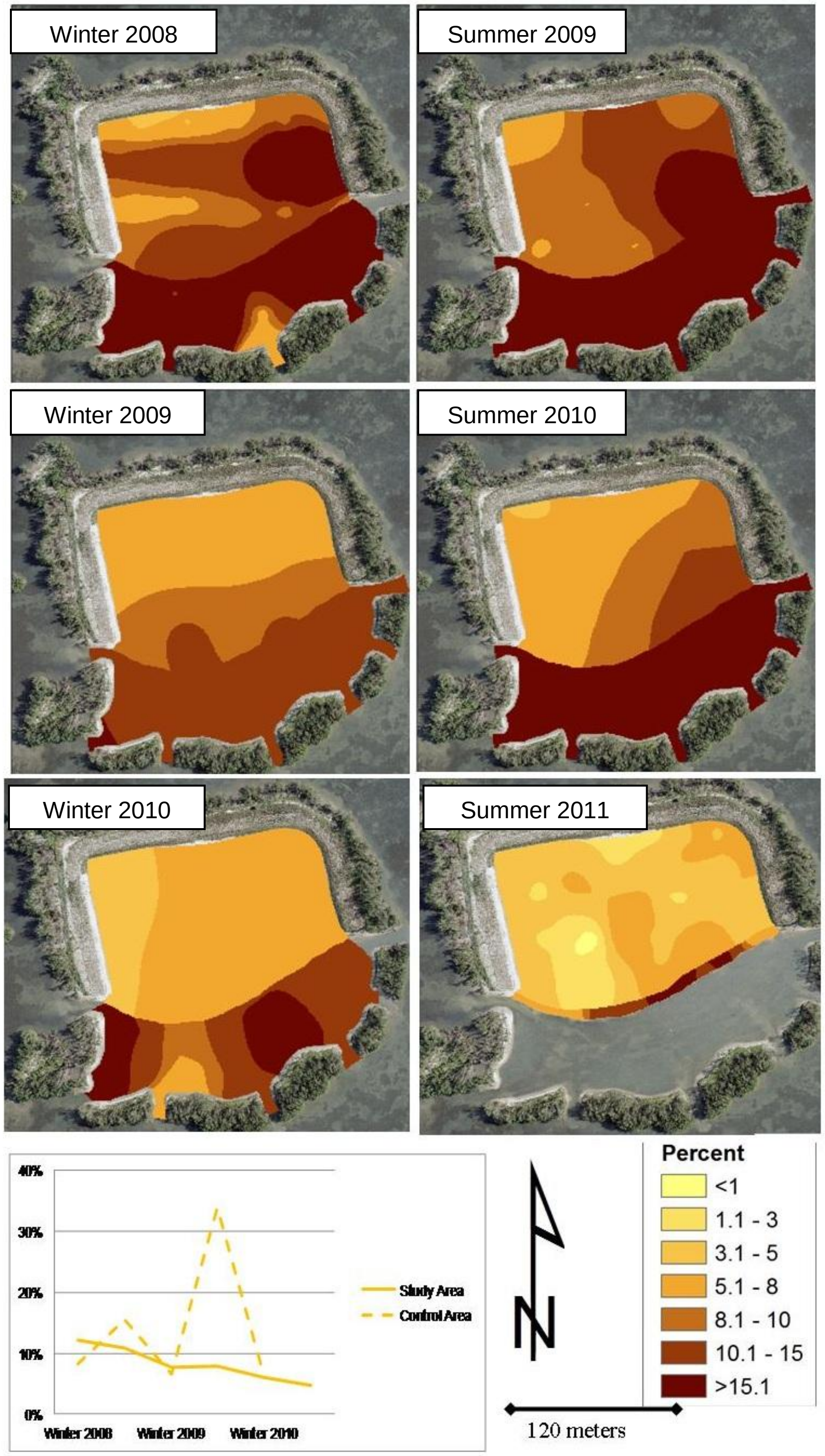

Figure 14. Percent fine particles within the seagrass recruitment area and the mangrove planting area form winter 2008 and summer 2011.

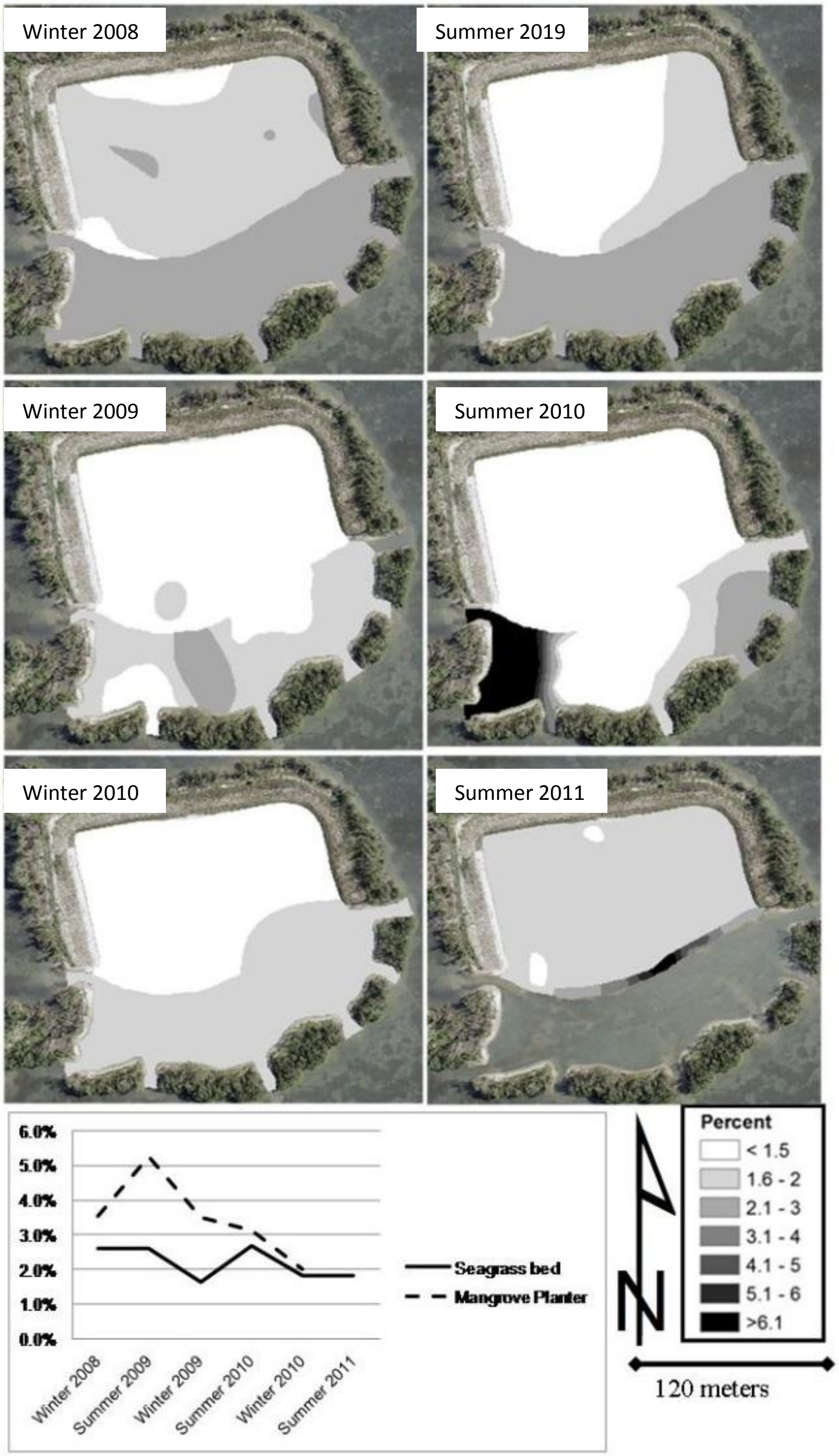

Figure 15. Percent organic matter within the seagrass recruitment area and the mangrove planting area form winter 2008 and summer 2011.

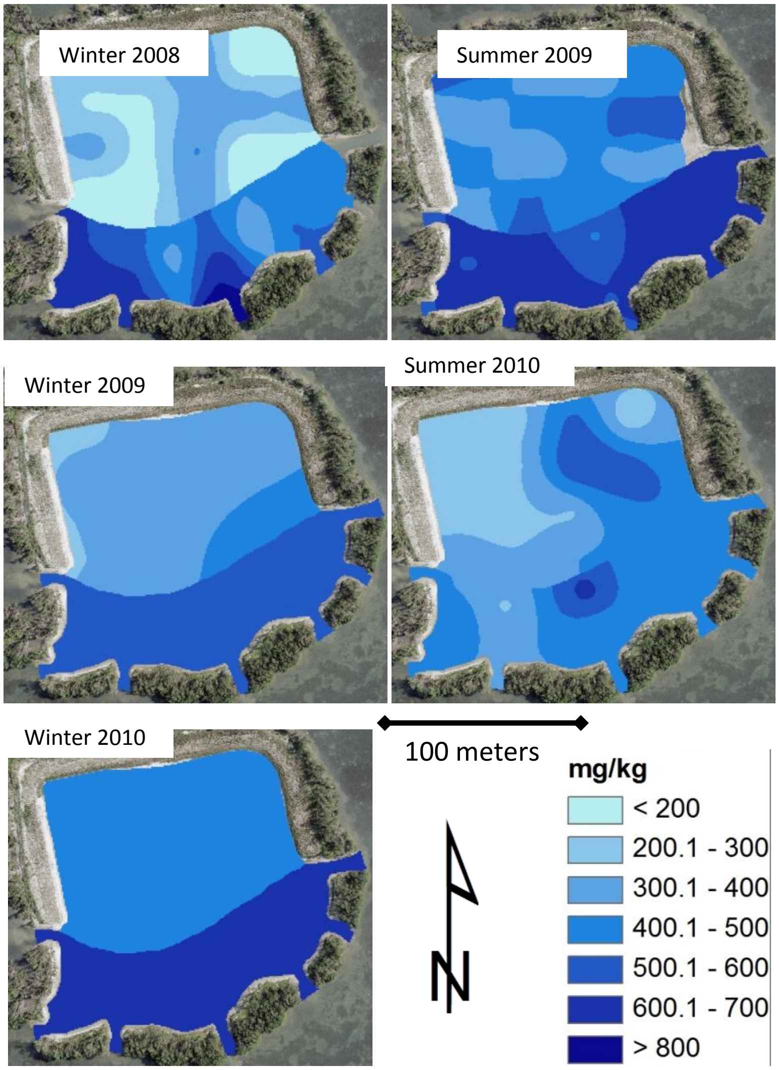

Figure 16. Total phosphorus within the seagrass recruitment area and the mangrove planting area form winter 2008 and summer 2011.

Figure 17. Ponded area on low tide (Ellis 2008).

CONCLUSIONS

The mitigation site SL-15 was observed to have suitable habitat for three mangrove species within the created mangrove habitat. Both monitoring methods reported the mangrove planter area to surpass the required survivorship set for by the permits. Benefits to utilizing the additional and post monitoring techniques can give project managers a better insight to where problematic areas may occur within the constructed habitat. The seagrass embayment met permit requirements utilizing the post construction monitoring methods. Future projects of this kind may take into consideration using both approaches described in the manuscript in order to given project mangers additional information to make more effective conservation decisions. Assessing not only survivorship of mangrove and seagrass coverage but also analyzing spatial patterns gives a more complete understanding of the these parameters. The success of this project also created habitat for marine wildlife including juvenile fish, birds, and insects. Since natural areas with the sufficient conditions to promote seagrass growth are sparse and pressure for coastal development will continue, this mitigation method may serve as a useful way to offset future impacts to seagrass and mangrove habitats.

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APPENDIX

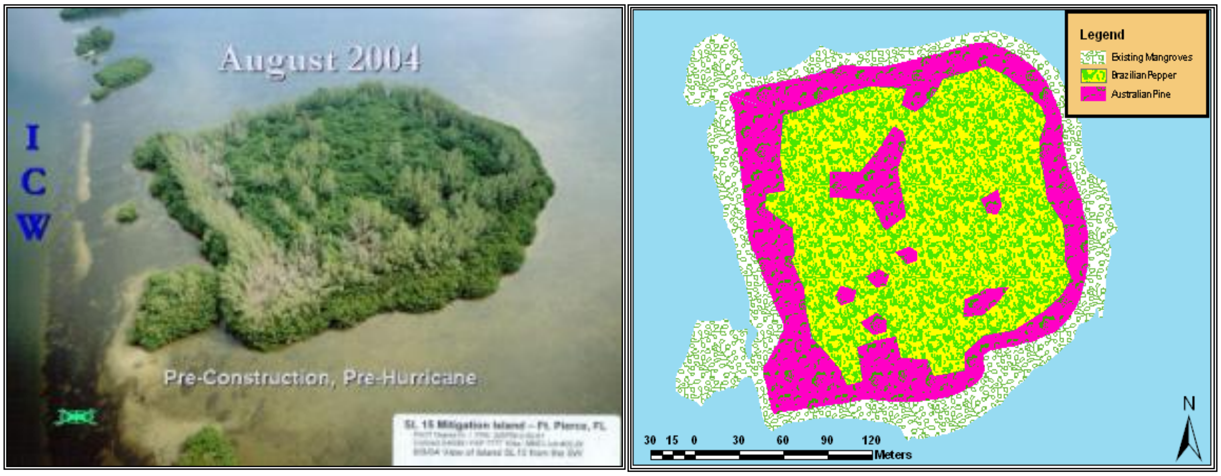


Figure A1. Arial photograph and species map of soil Island SL-15 prior to mitigation (Marcus et al. 2006).

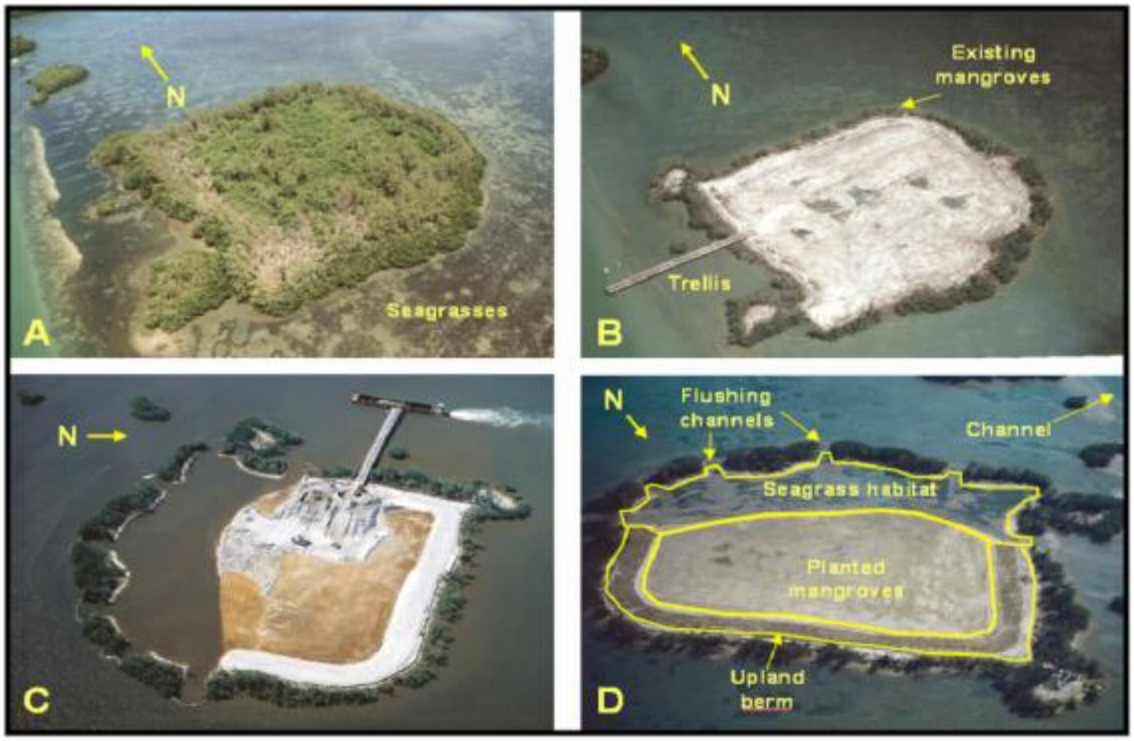


Figure A2. Transformation of SL15. Aerial photos taken in (A) June 2004, (B) May, 2005, (C) November, 2005, and (D) December,2005. The constructed seagrass, mangrove and upland habitats are shown by the yellow polygons (Fischler 2006).

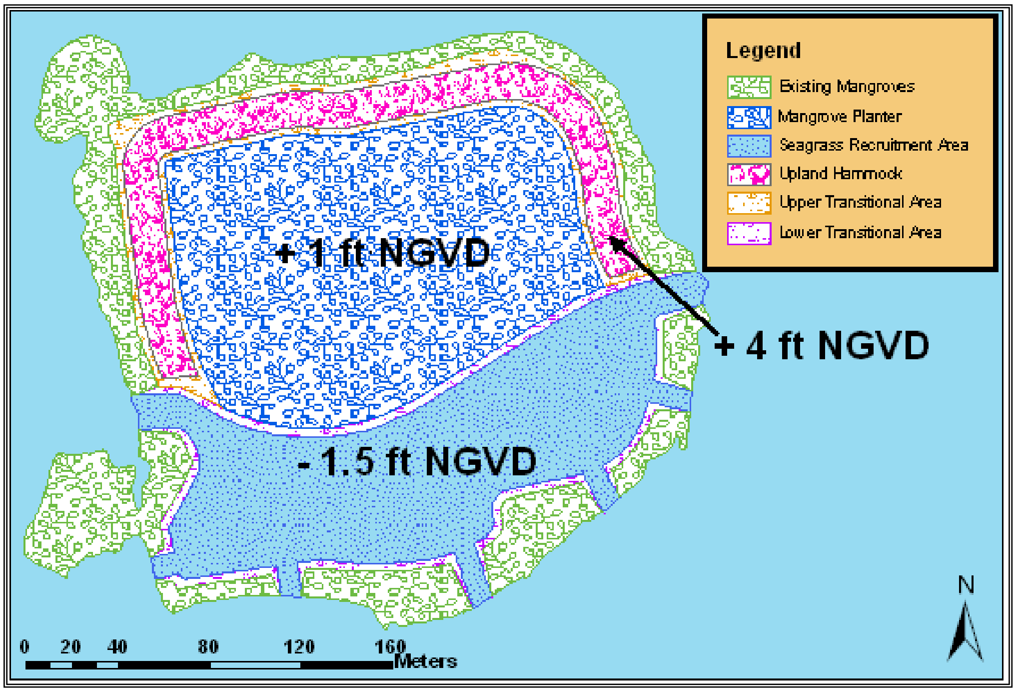


Figure A3. Elevations of the constructed seagrass, mangrove and upland habitats with the flushing channels (Marcus et al. 2006).

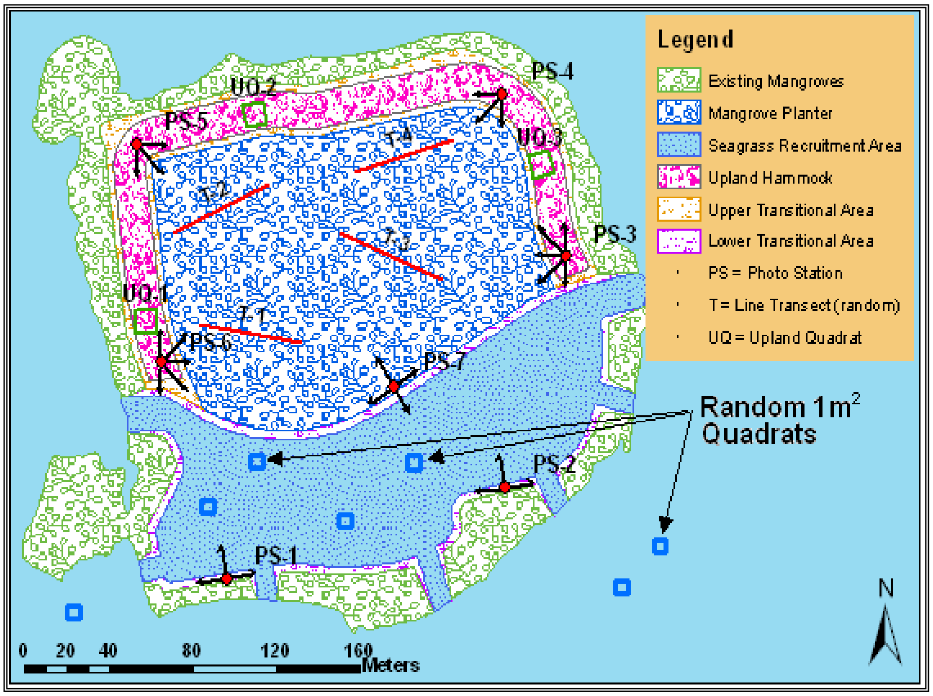


Figure A4. SL-15 post construction mangrove and seagrass monitoring locations (Marcus et al. 2006).

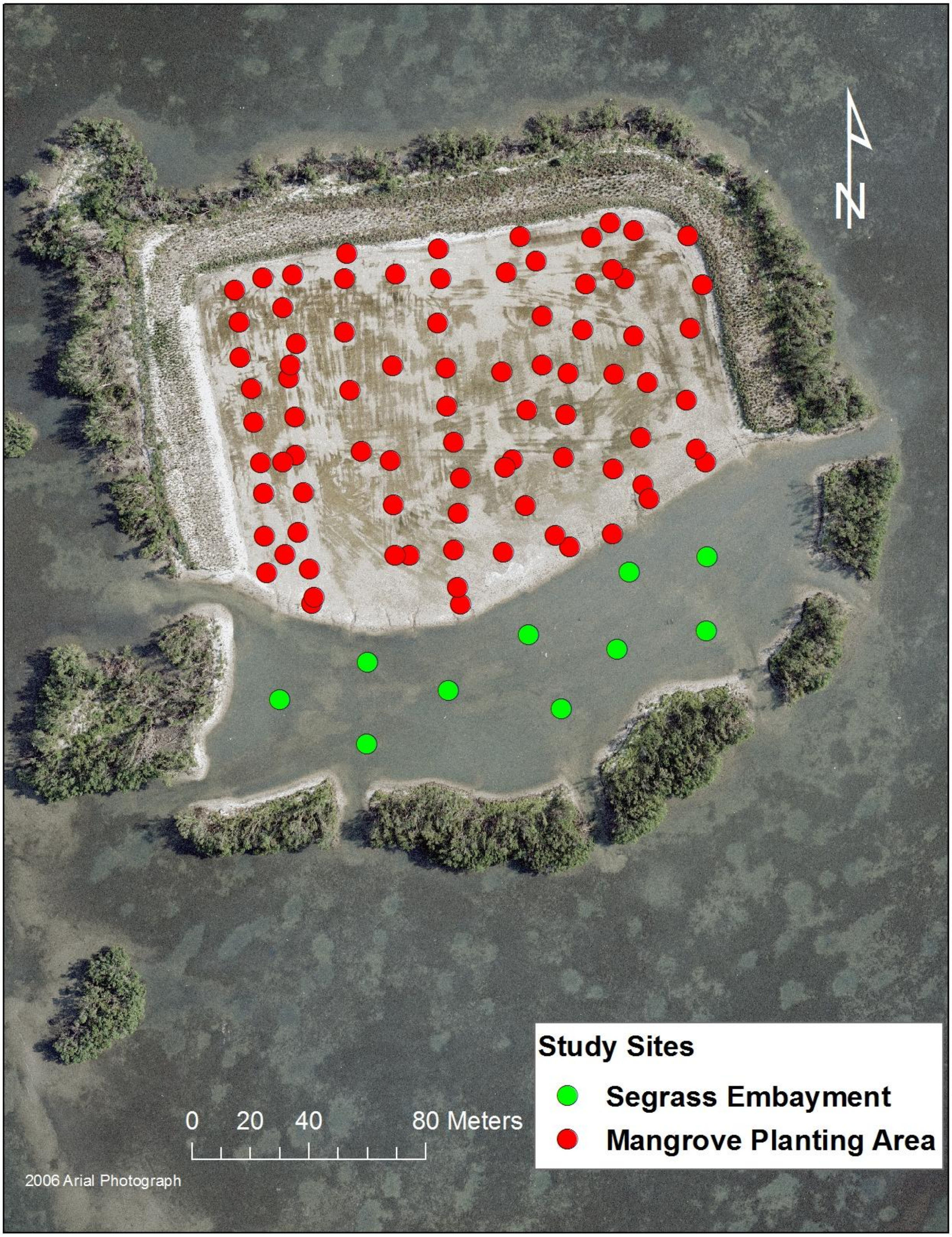


Figure A5. Study sites within the mangrove planting area and seagrass embayment.

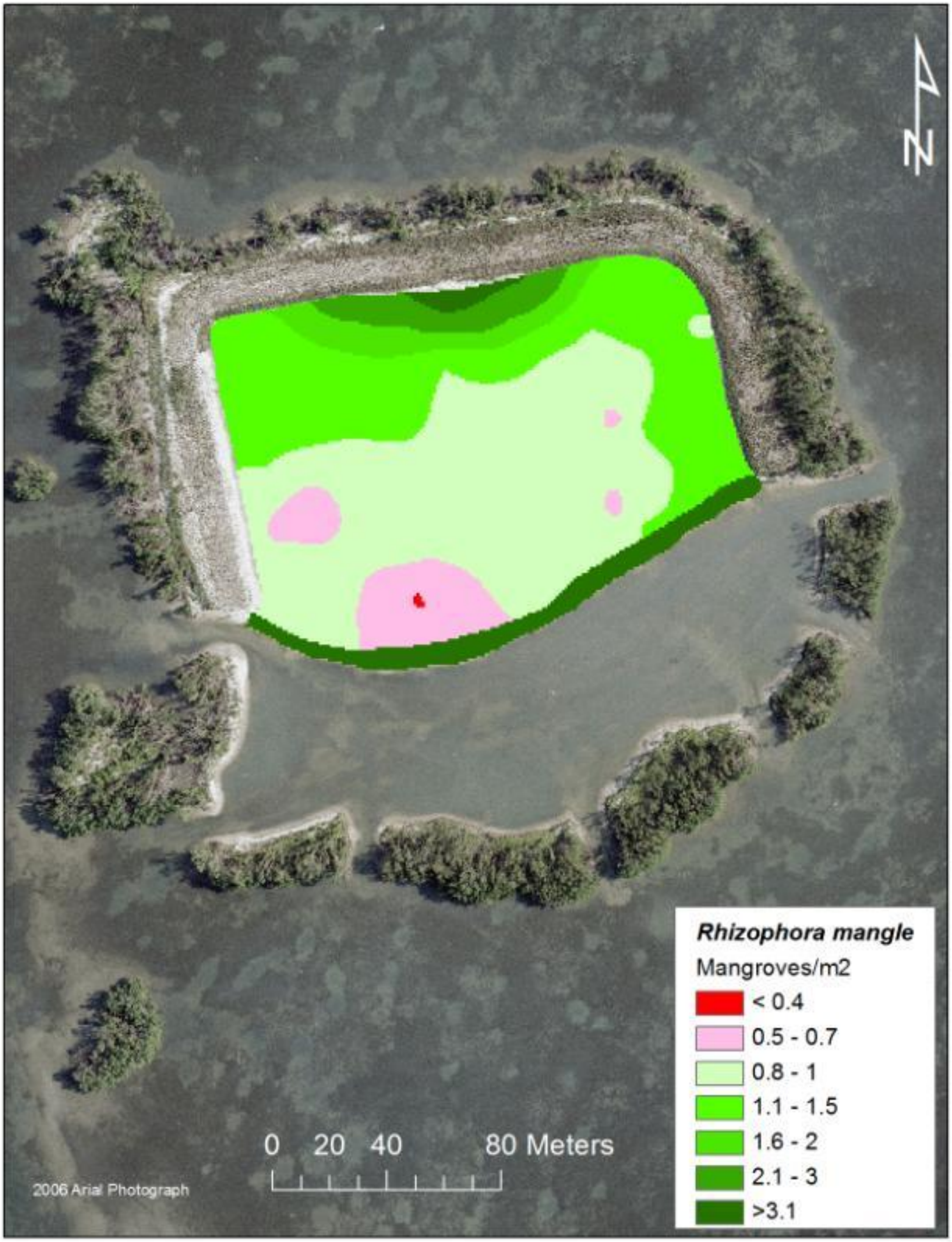


Figure A6. *R. mangle* density in the mangrove planter for summer 2009.

Figure A7. *R. mangle* density in the mangrove planter for winter 2009.

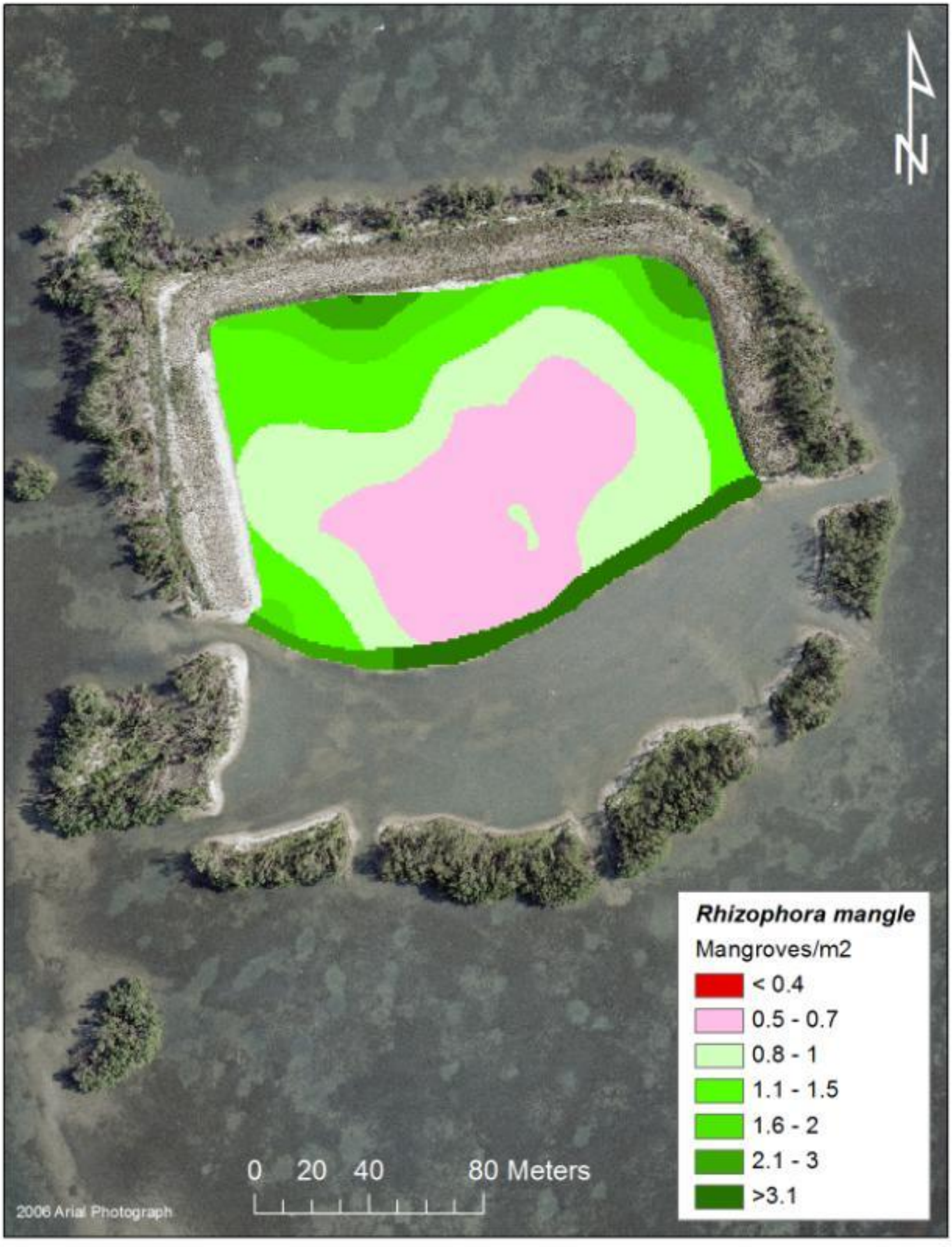


Figure A7. *R. mangle* density in the mangrove planter for winter 2009.

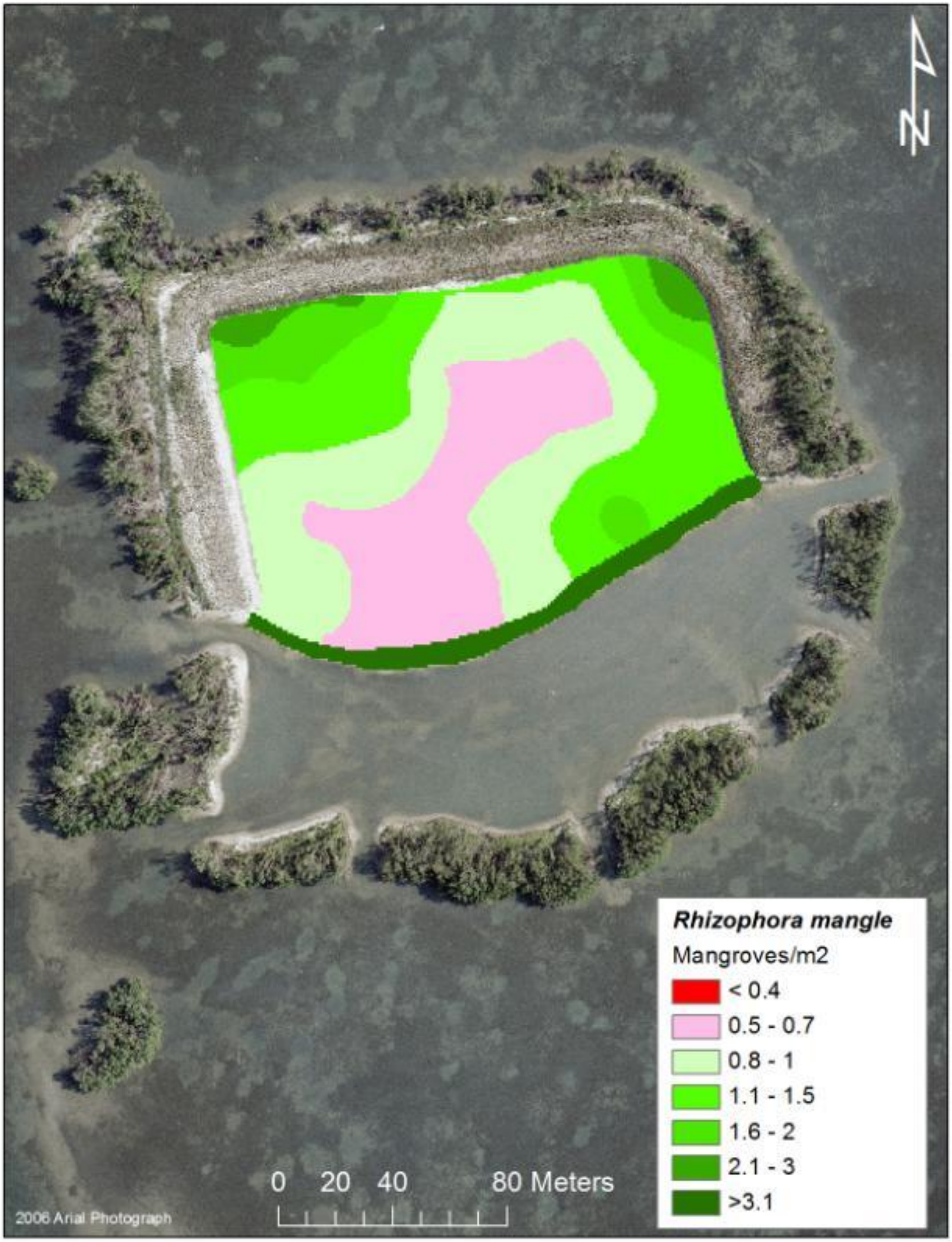


Figure A8. *R. mangle* density in the mangrove planter for summer 2010.

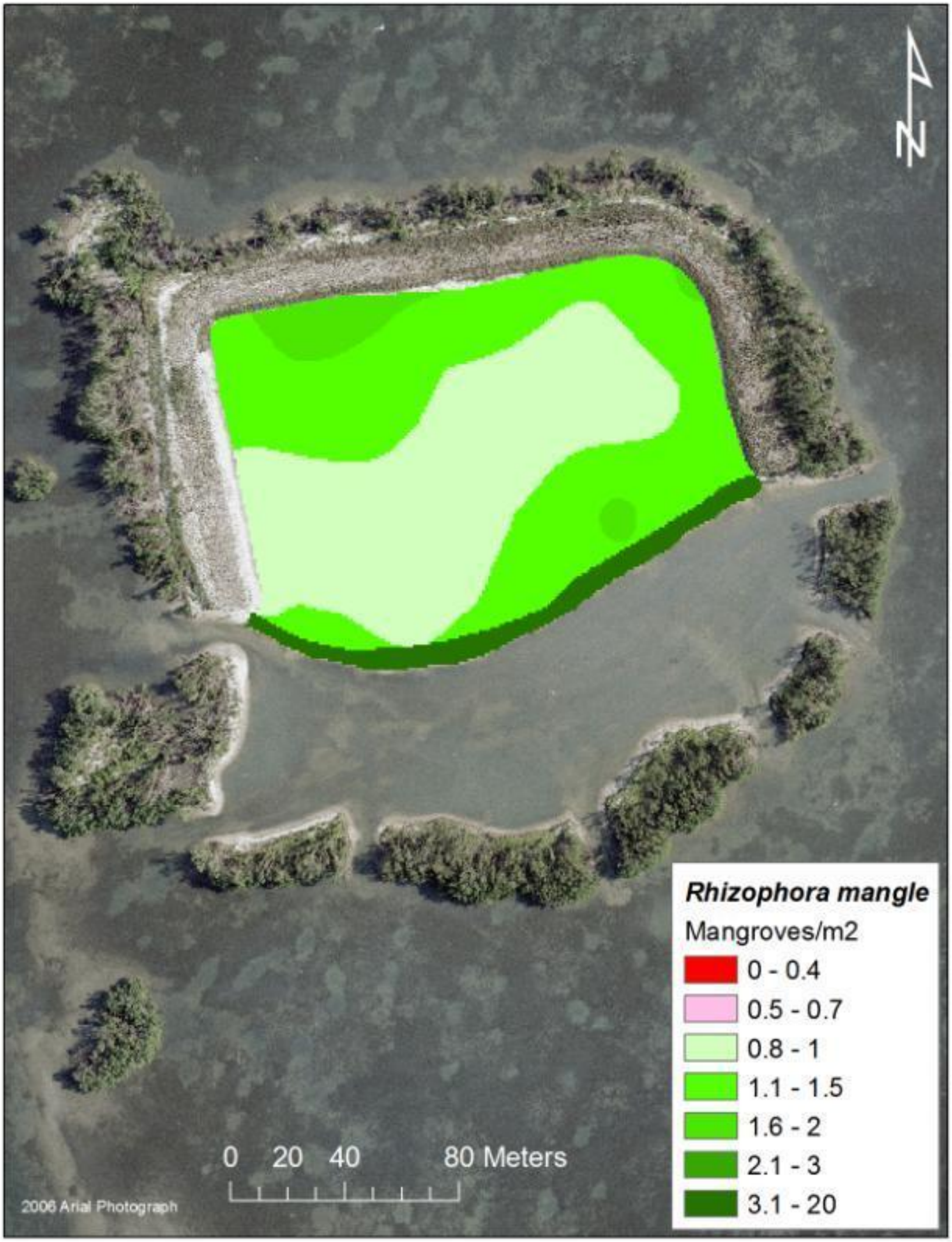


Figure A9. *R. mangle* density in the mangrove planter for winter 2010.

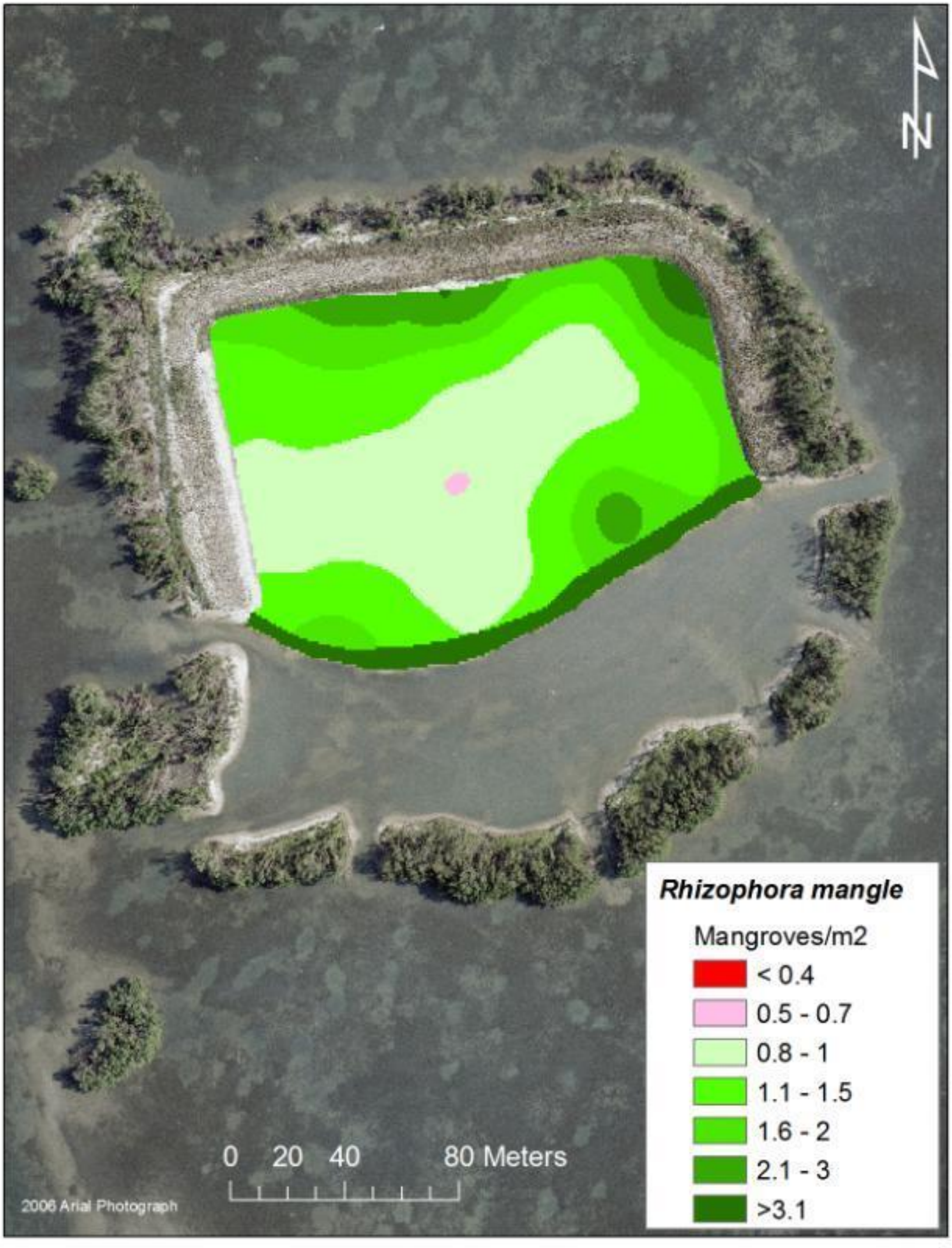


Figure A10. *R. mangle* density in the mangrove planter for summer 2011.

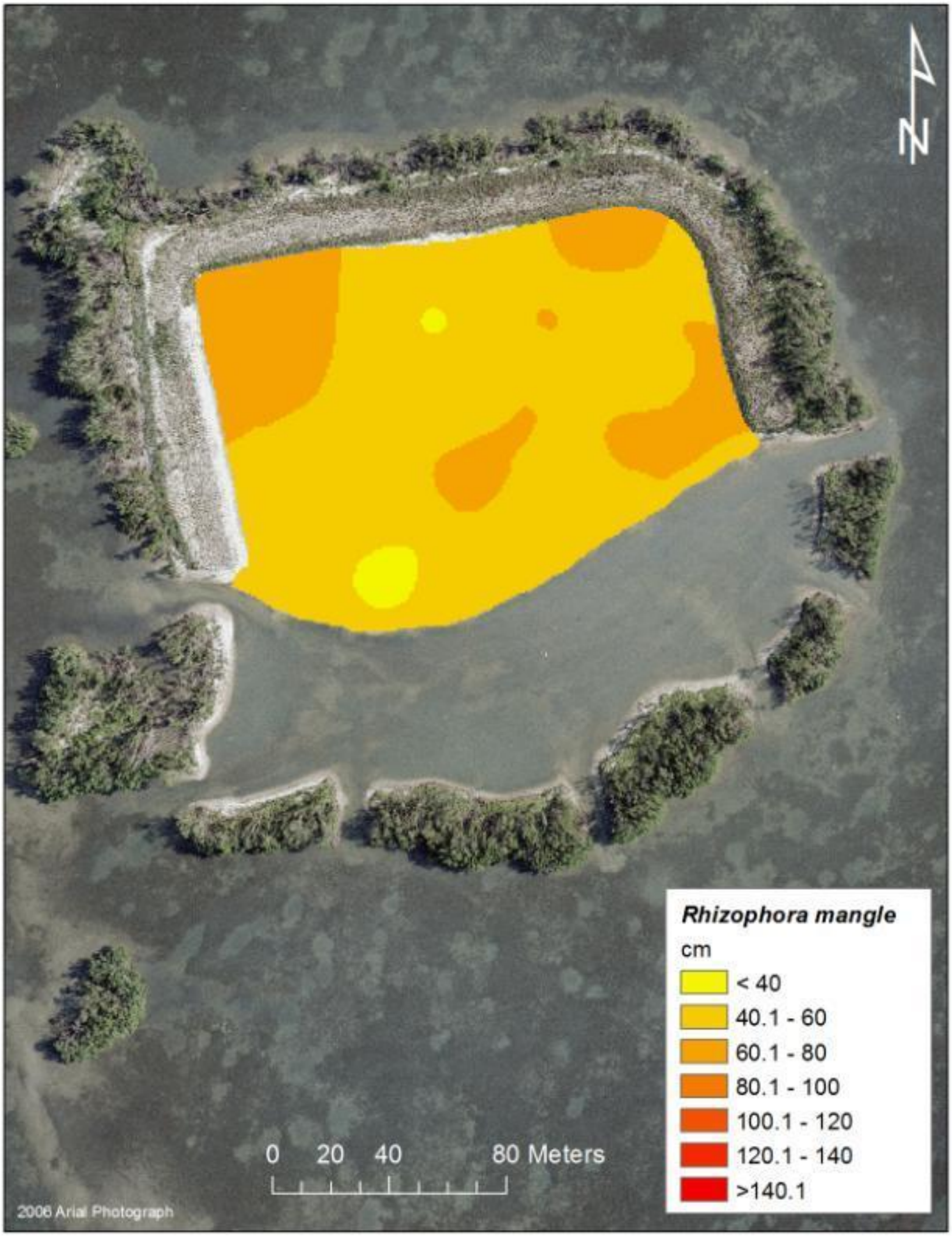


Figure A11. *R. mangle* average mangrove height in summer 2009.

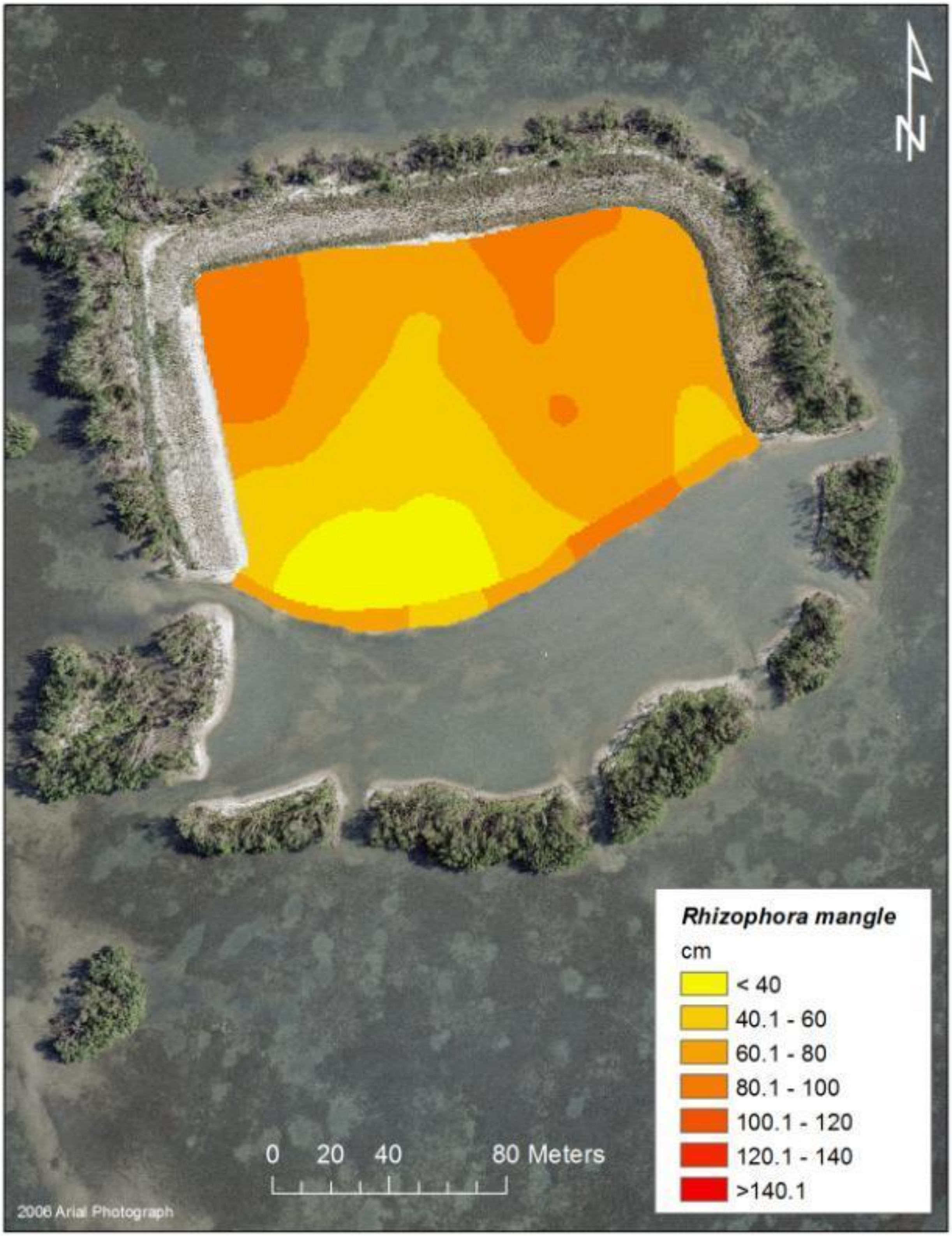


Figure A12. *R. mangle* average mangrove height in winter 2009.

Figure A13. *R. mangle* average mangrove height in summer 2010.

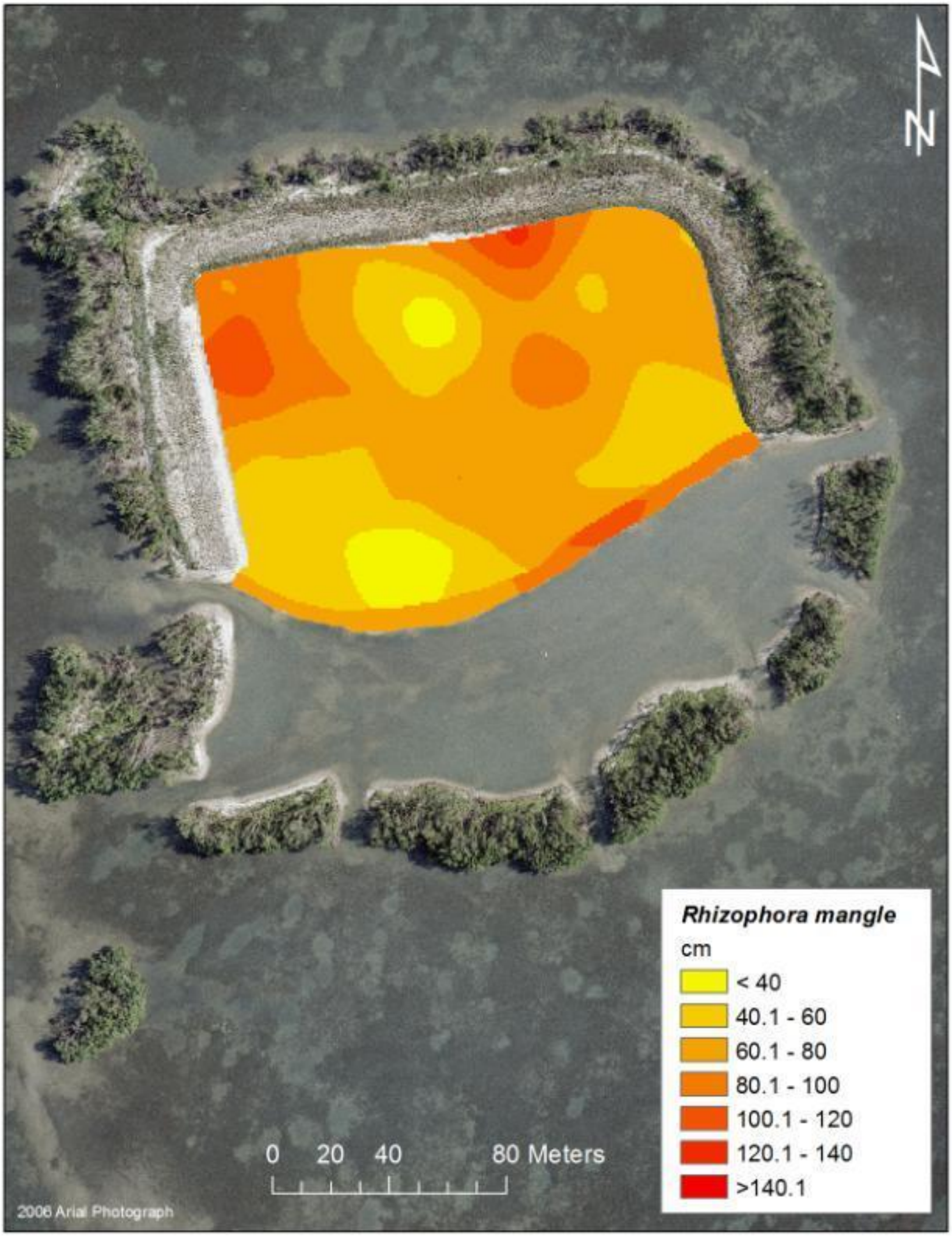


Figure A14. *R. mangle* average mangrove height in winter 2010.

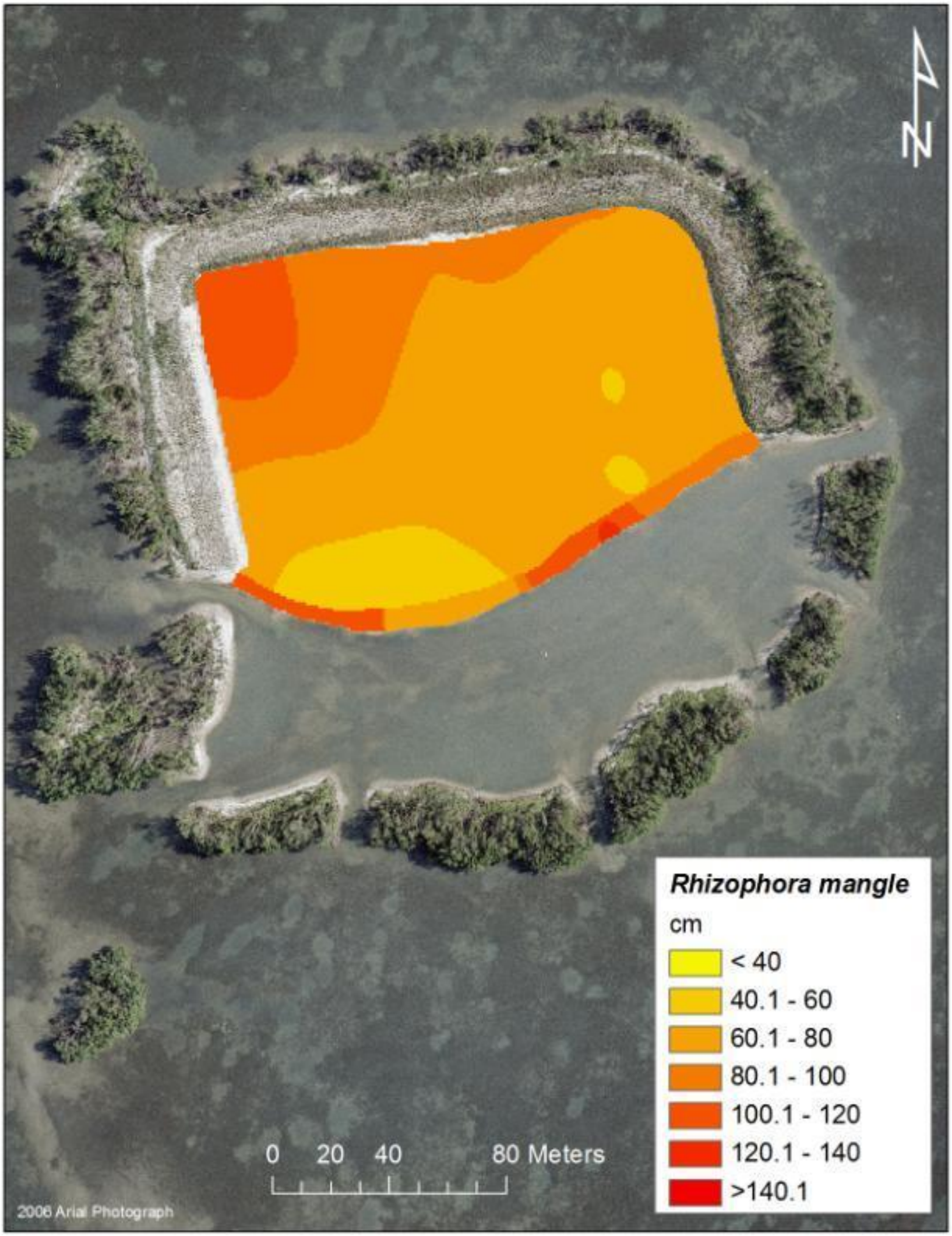


Figure A14. *R. mangle* average mangrove height in winter 2010.

Figure A15. *R. mangle* average mangrove height in summer 2011.

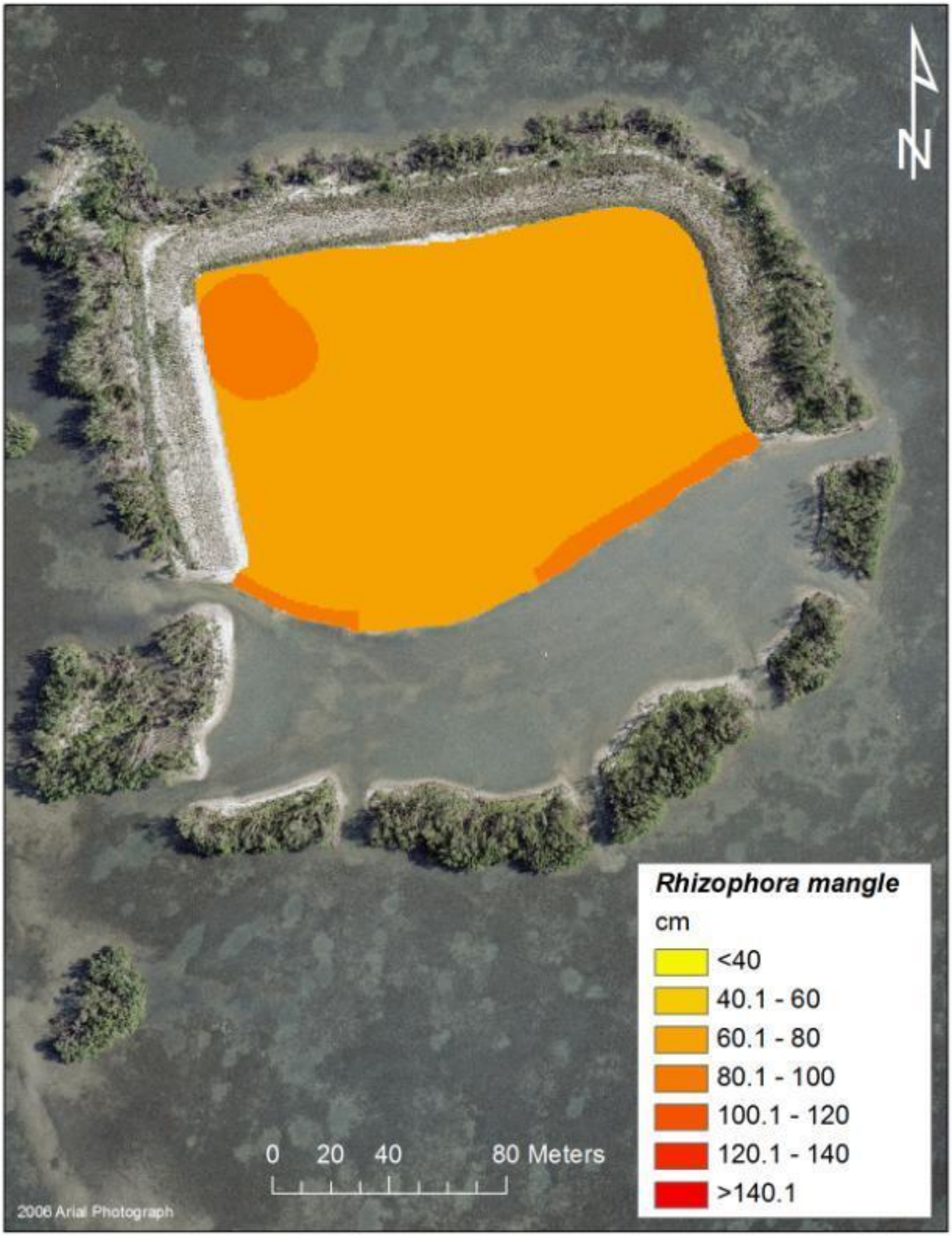


Figure A15. *R. mangle* average mangrove height in summer 2011.

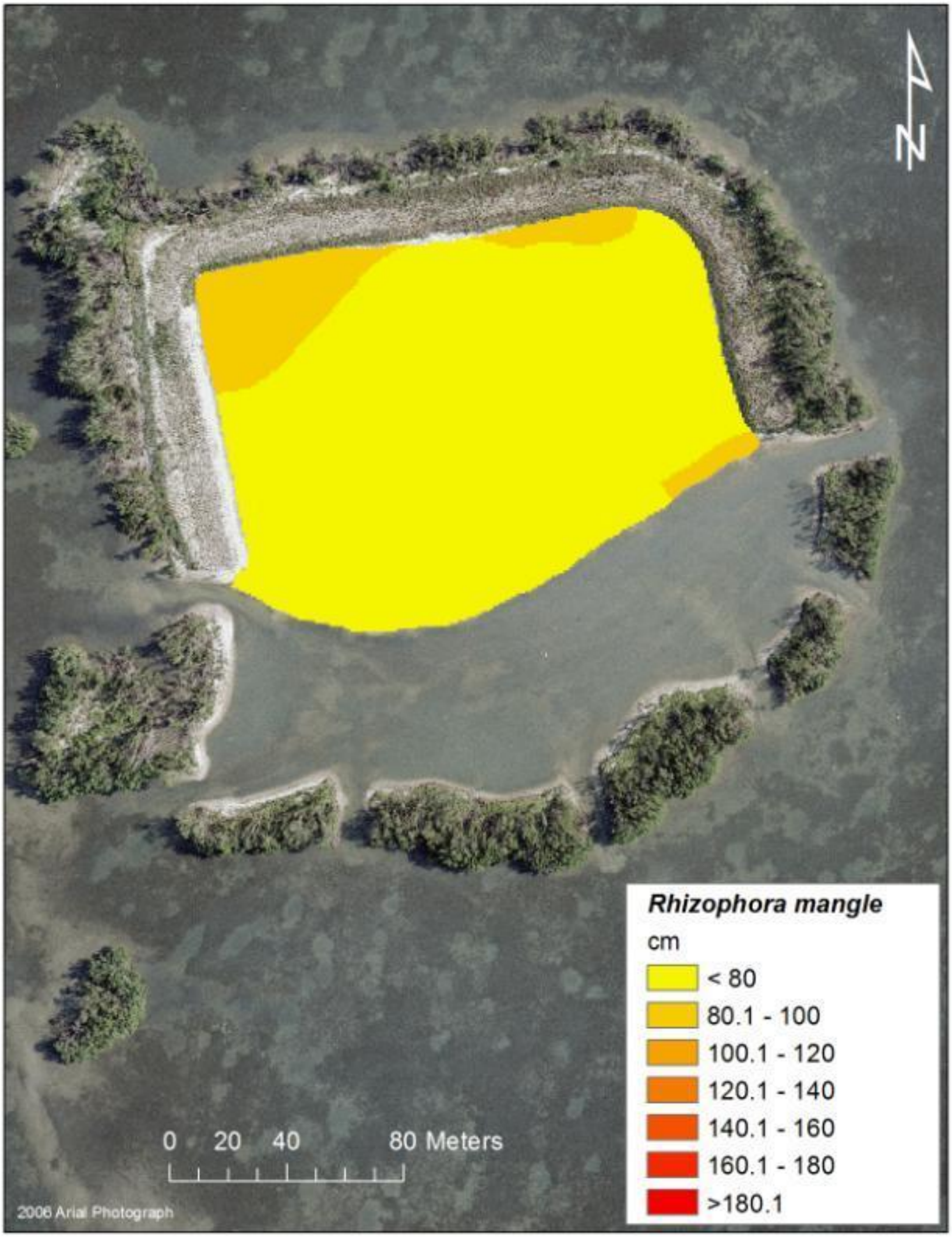
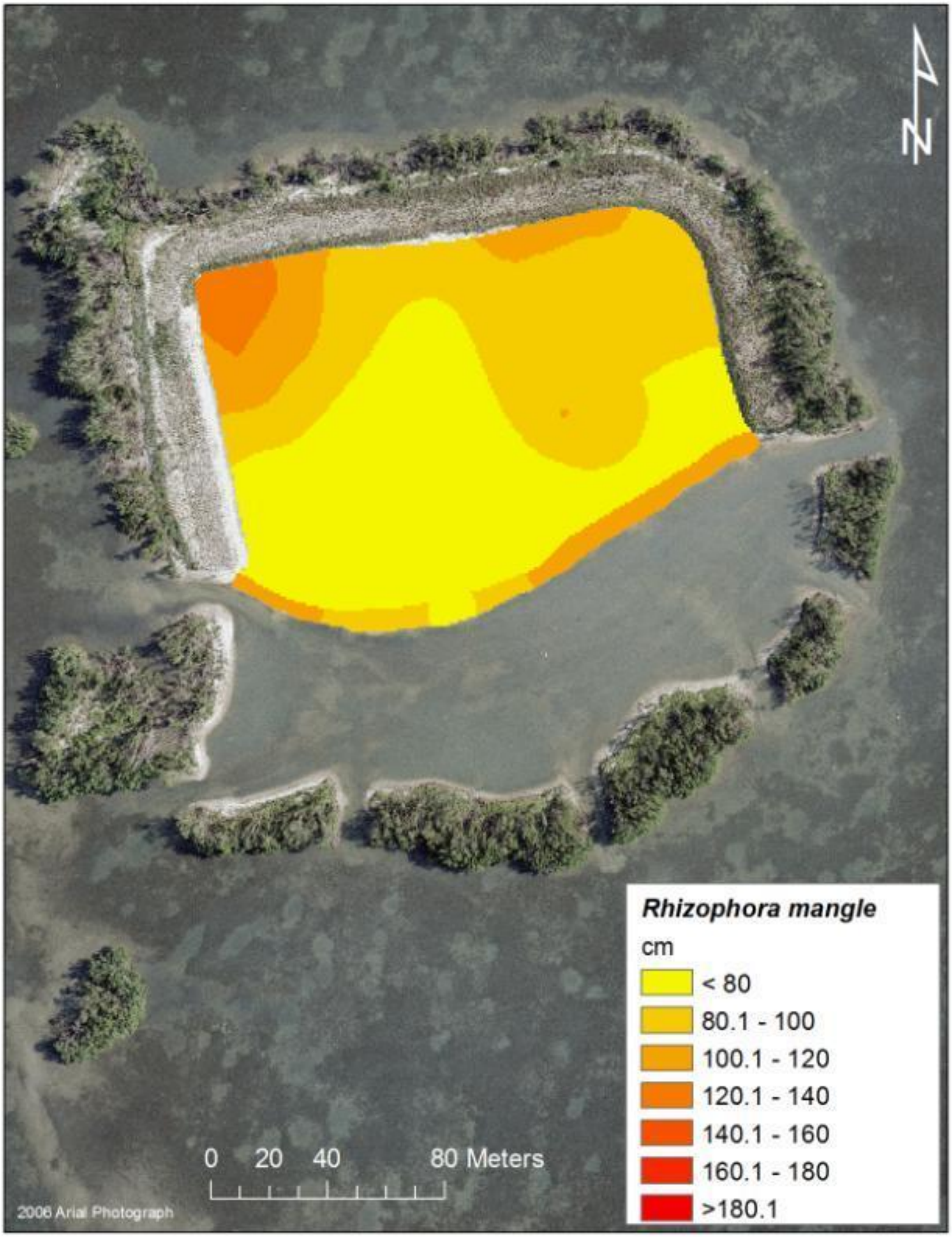


Figure A16. *R. mangle* maximum mangrove height in summer 2009.

Figure A17. *R. mangle* maximum mangrove height in winter 2009.



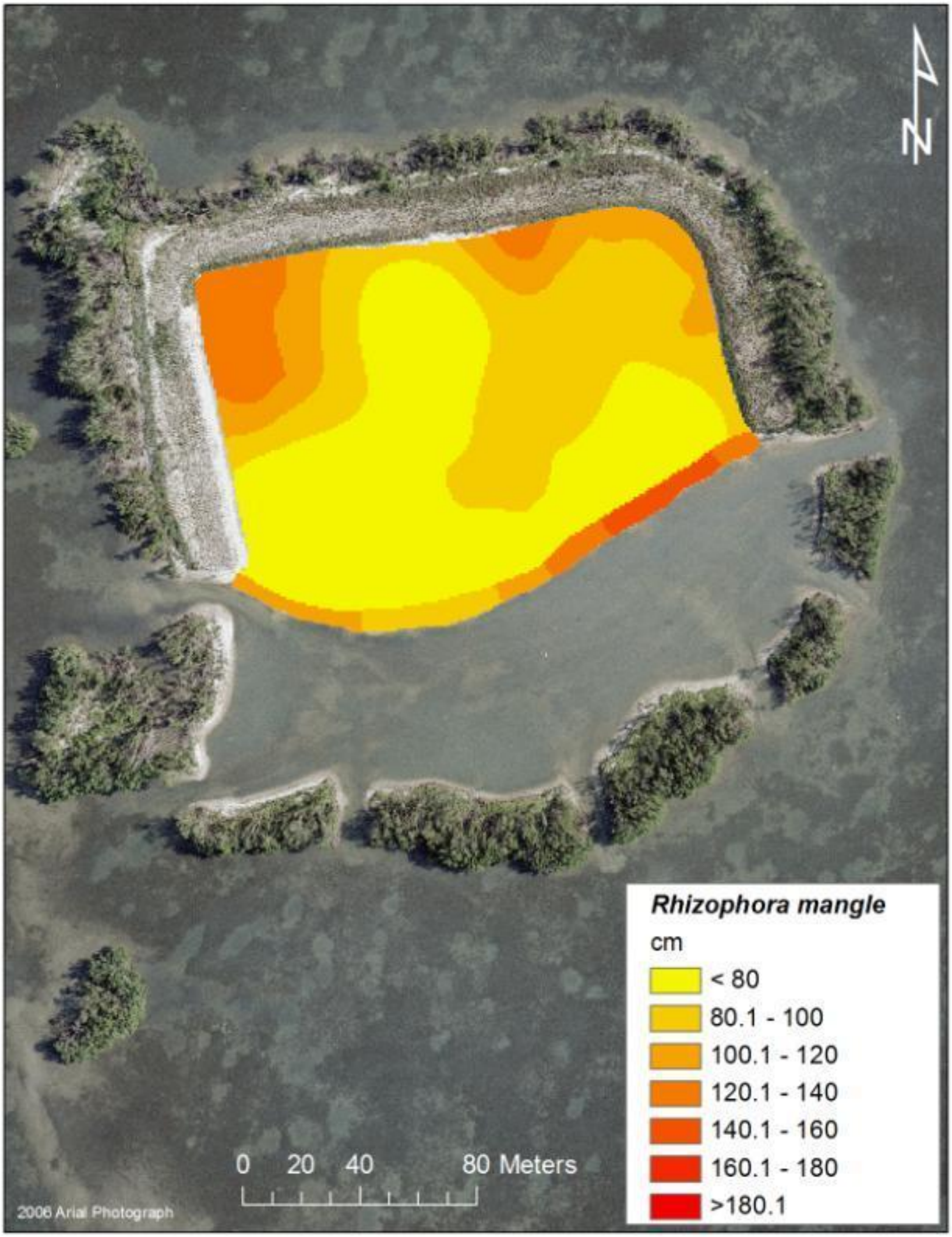


Figure A18. *R. mangle* maximum mangrove height in summer 2010.

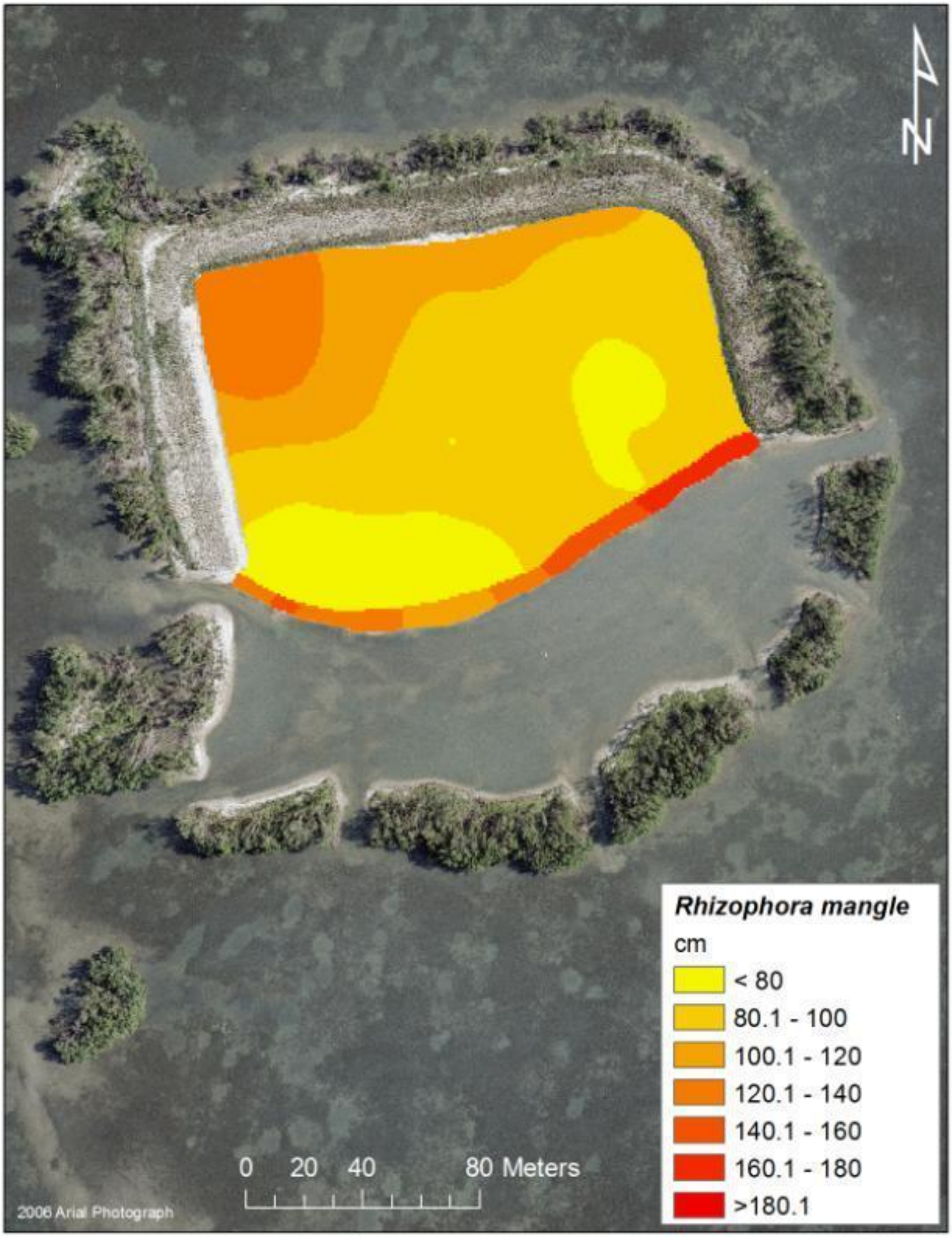


Figure A19. *R. mangle* maximum mangrove height in winter 2010.

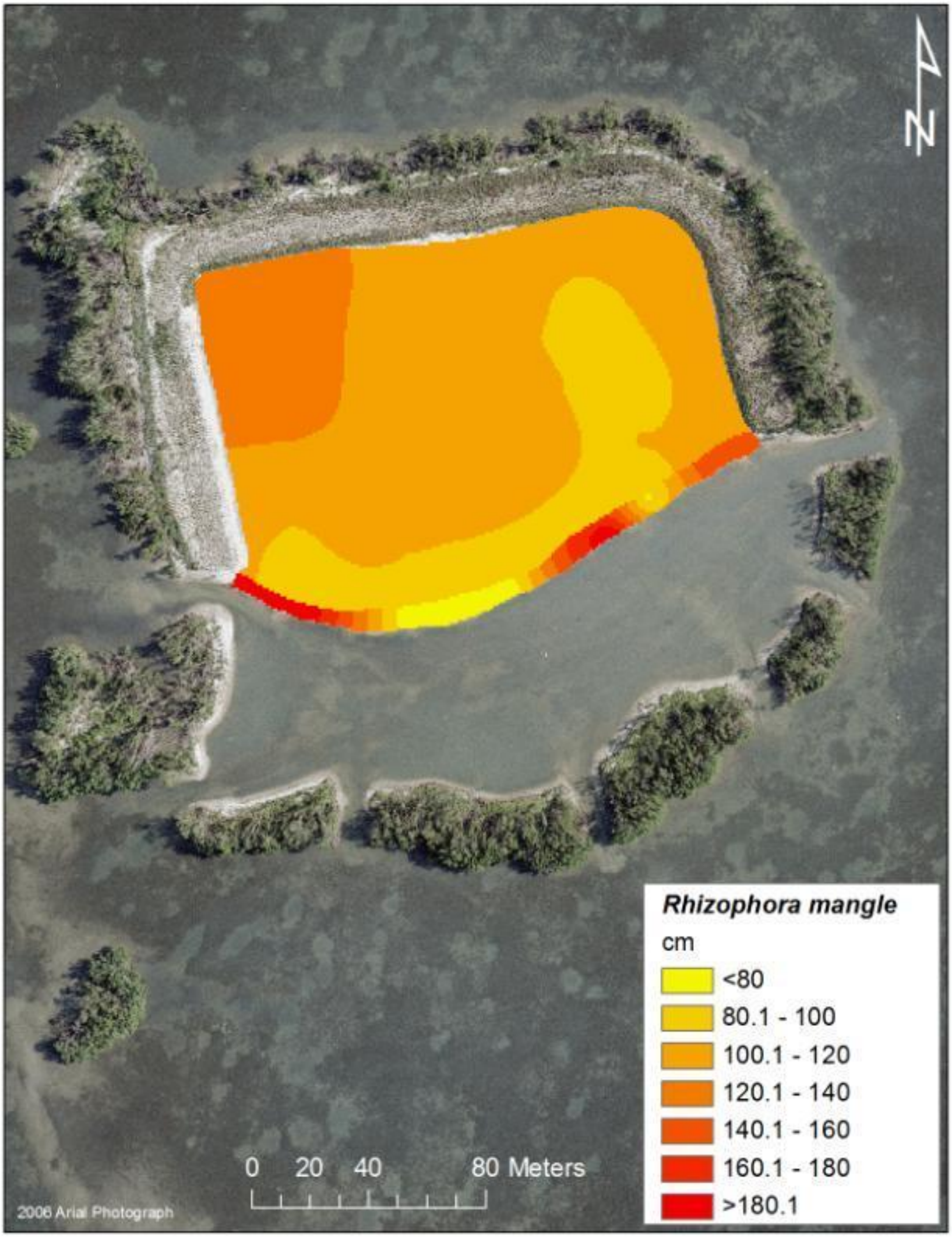


Figure A20. *R. mangle* maximum mangrove height in summer 2011.

Figure A21. *R.mangle* calculated canopy area/m2 for summer 2011.

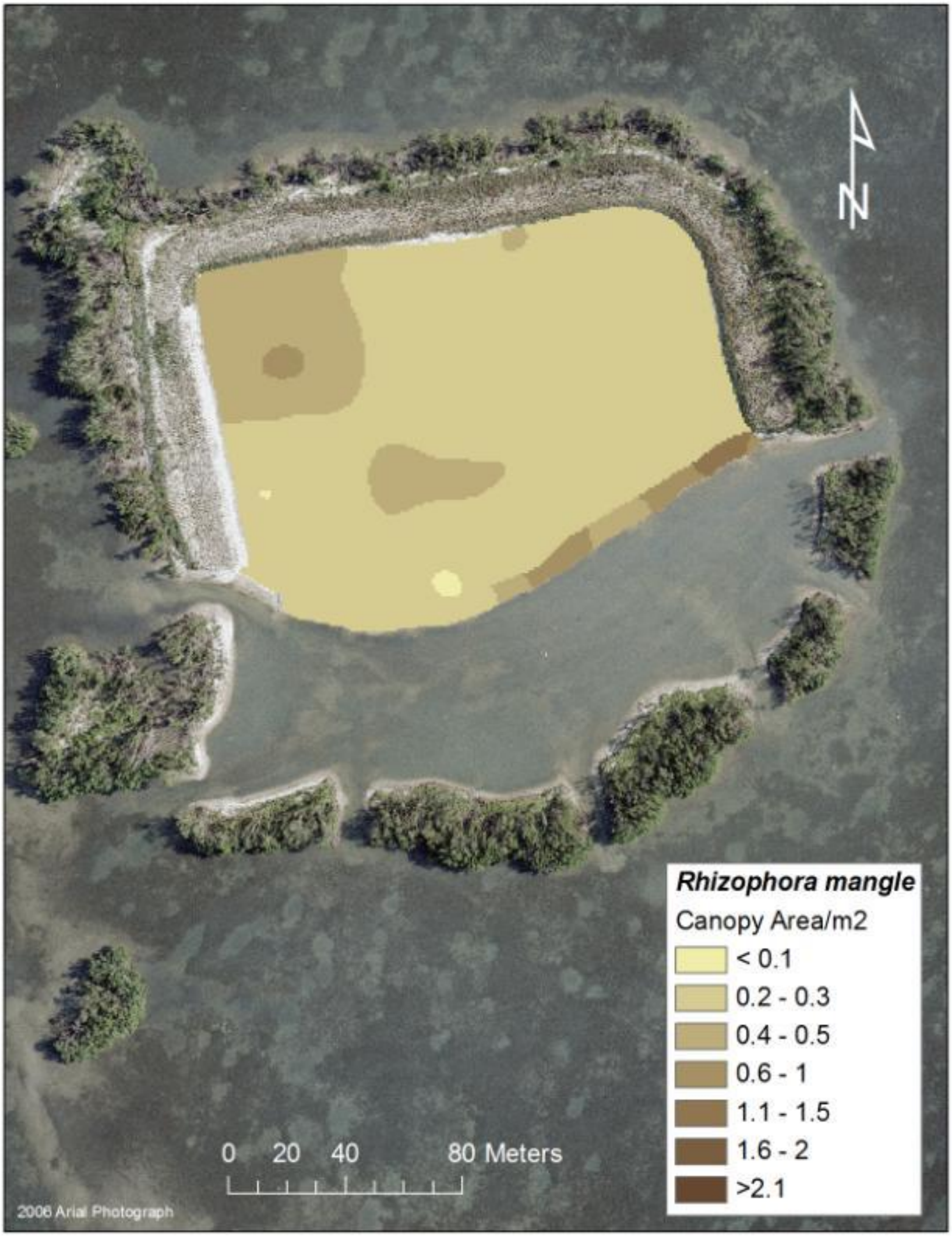


Figure A21. *R.mangle* calculated canopy area/m2 for summer 2011.

Figure A22. *R.mangle* calculated volume area/m3 for summer 2011.

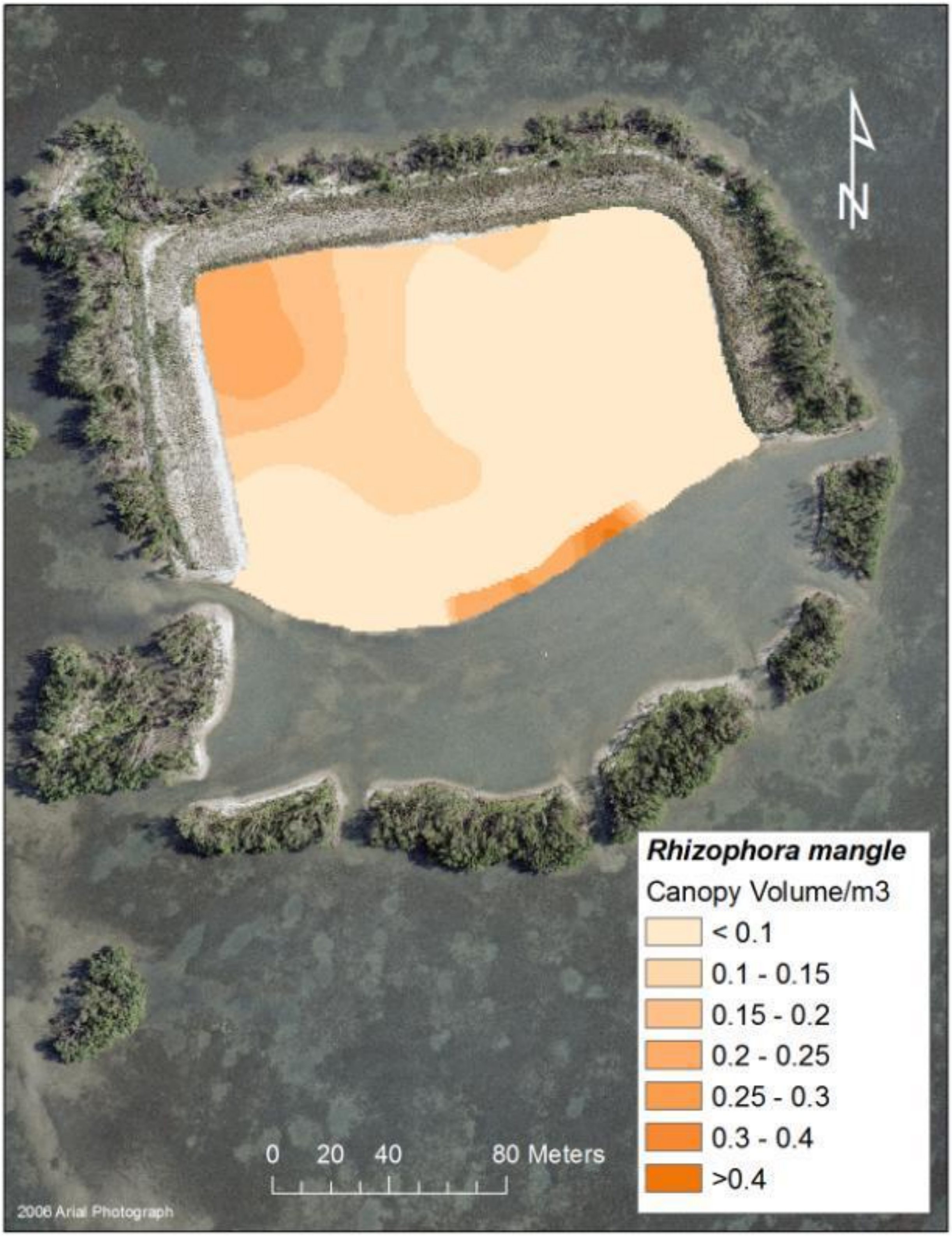


Figure A23. *R. mangle* juvenile new recruits in summer 2011.

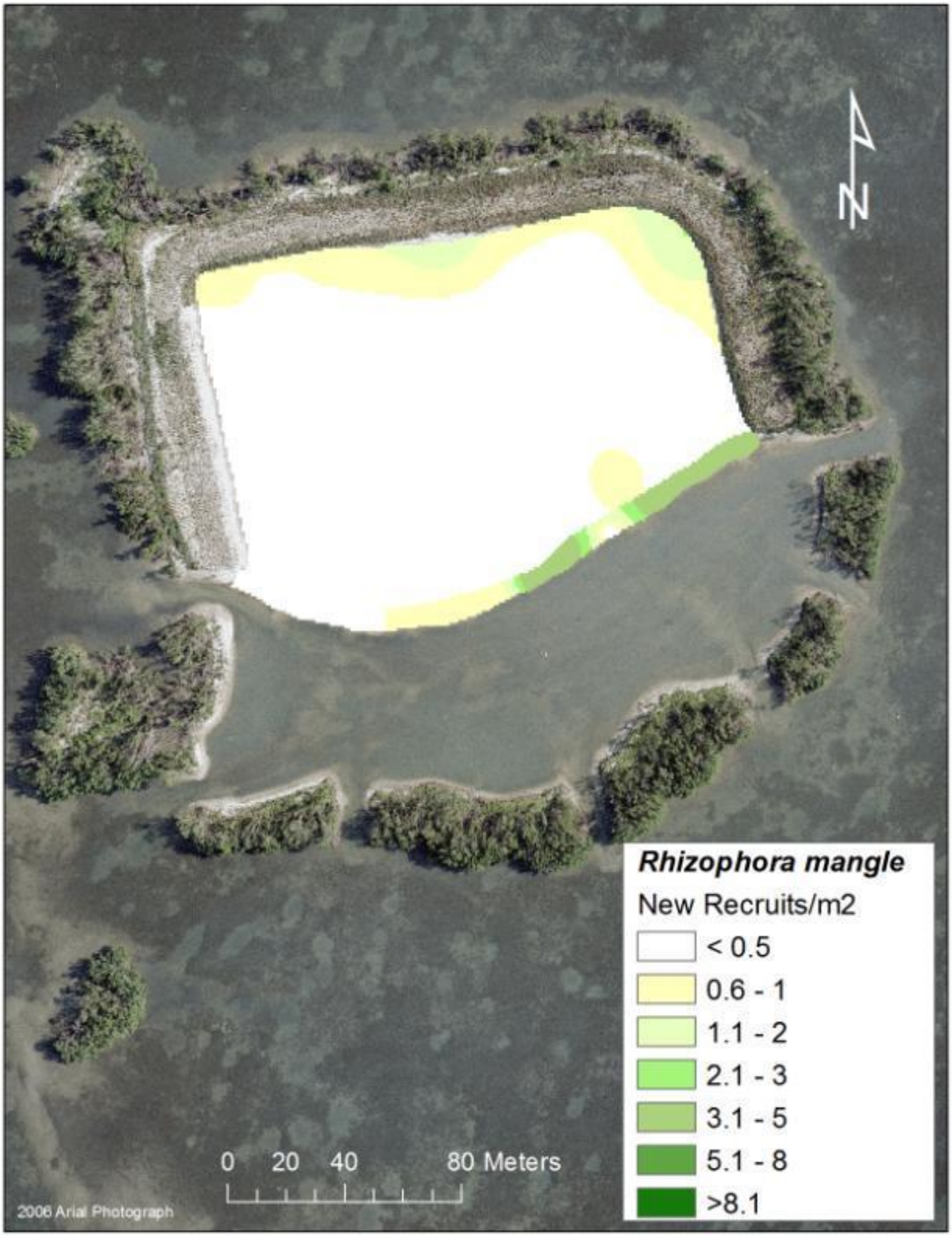


Figure A23. *R. mangle* juvenile new recruits in summer 2011.

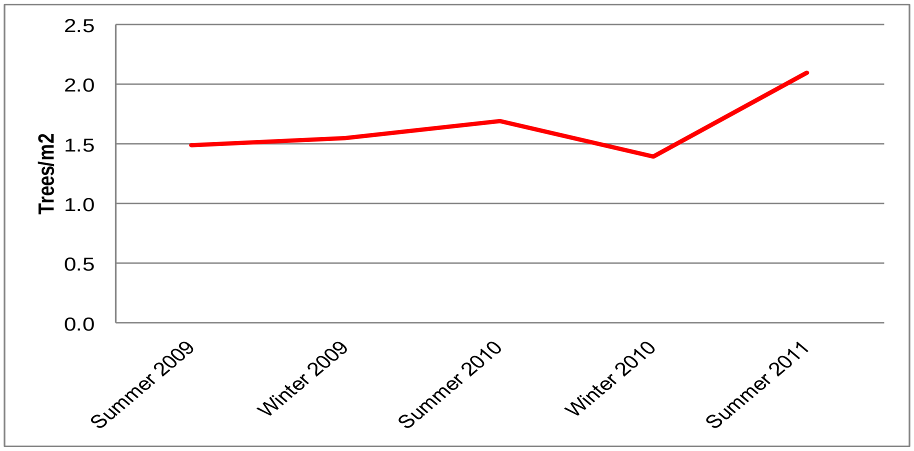


Figure A24. Average *R. mangle* density (trees/m2) from summer 2009 to summer2011.

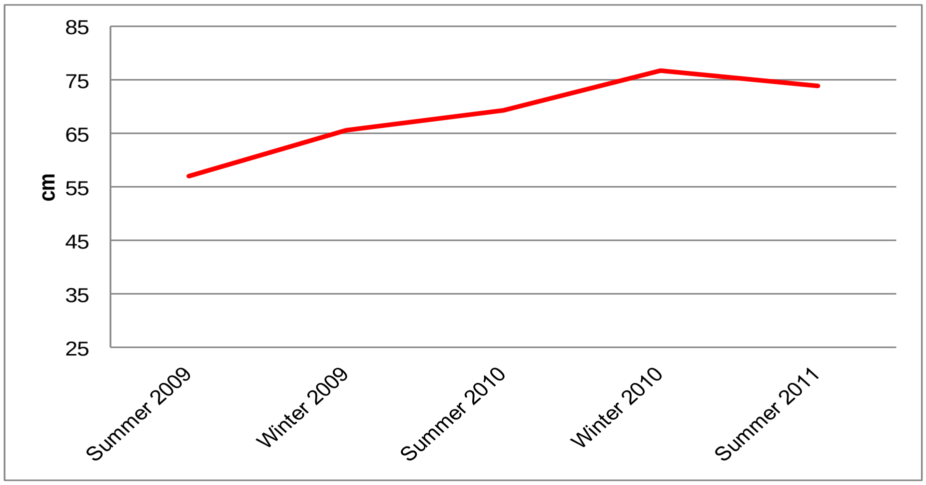


Figure A25. Average *R. mangle* height from summer 2009 to summer2011.

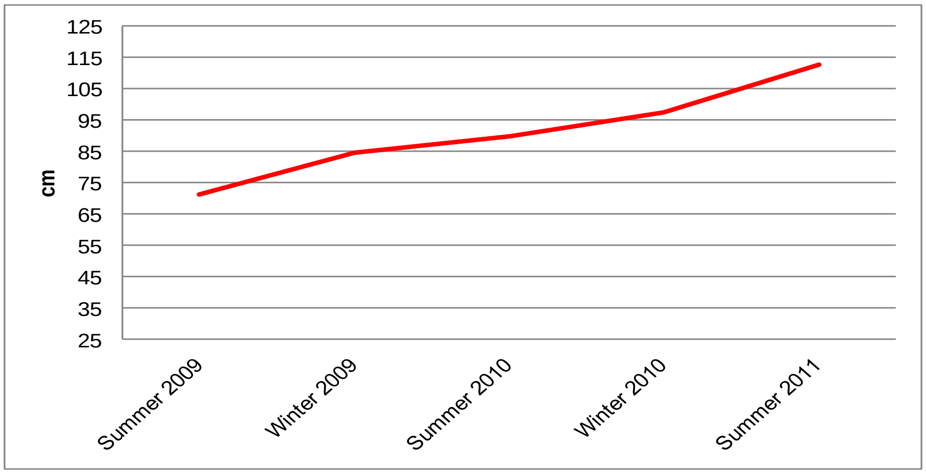


Figure A26. Average *R. mangle* maximum height from summer 2009 to summer2011.

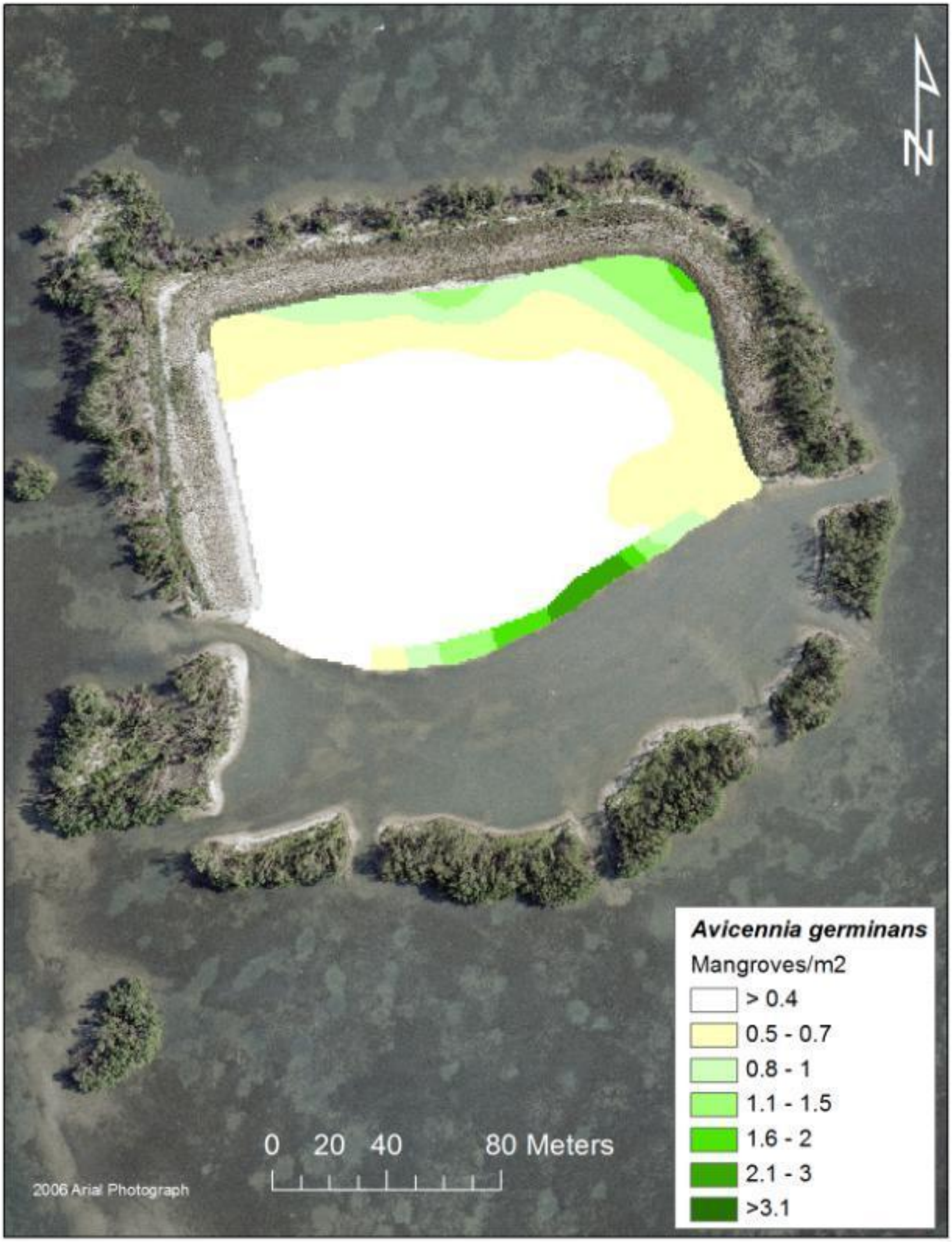


Figure A27. *A. germinans* density in the mangrove planter for summer 2009.

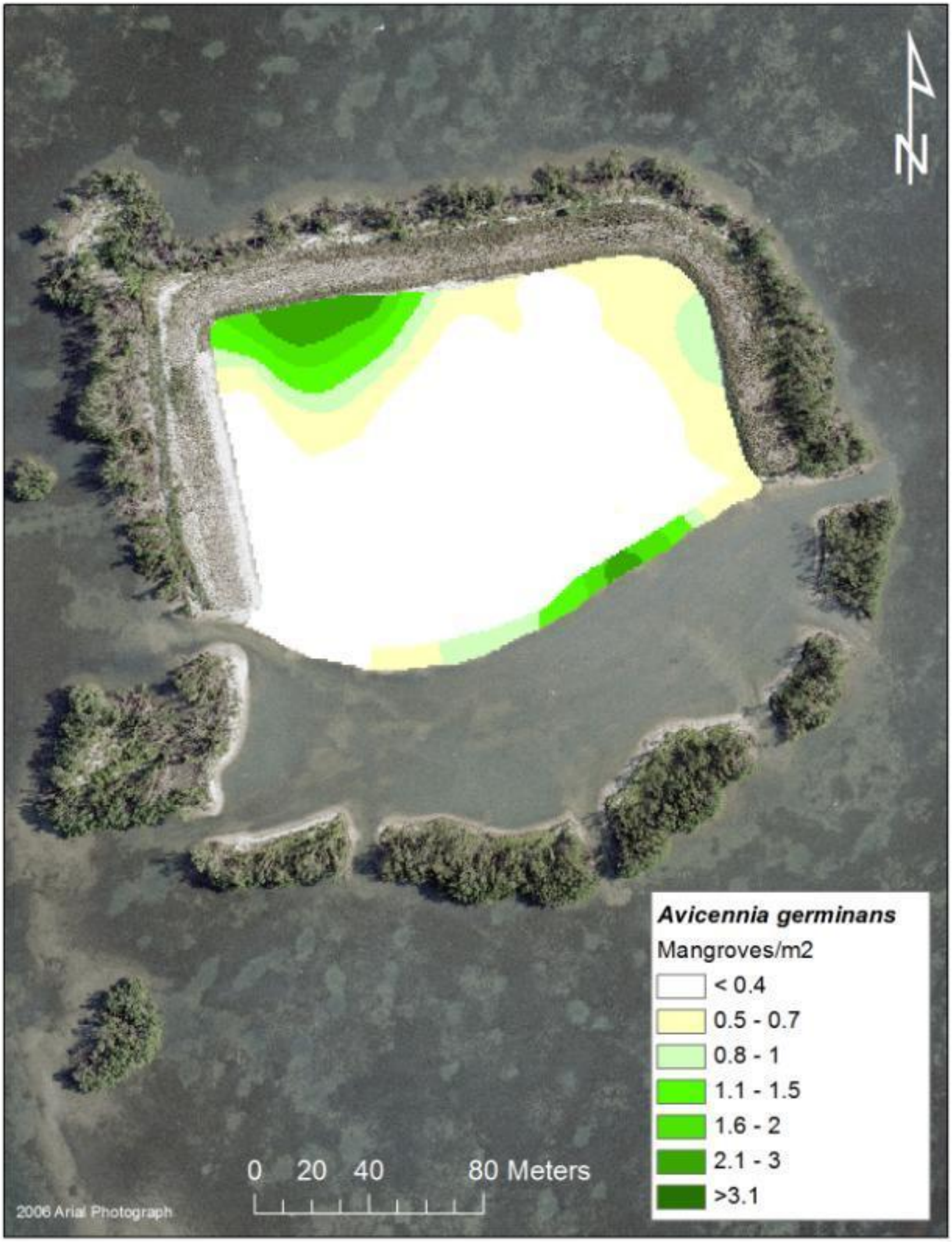


Figure A28. *A. germinans* density in the mangrove planter for winter 2009.

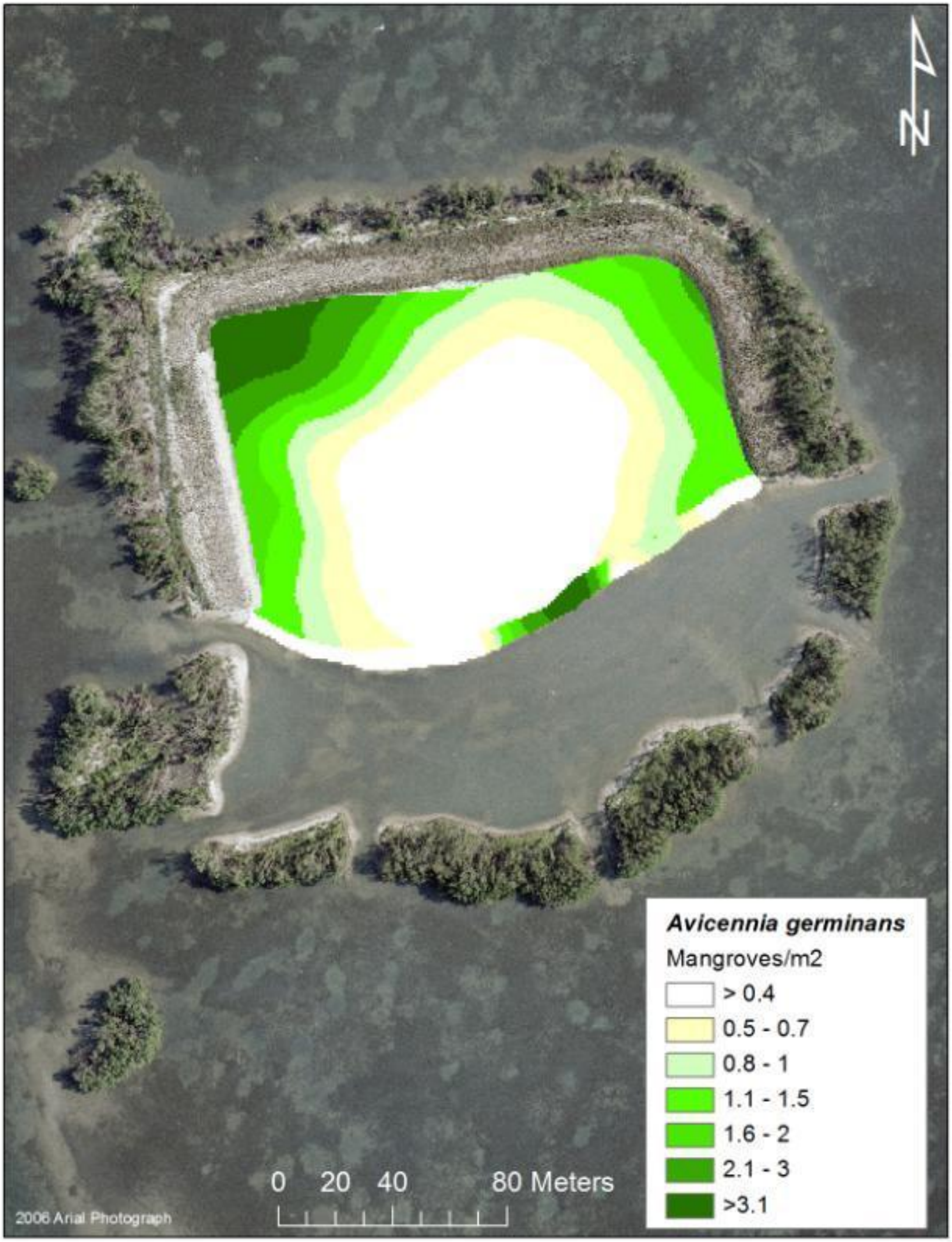


Figure A29. *A. germinans* density in the mangrove planter for summer 2010.

Figure A30. *A. germinans* density in the mangrove planter for winter 2010.

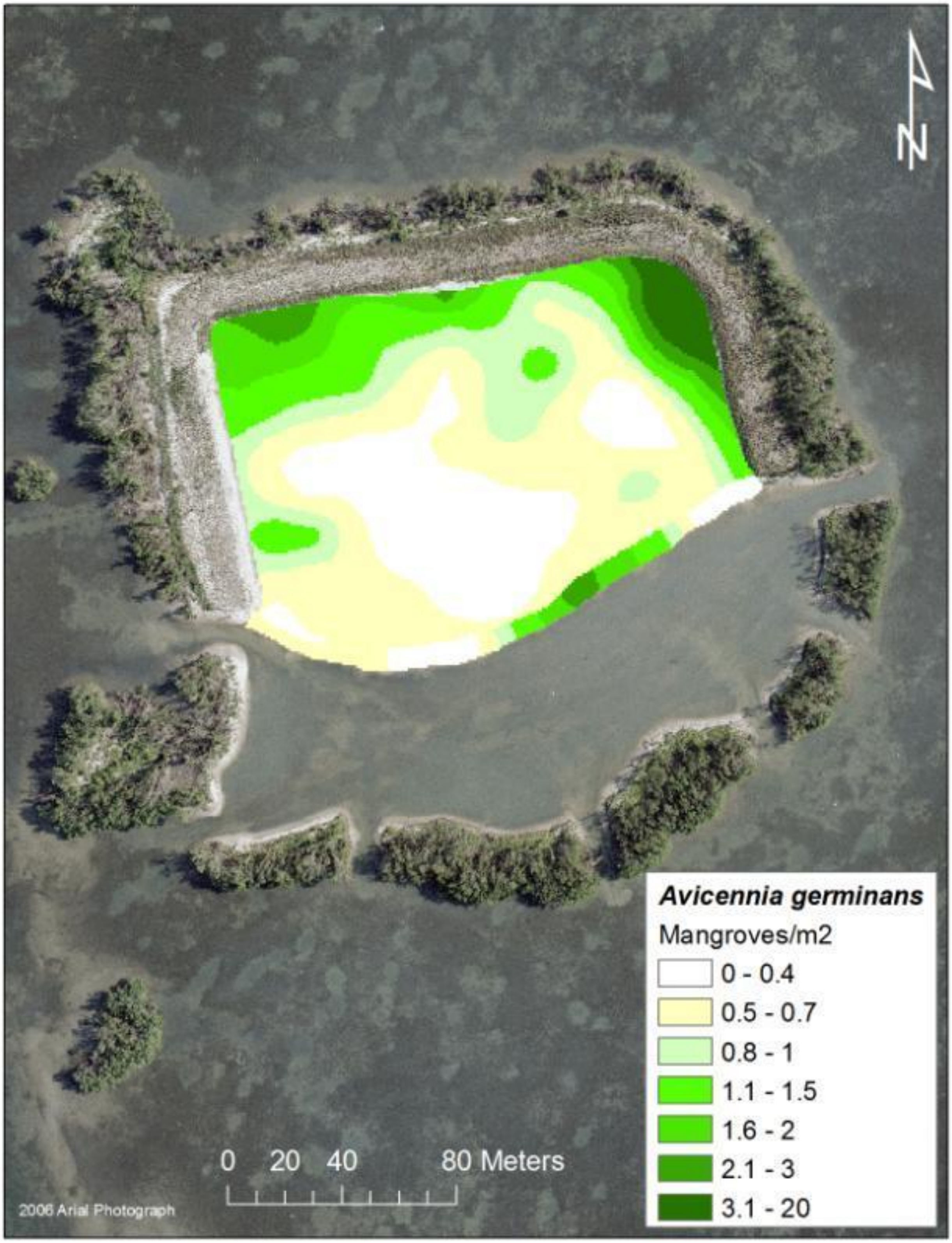


Figure A30. *A. germinans* density in the mangrove planter for winter 2010.

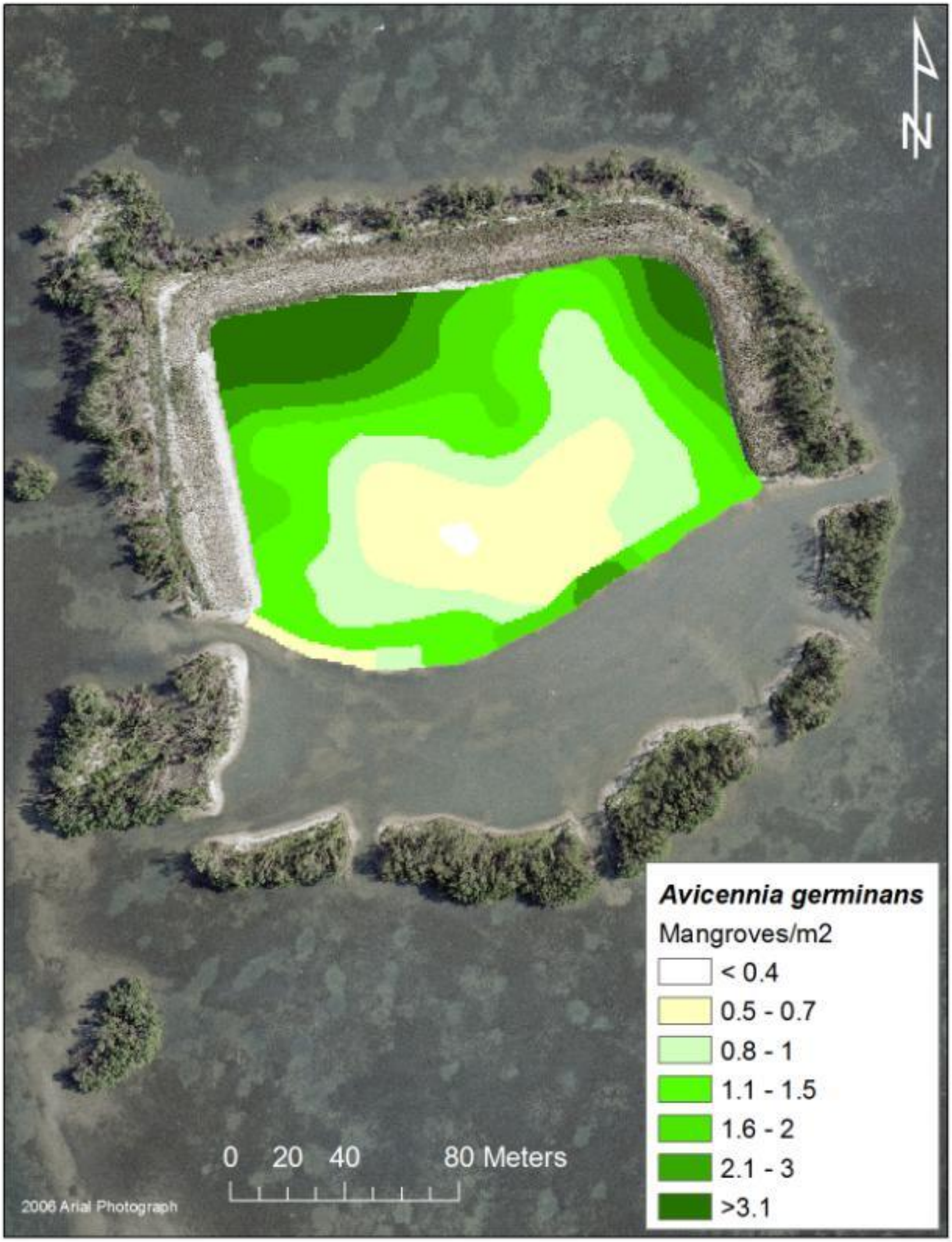
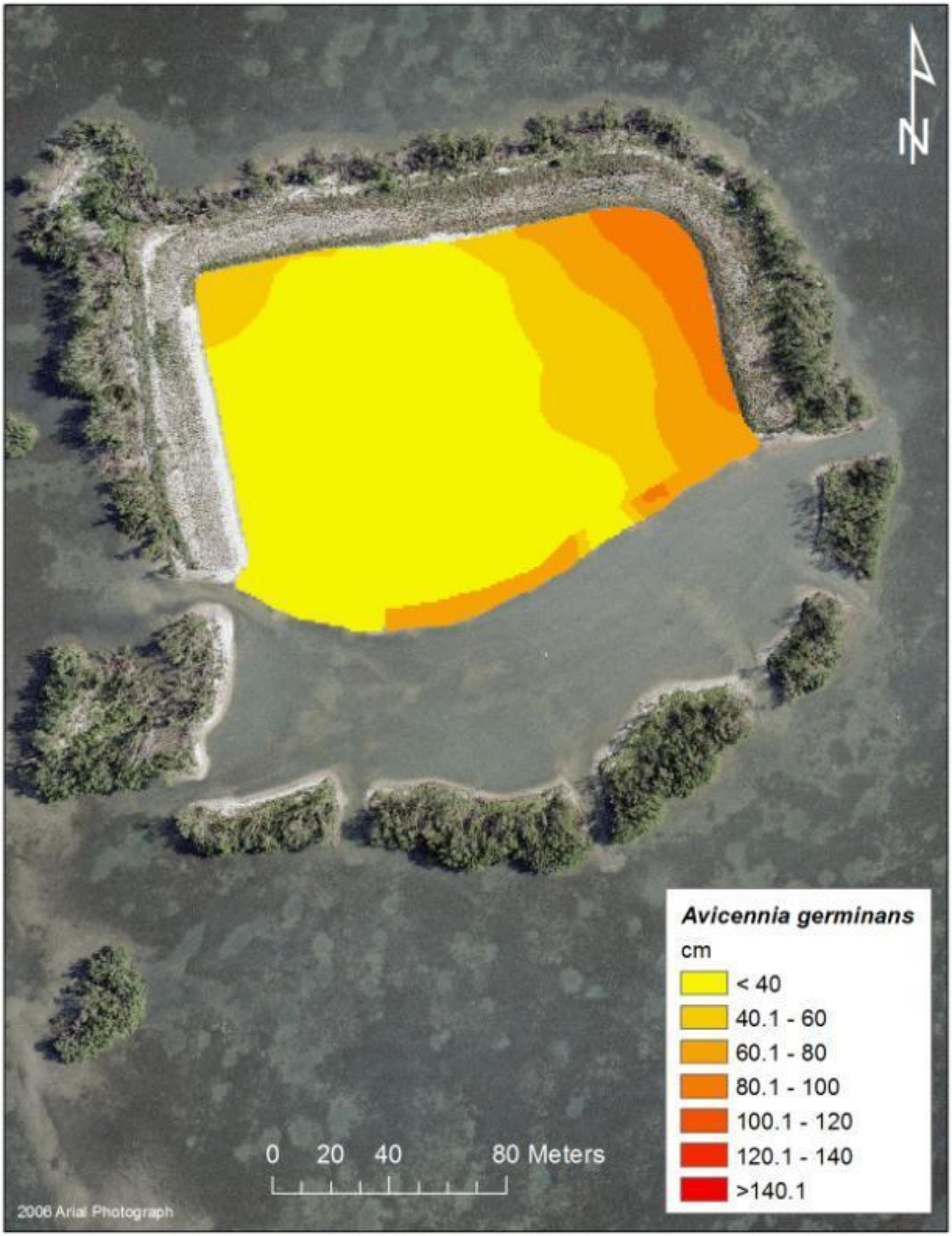


Figure A31. *A. germinans* density in the mangrove planter for summer 2011.

Figure A32. *A. germinans* average height for summer 2009.



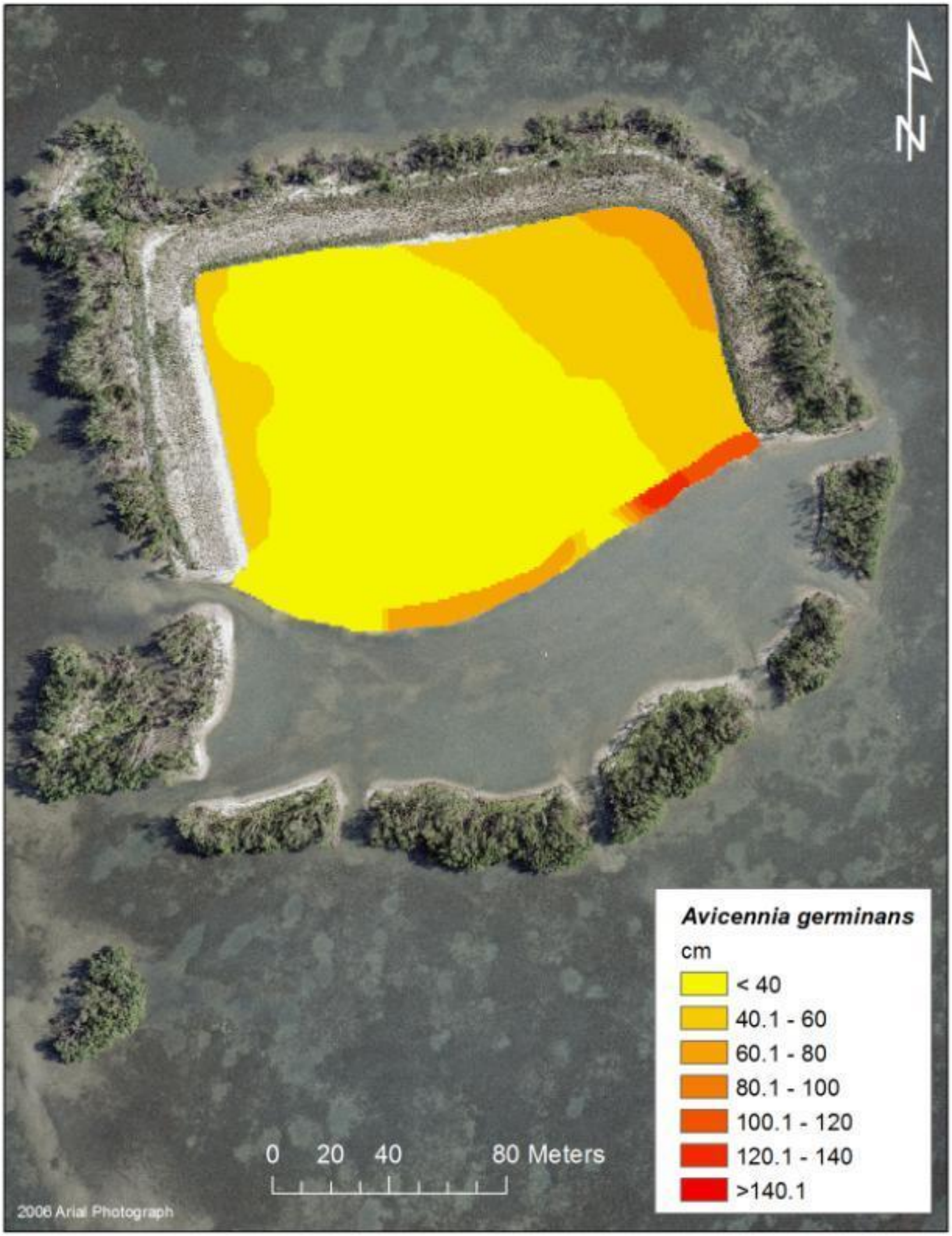


Figure A33. *A. germinans* average height for winter 2009.

Figure A34. *A. germinans* average height for summer 2010.

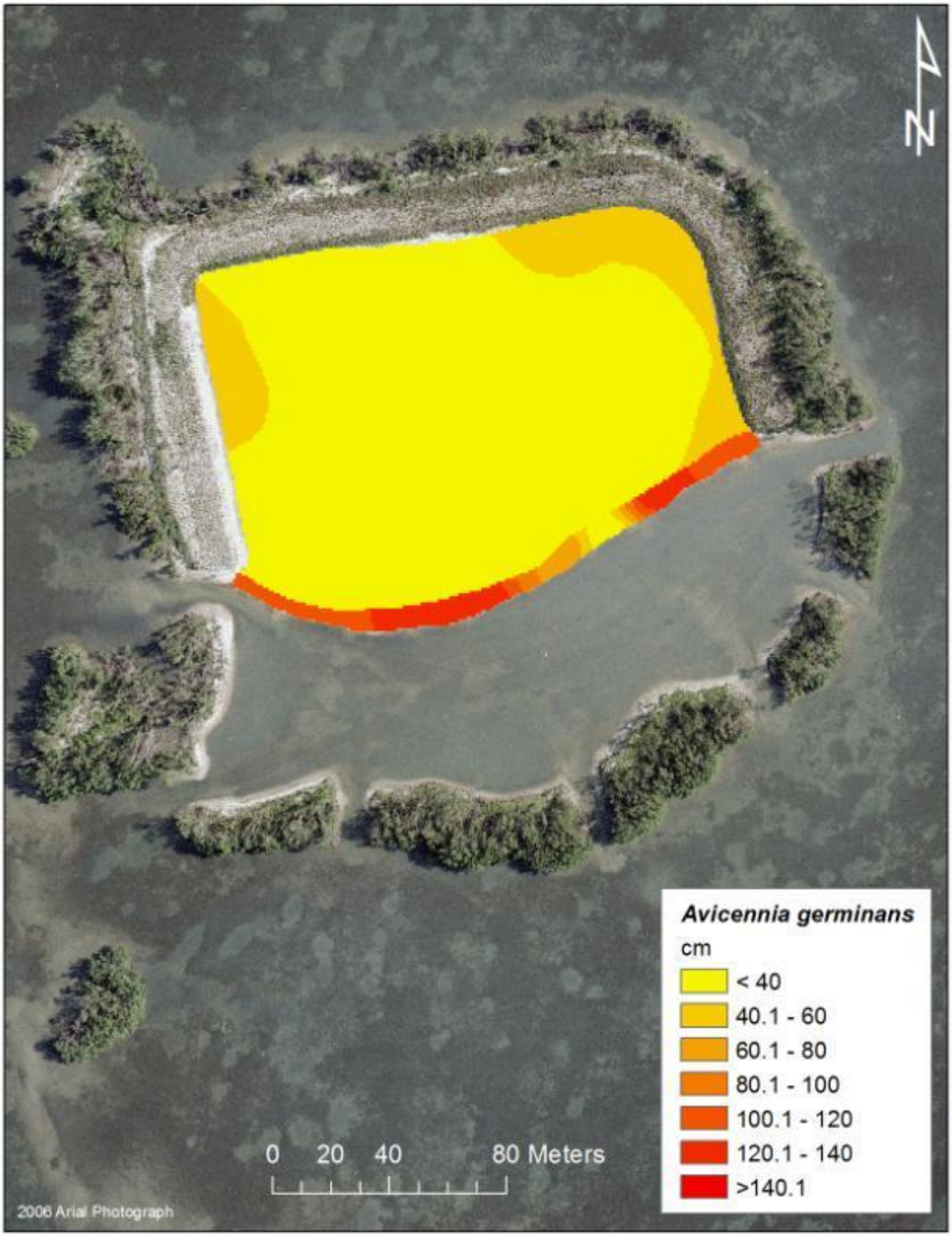
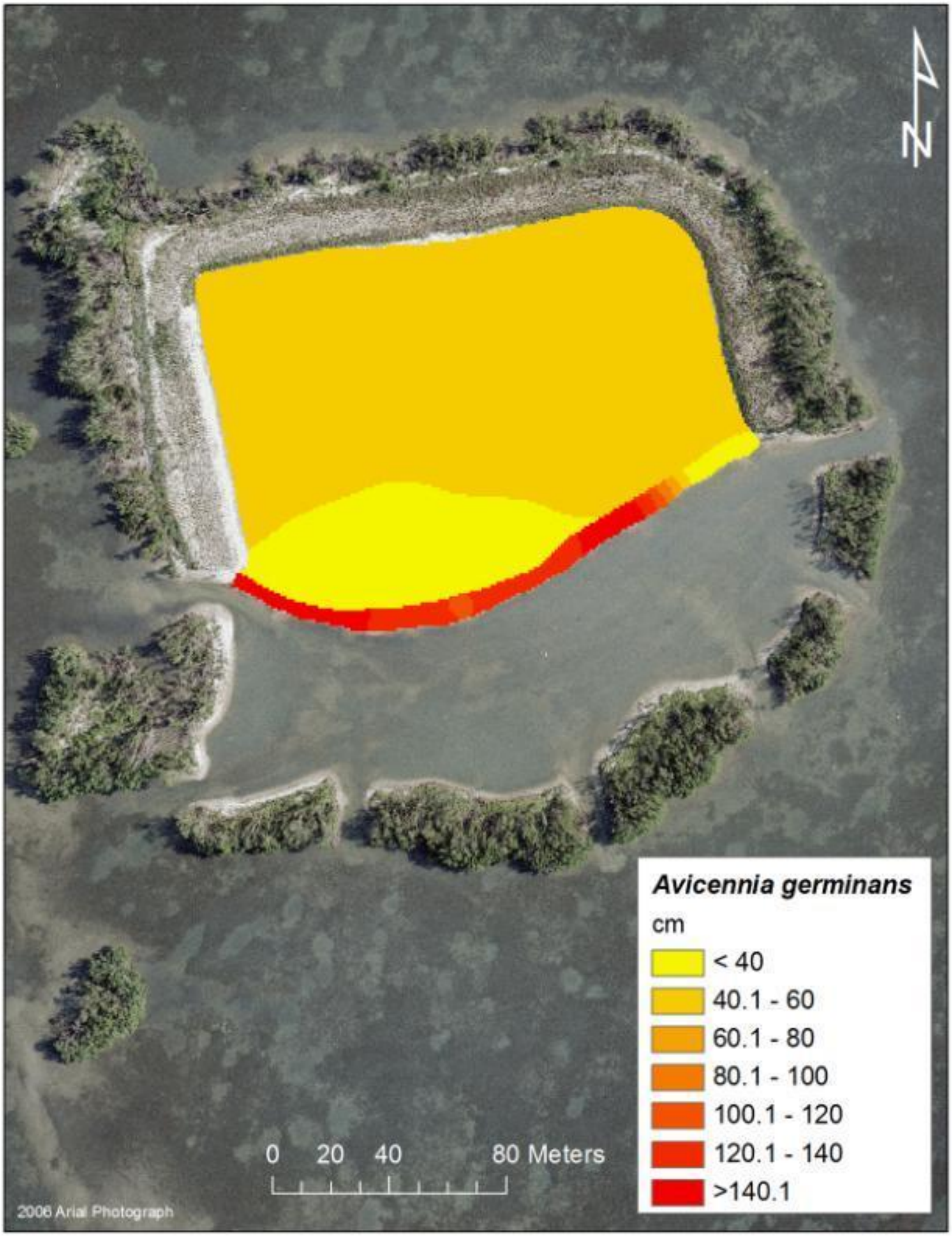


Figure A35. *A. germinans* average height for winter 2010.



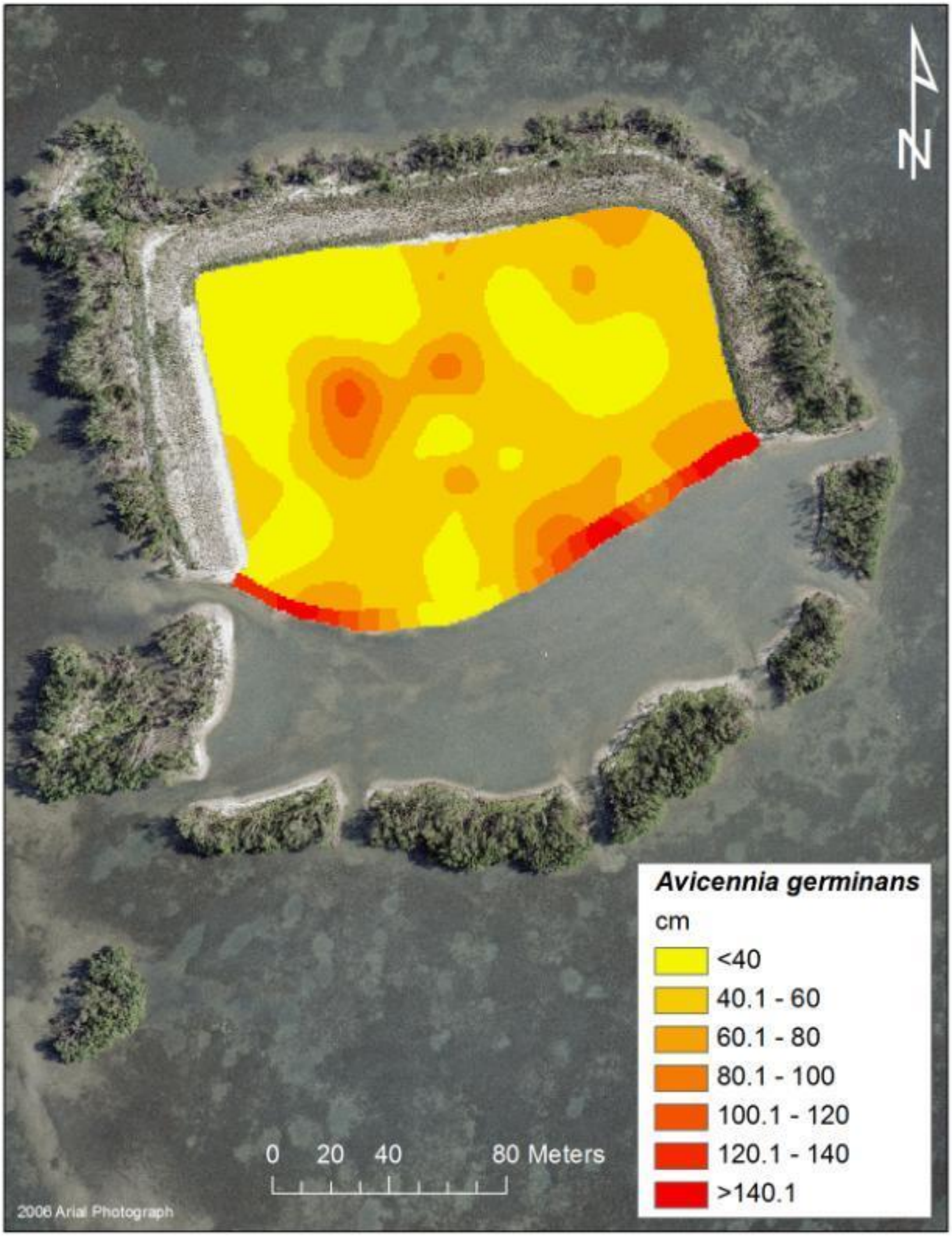


Figure A36. *A. germinans* average height for summer 2011.

Figure A37. *A. germinans* maximum height for summer 2009.

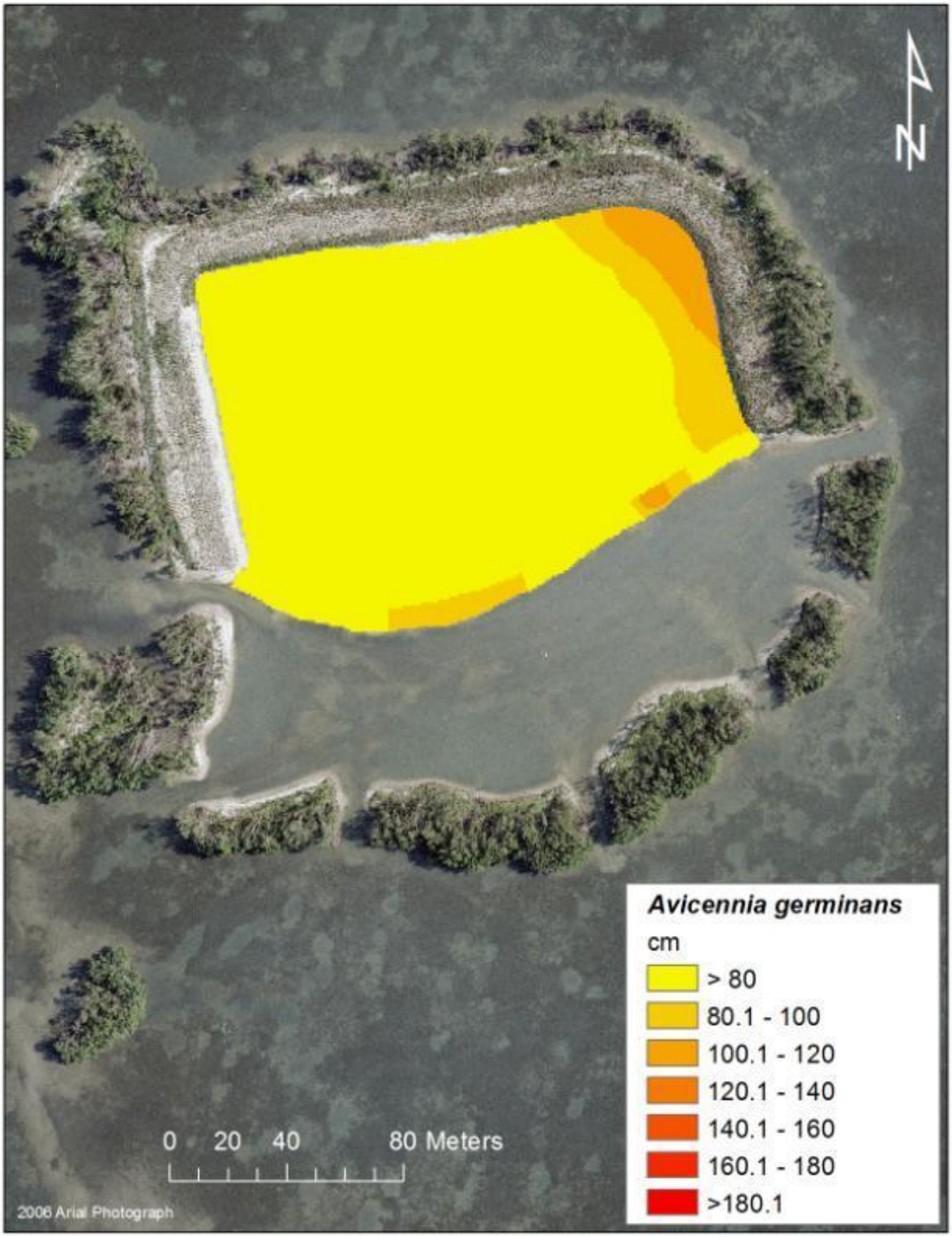


Figure A38. *A. germinans* maximum height for winter 2009.

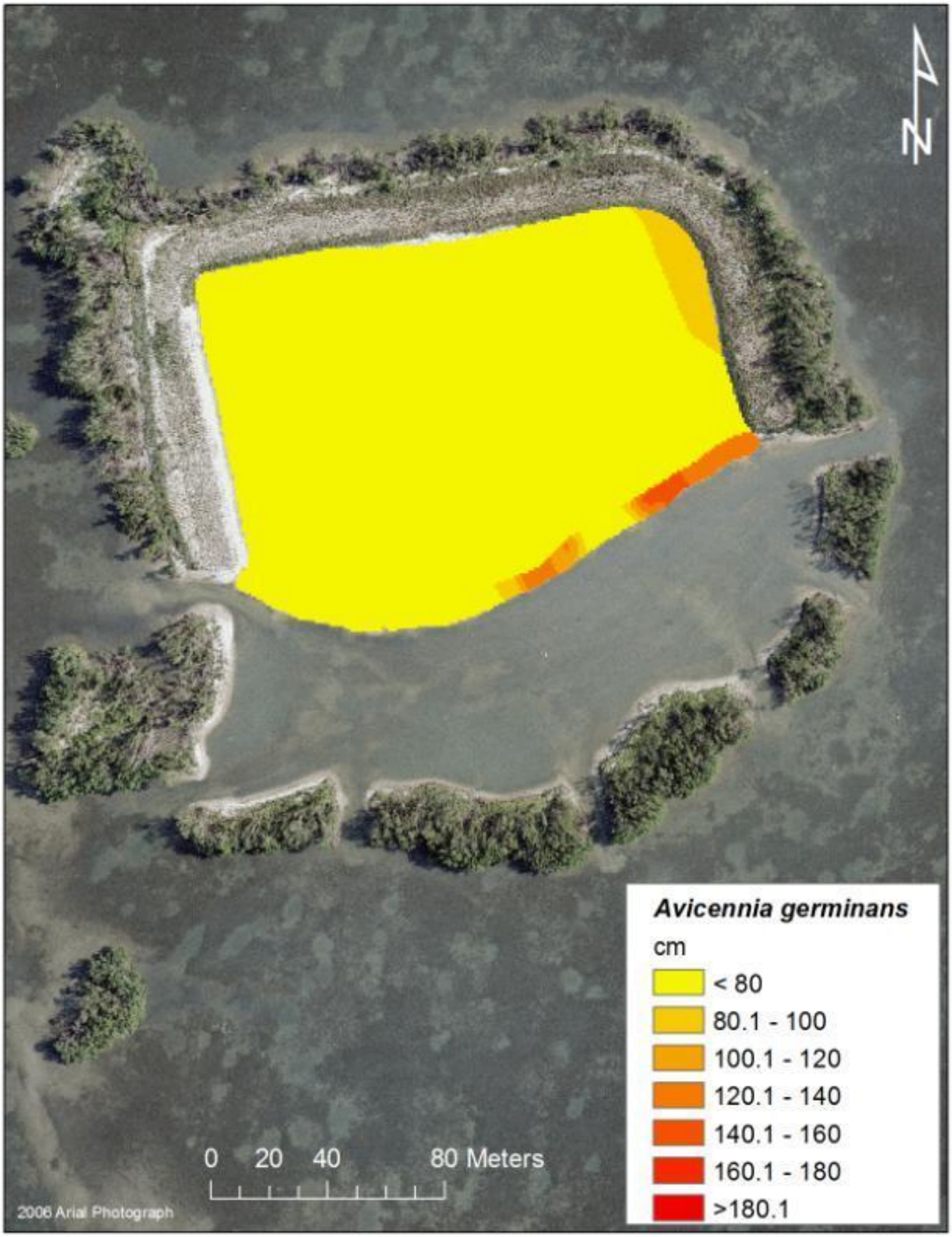


Figure A38. *A. germinans* maximum height for winter 2009.

Figure A39. *A. germinans* maximum height for summer 2010.

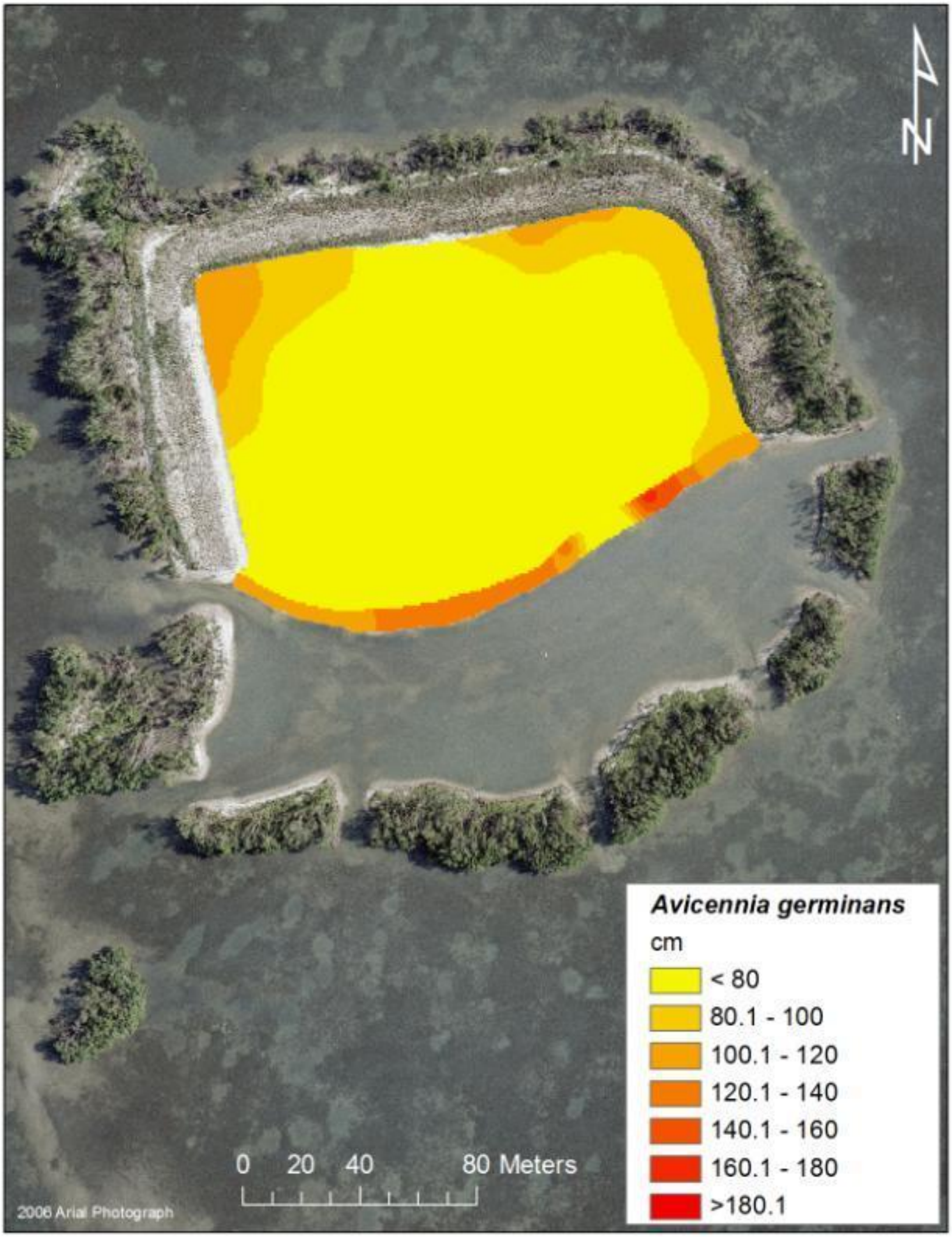


Figure A39. *A. germinans* maximum height for summer 2010.

Figure A40. *A. germinans* maximum height for winter 2010.

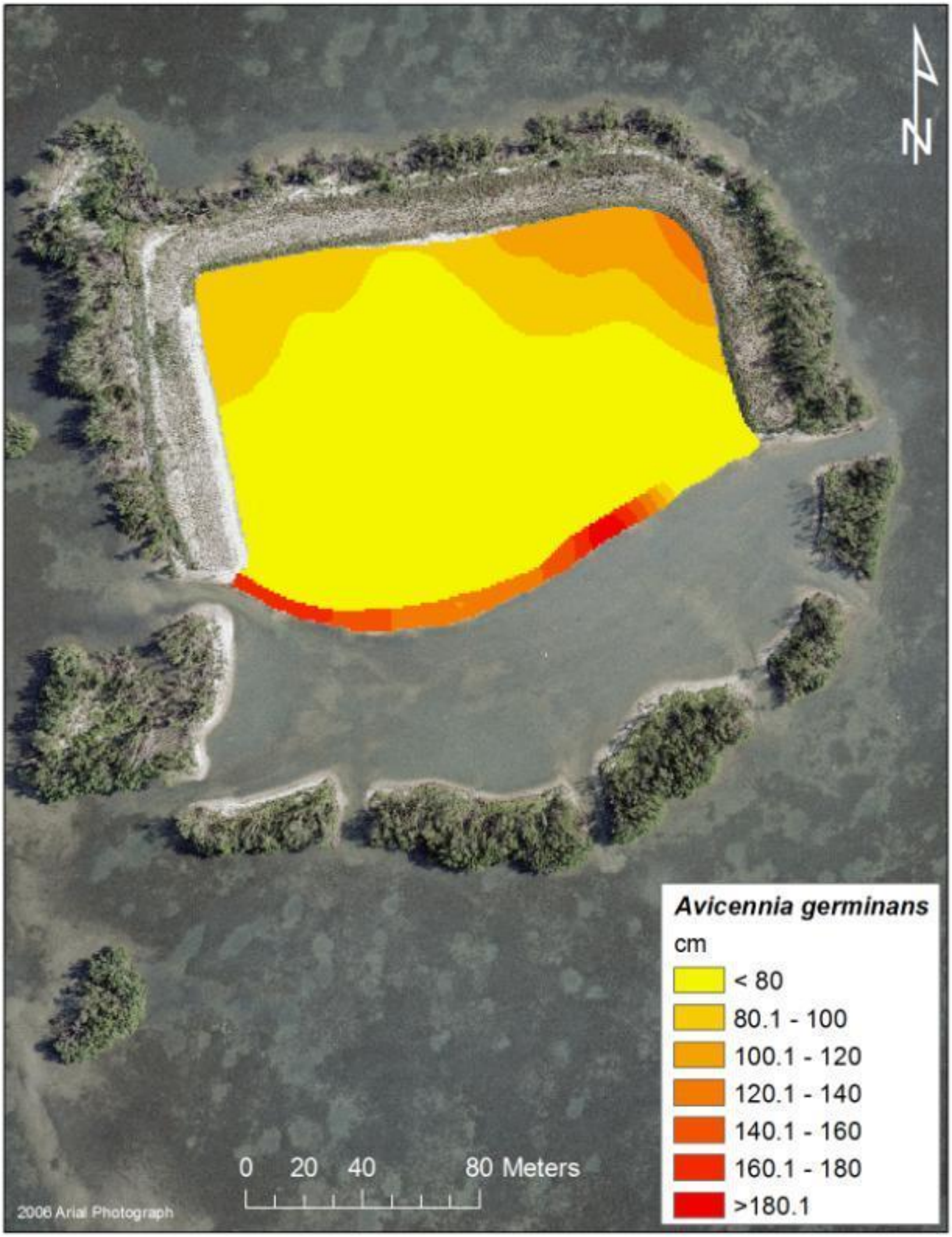


Figure A40. *A. germinans* maximum height for winter 2010.

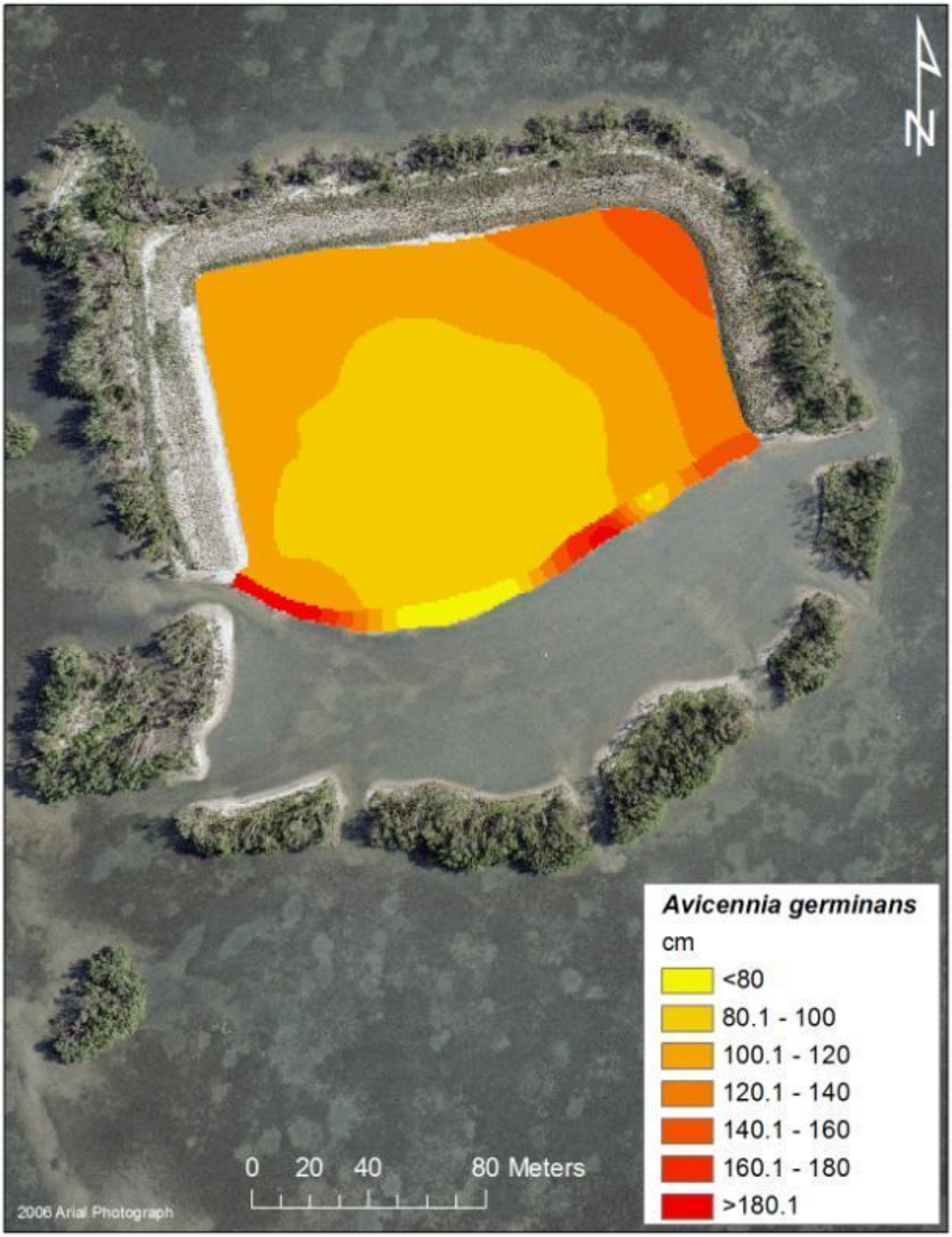


Figure A41. *A. germinans* maximum height for summer 2011.

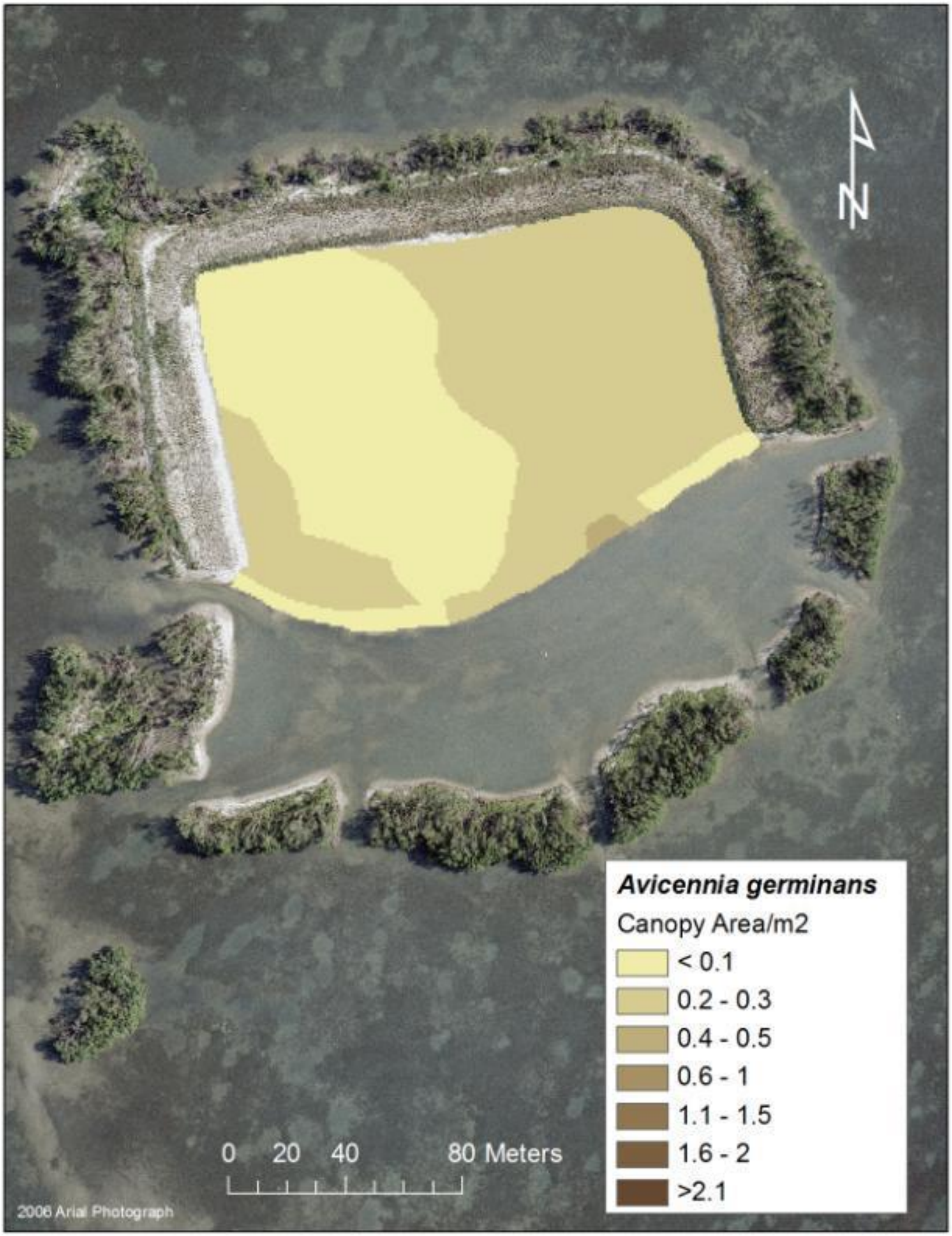


Figure A42. *A. germinans* calculated canopy area/m2 for summer 2011.

Figure A43. *A. germinans* calculated volume area/m3 for summer 2011.

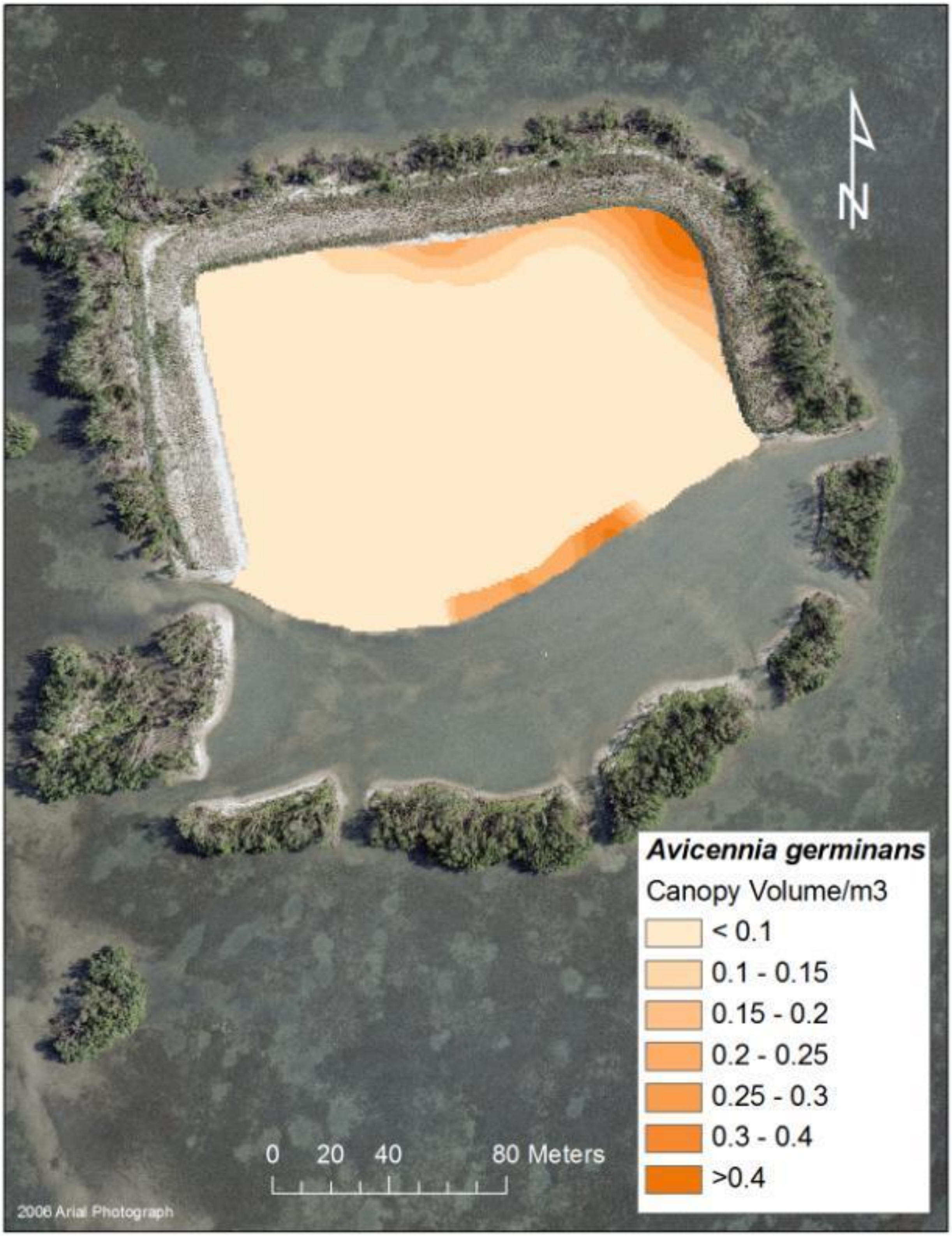
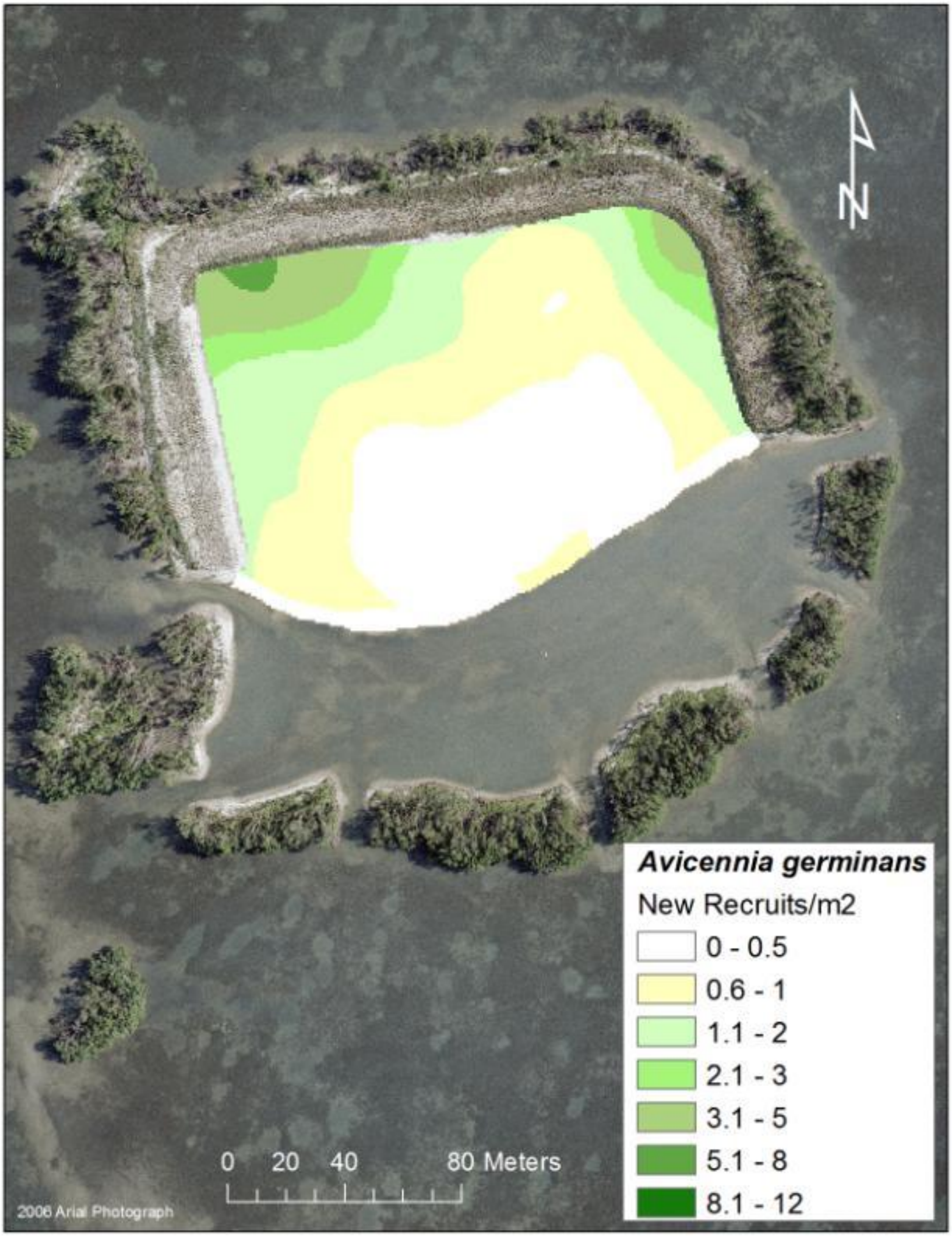


Figure A43. *A. germinans* calculated volume area/m3 for summer 2011.

Figure A44. *A. germinans* juvenile new recruits in summer 2011.



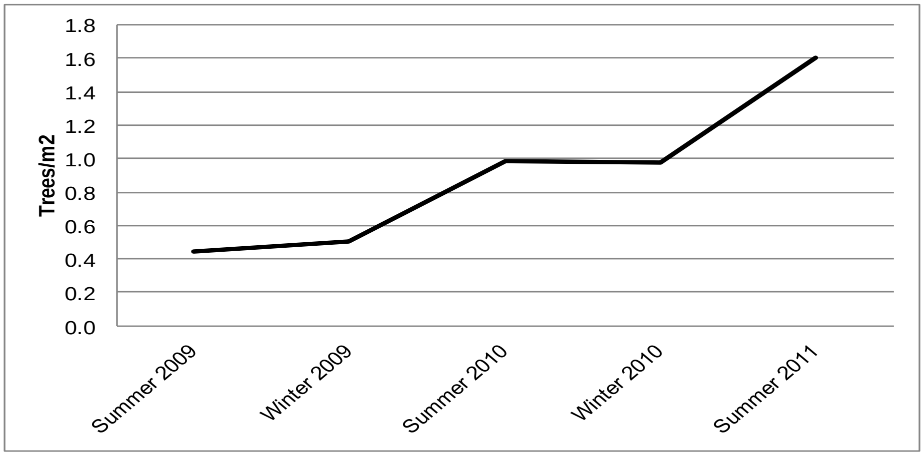


Figure A45. Average *A. germinans* mangrove density (trees/m2) from summer 2009 to summer 2011.

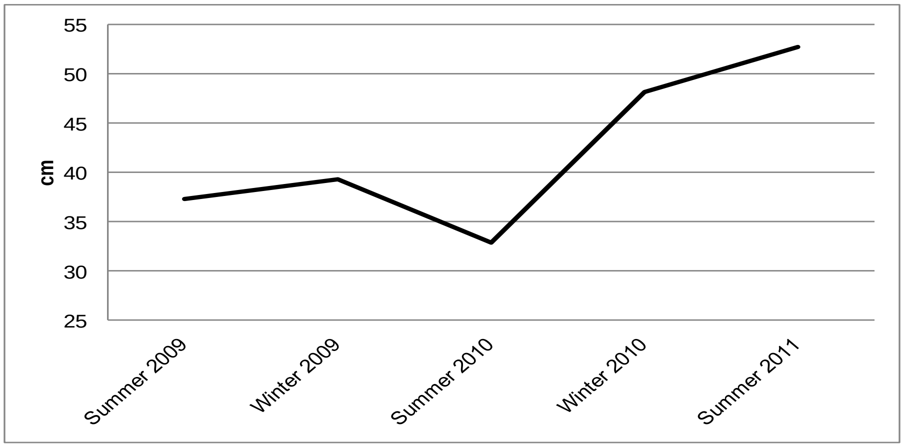


Figure A46. Average *A. germinans* mangrove height from summer 2009 to summer 2011.

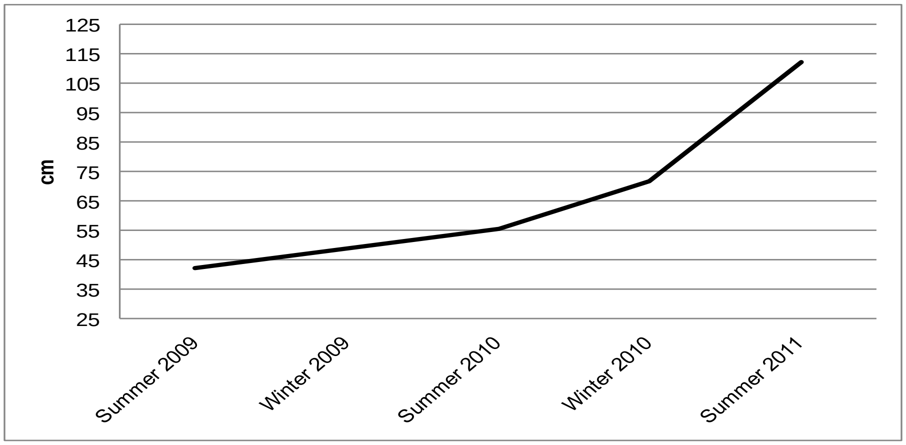


Figure A47. Average *A. germinans* mangrove height from summer 2009 to summer 2011.

Figure A48. *L racemosa* density in the mangrove planter for summer 2009.

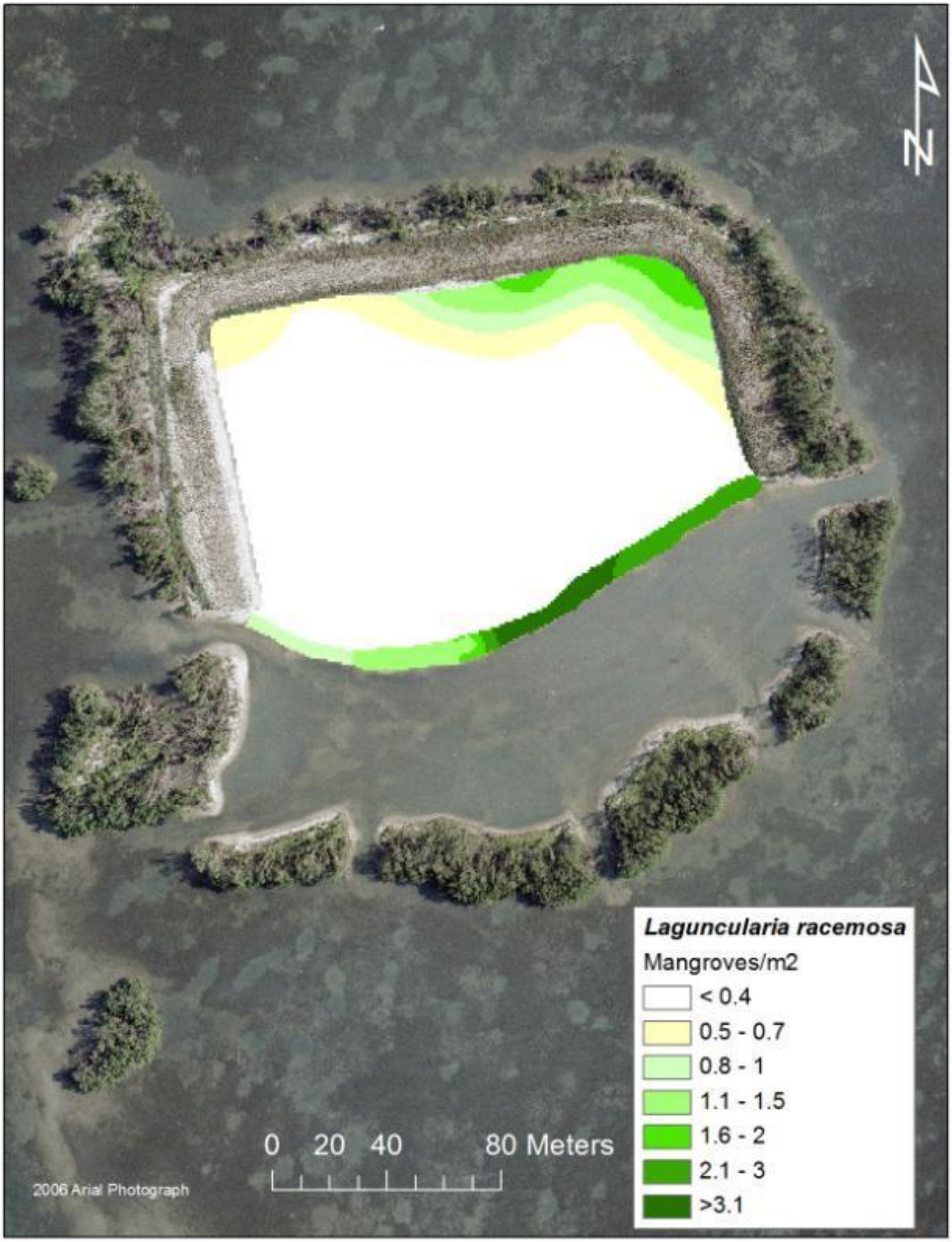


Figure A48. *L racemosa* density in the mangrove planter for summer 2009.

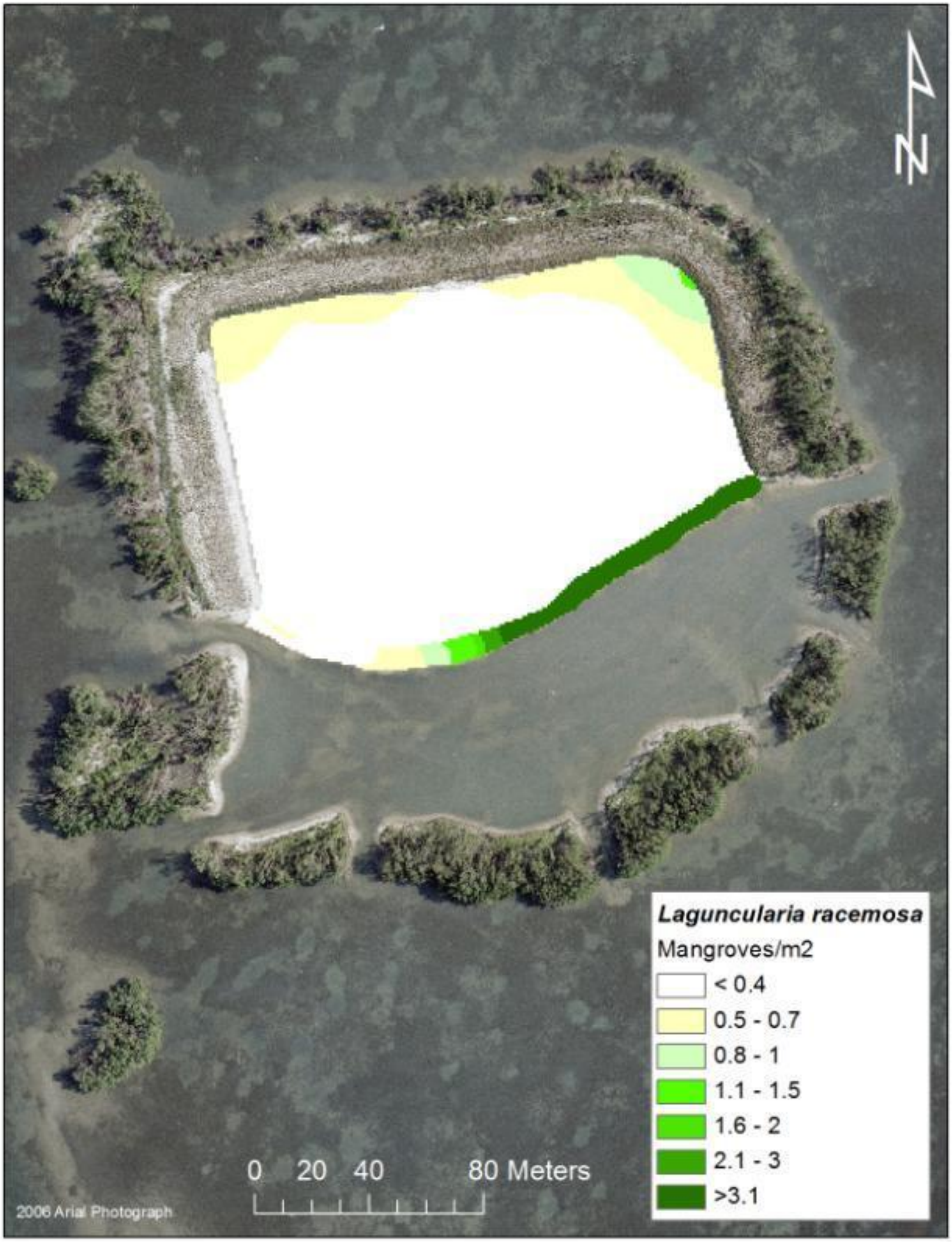


Figure A49. *L racemosa* density in the mangrove planter for winter 2009.

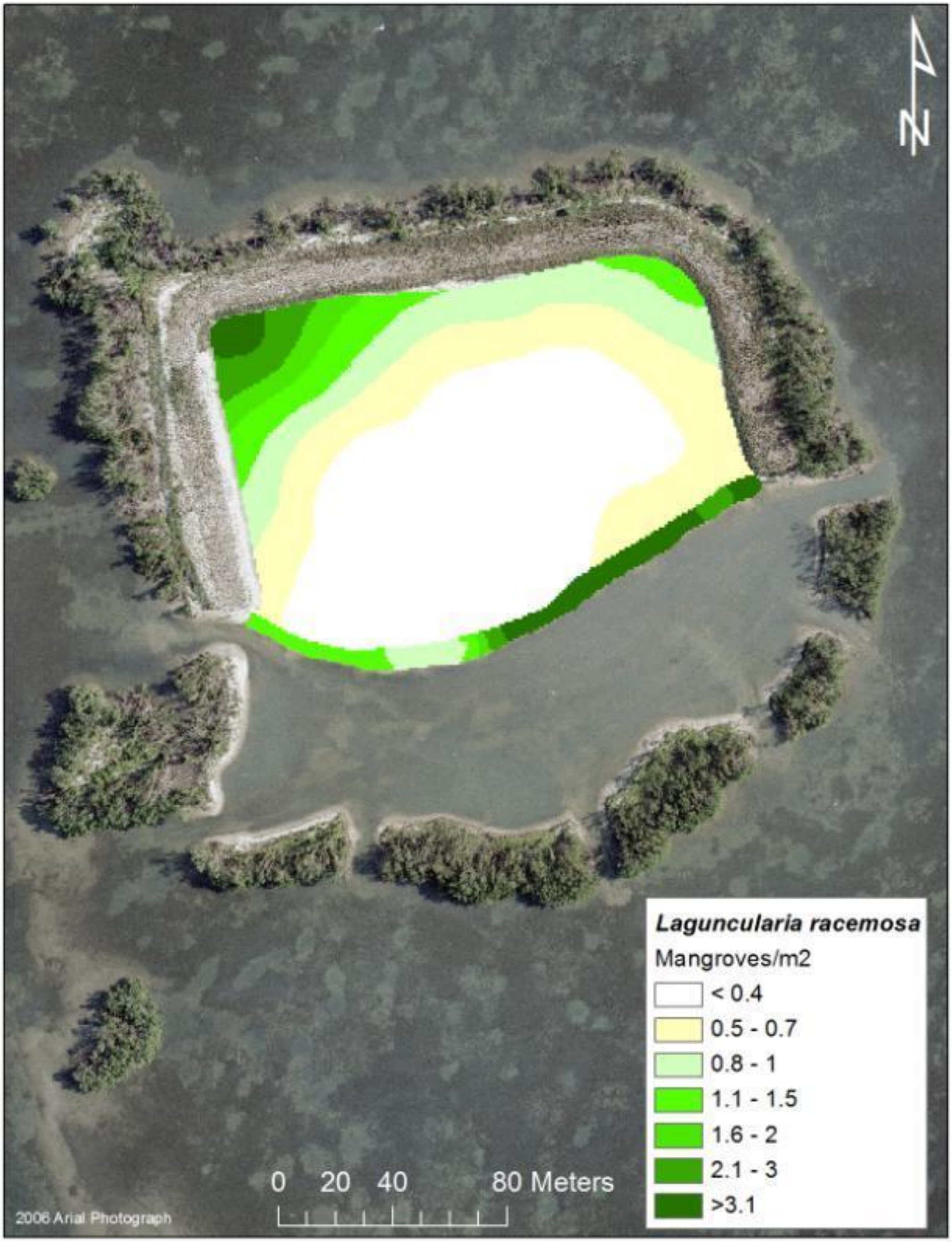
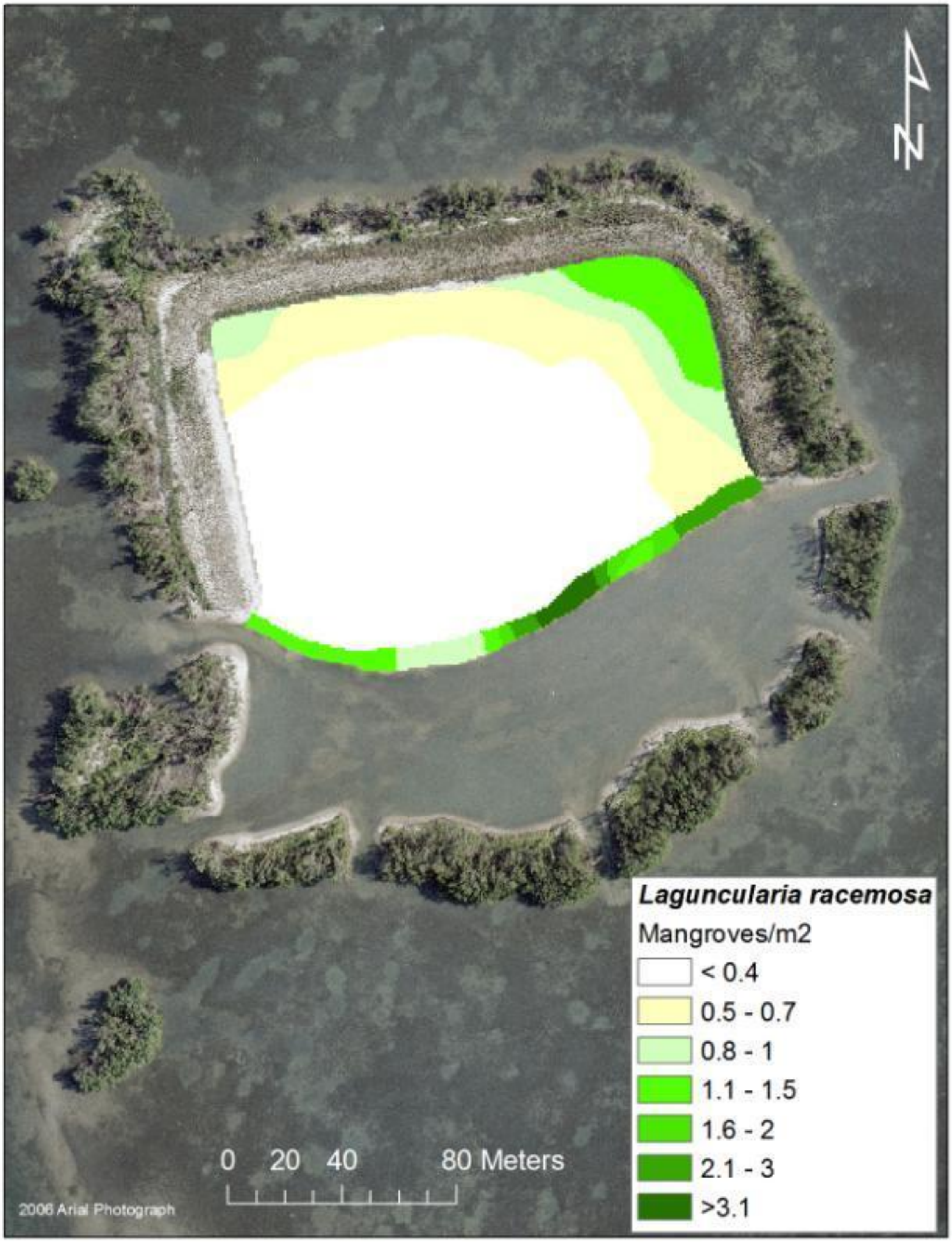


Figure A50. *L racemosa* density in the mangrove planter for summer 2010.

Figure A51. *L racemosa* density in the mangrove planter for winter 2010.



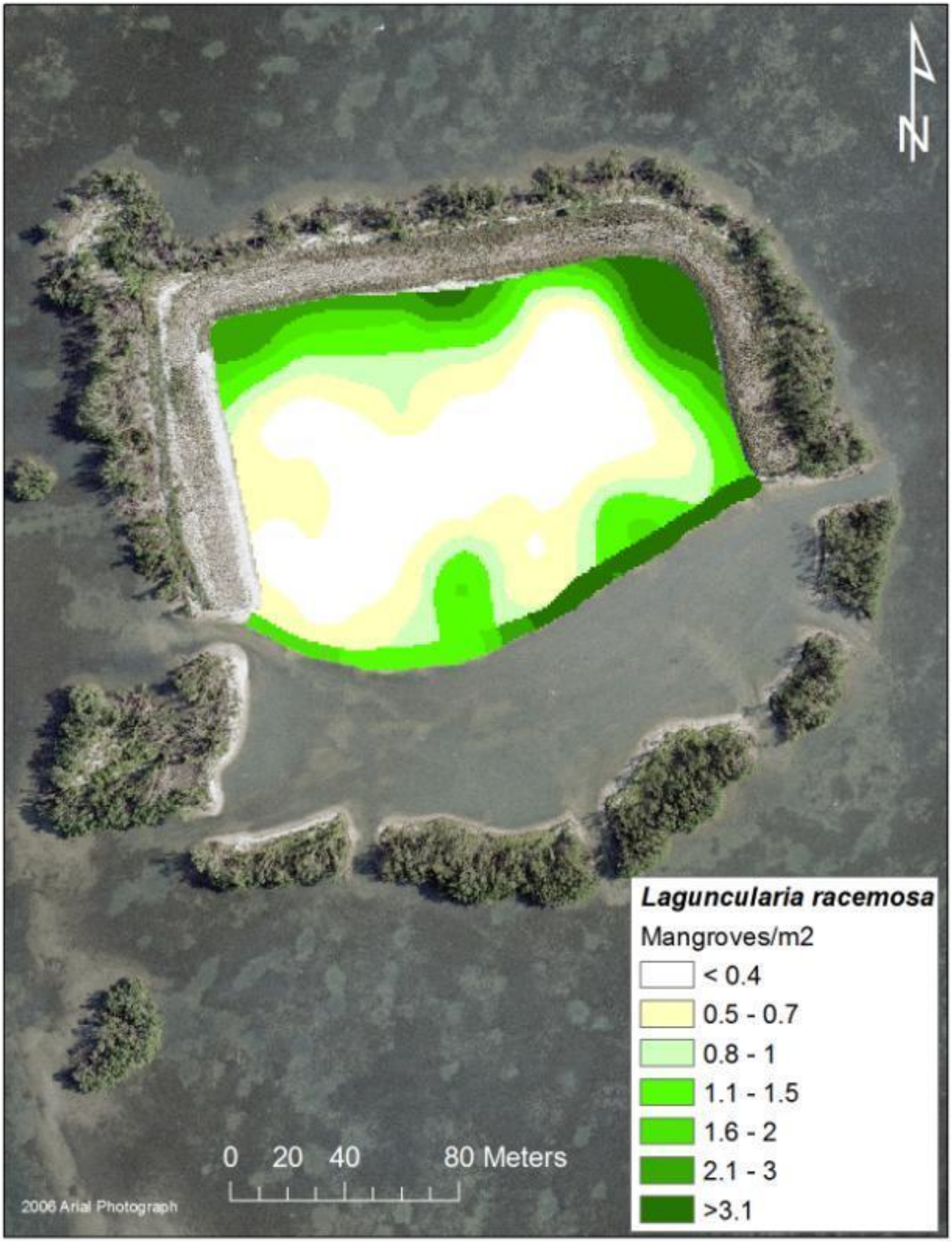
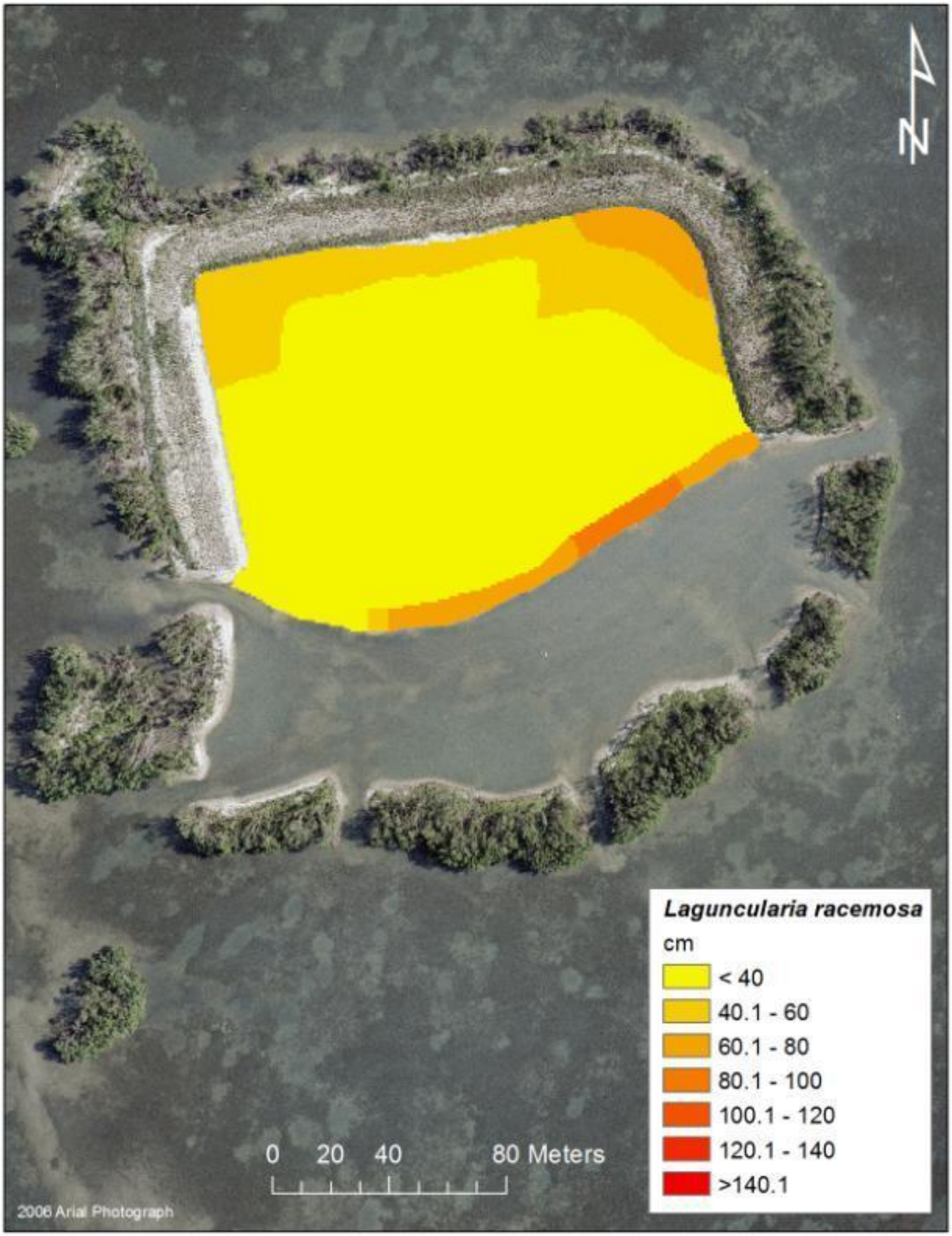


Figure A52. *L racemosa* density in the mangrove planter for summer 2011.

Figure A53. *L racemosa* average height for summer 2009.



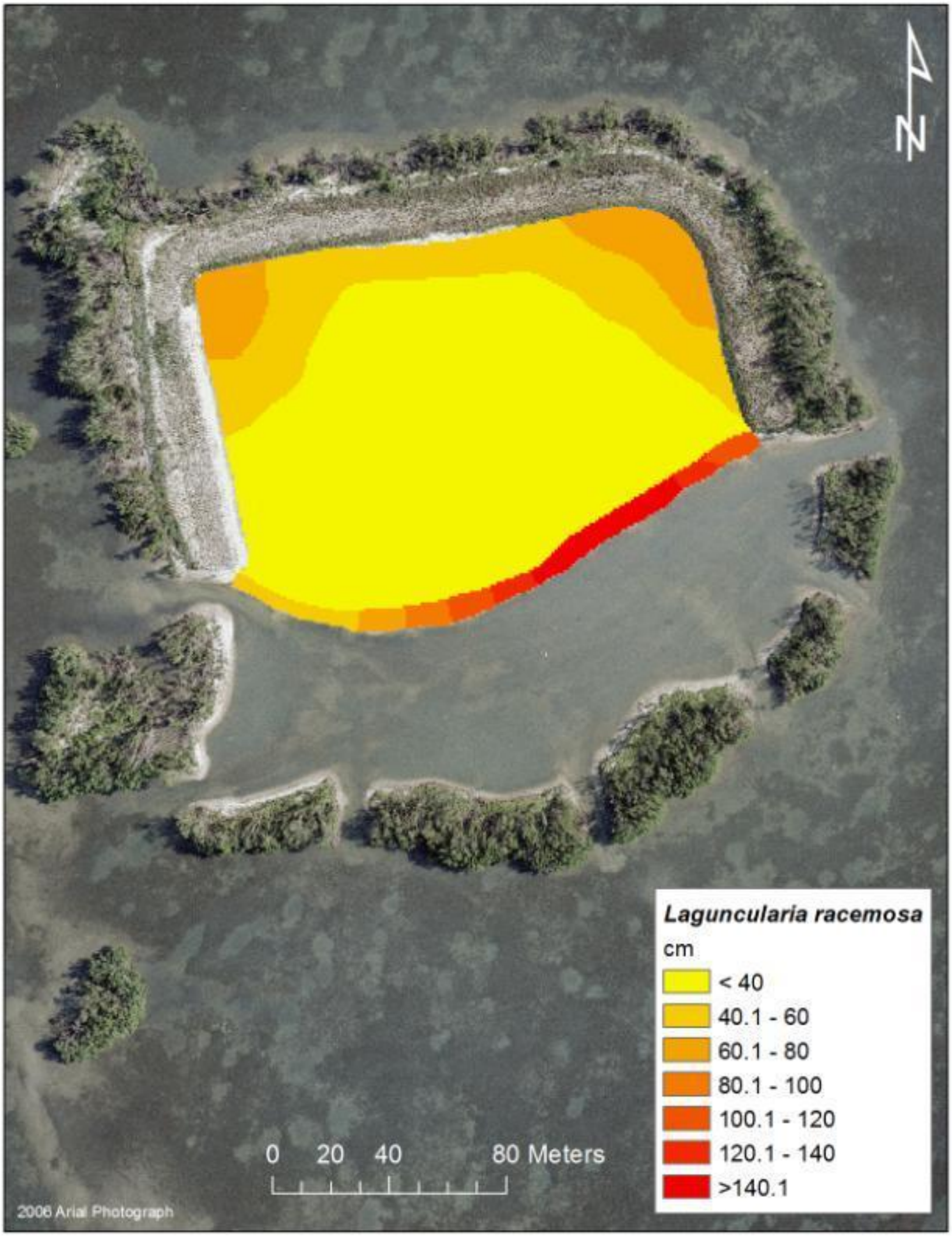


Figure A54. *L racemosa* density in the mangrove planter for winter 2009.

Figure A55. *L racemosa* density in the mangrove planter for summer 2010.

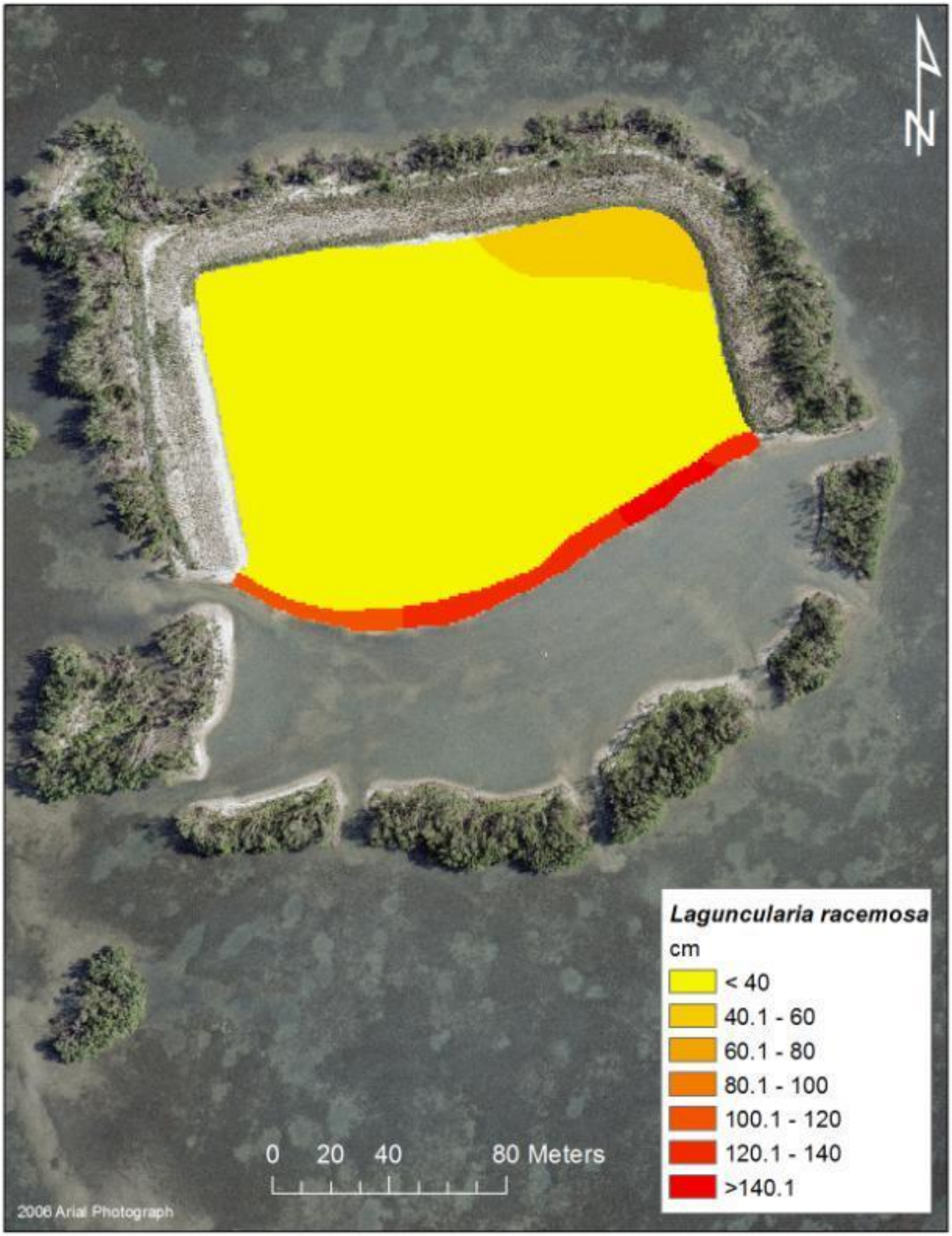


Figure A56. *L racemosa* density in the mangrove planter for winter 2009.

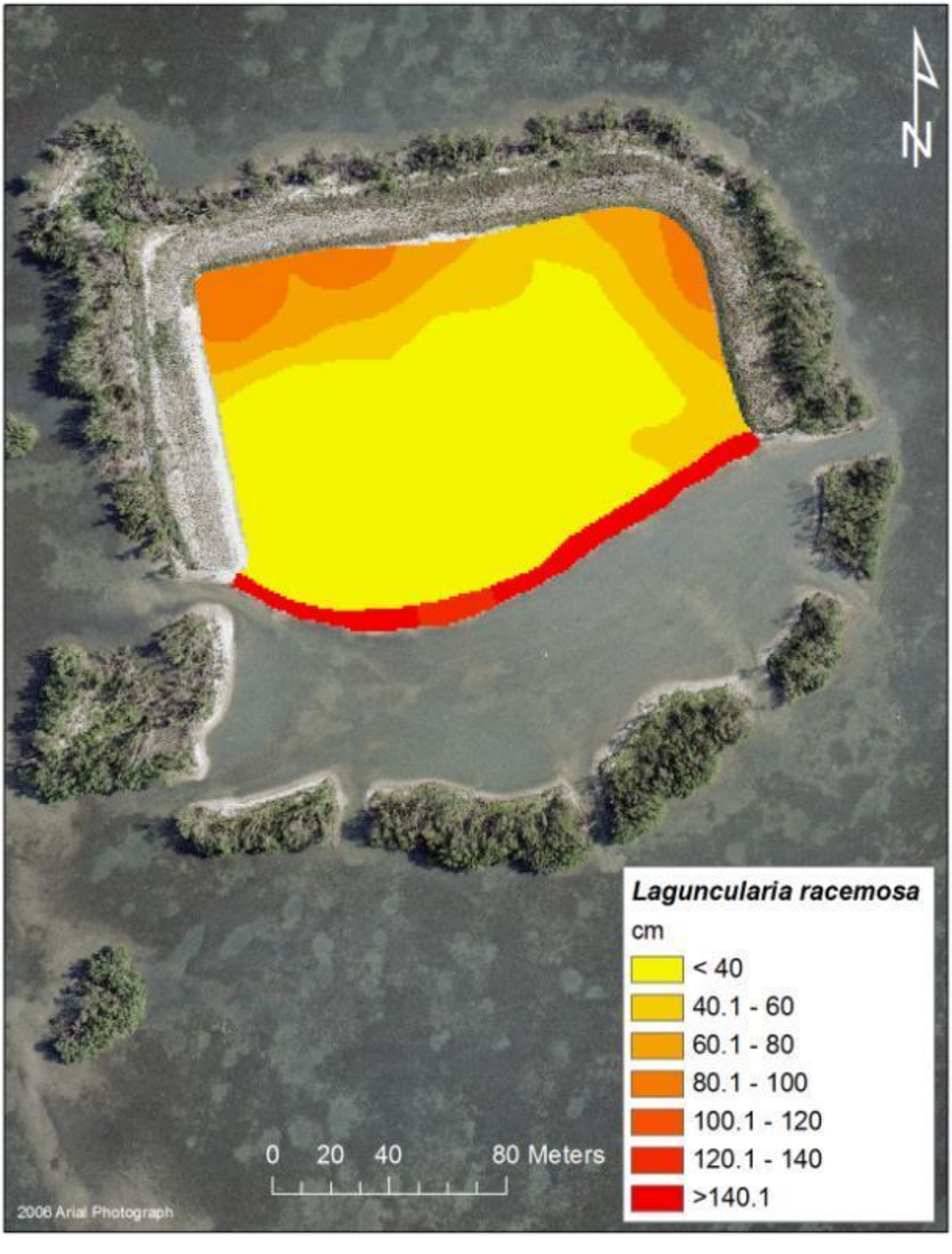


Figure A56. *L racemosa* density in the mangrove planter for winter 2009.

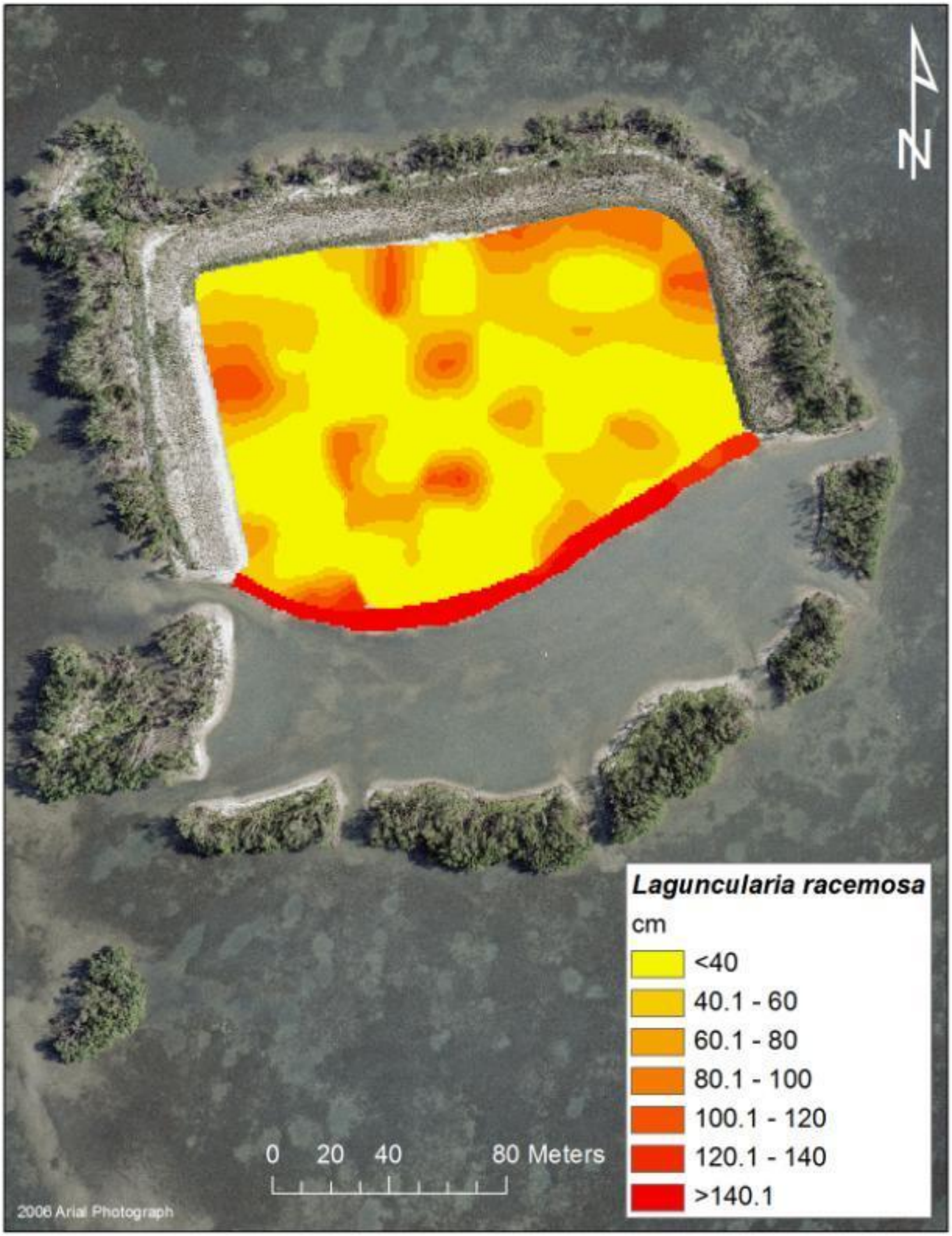


Figure A57. *L racemosa* density in the mangrove planter for summer 2011.

Figure A58. *L racemosa* maximum height for summer 2009.

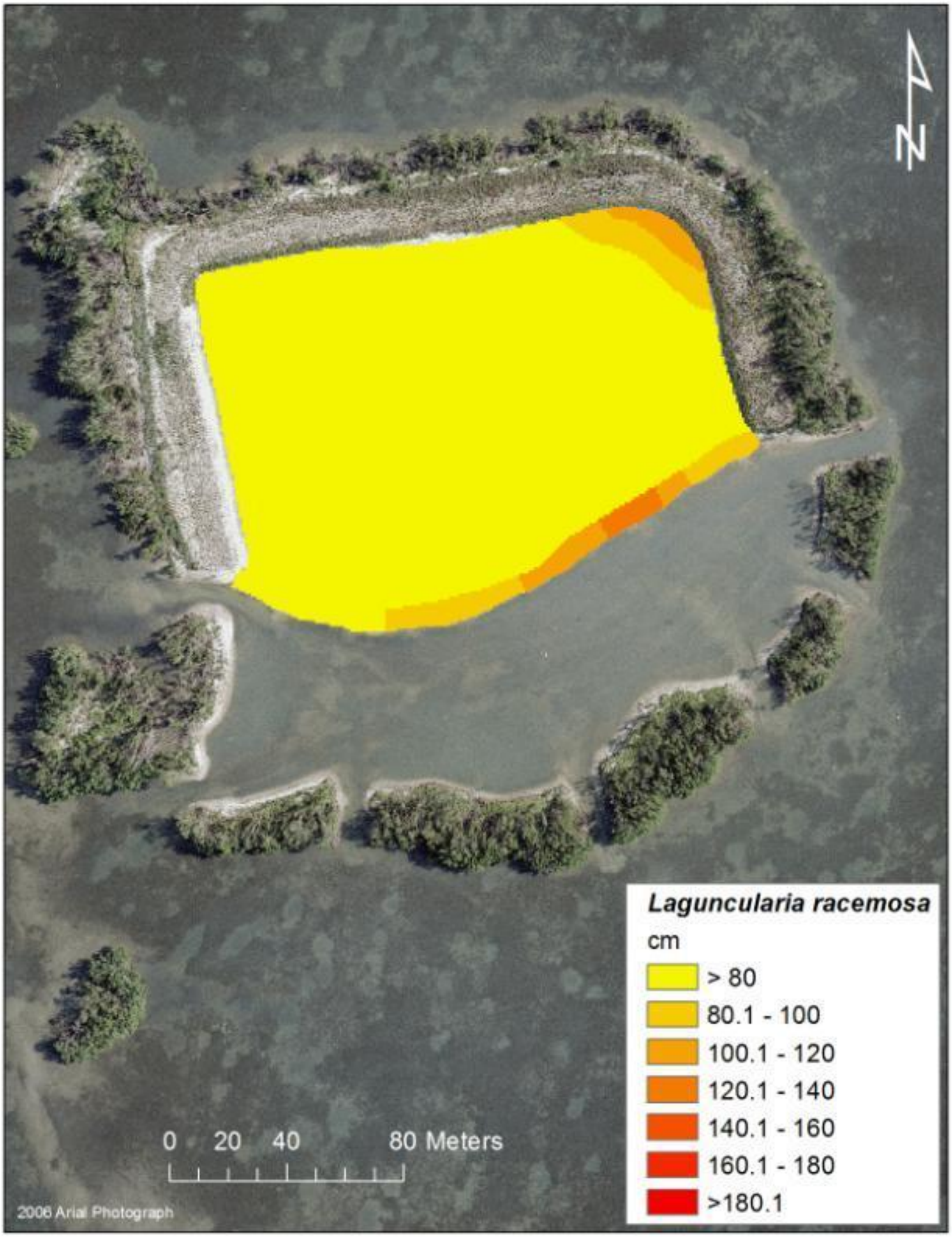


Figure A58. *L racemosa* maximum height for summer 2009.

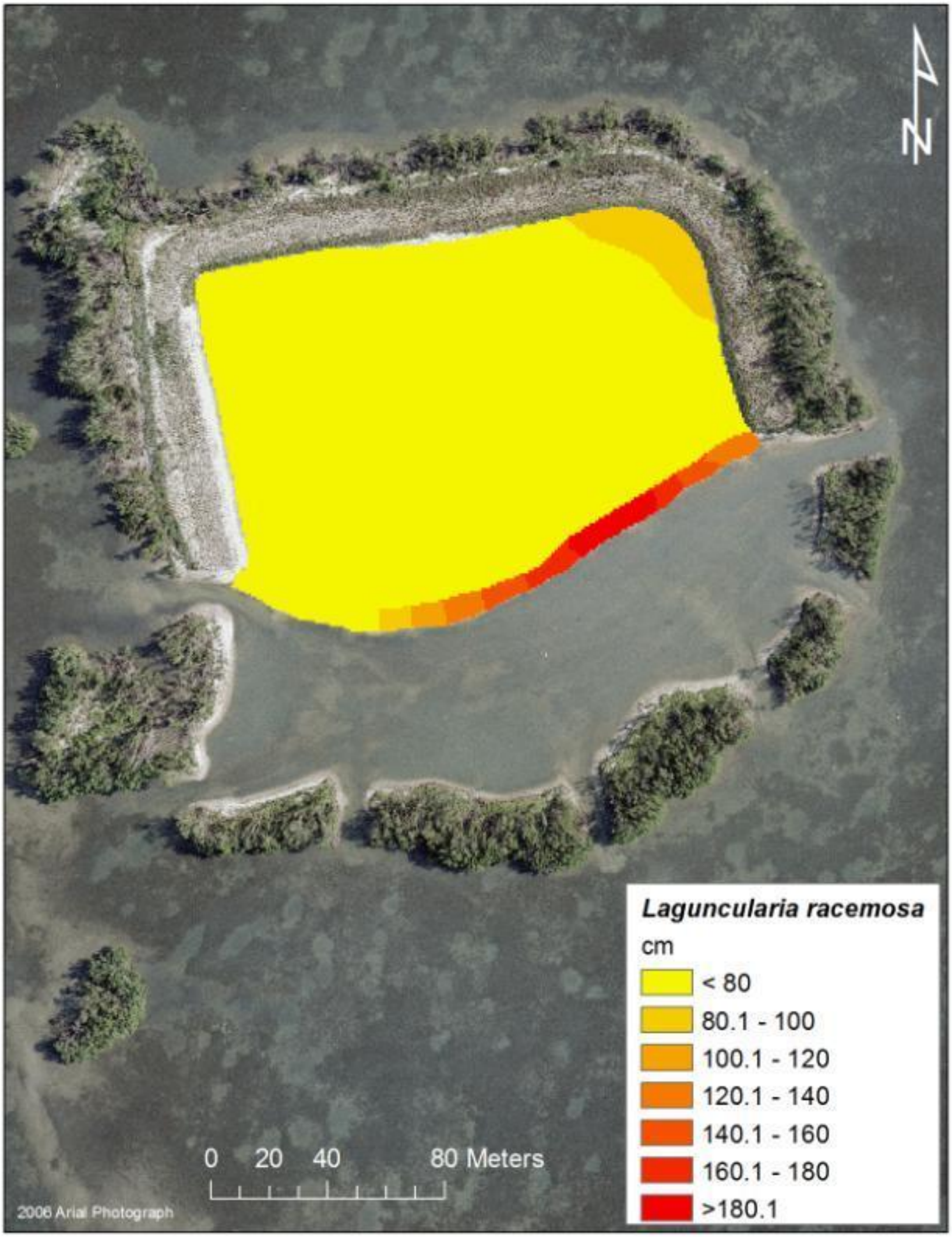


Figure A59. *L racemosa* maximum height for winter 2009.

Figure A60. *L racemosa* maximum height for summer 2010.

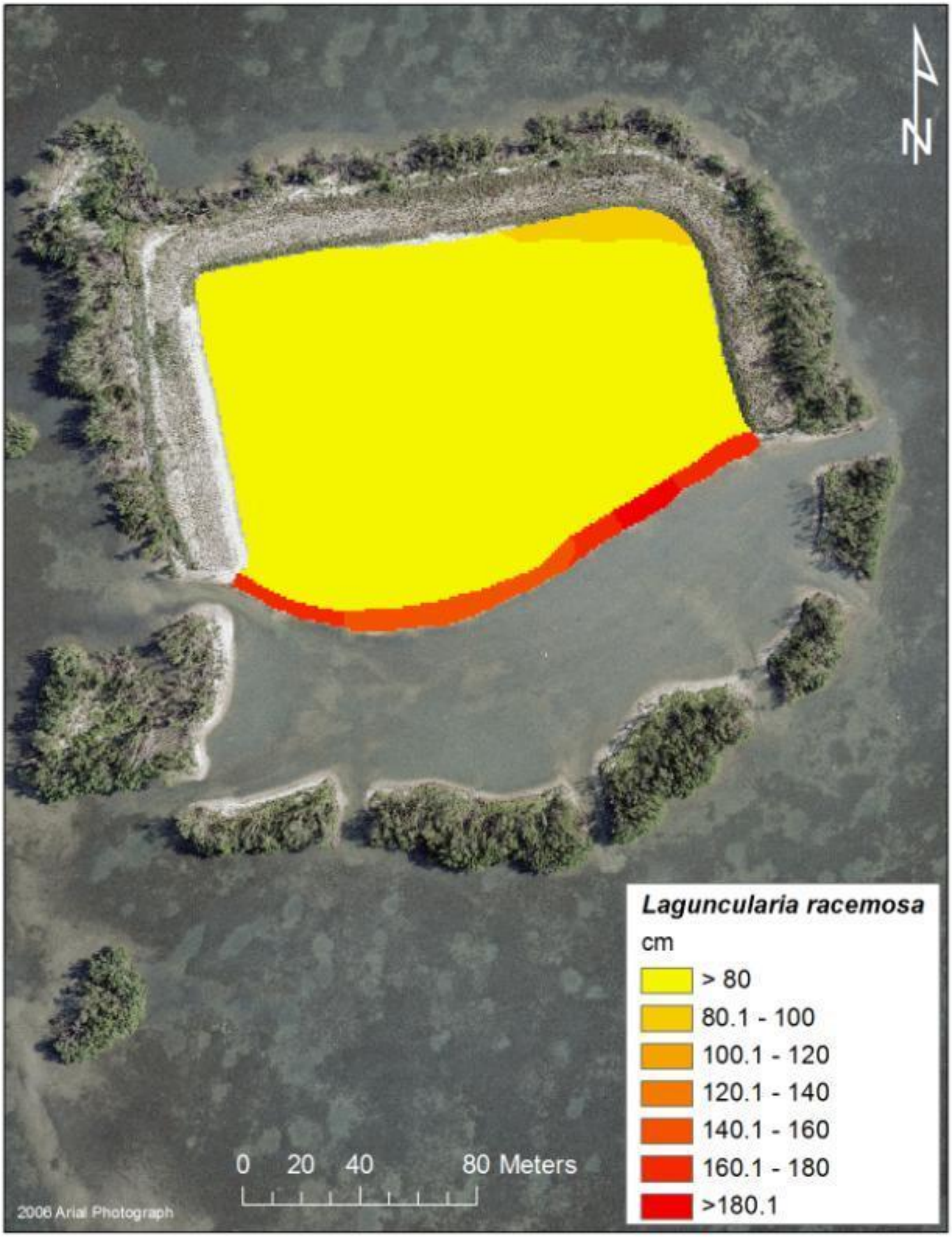


Figure A60. *L racemosa* maximum height for summer 2010.

Figure A61. *L racemosa* maximum height for winter 2010.

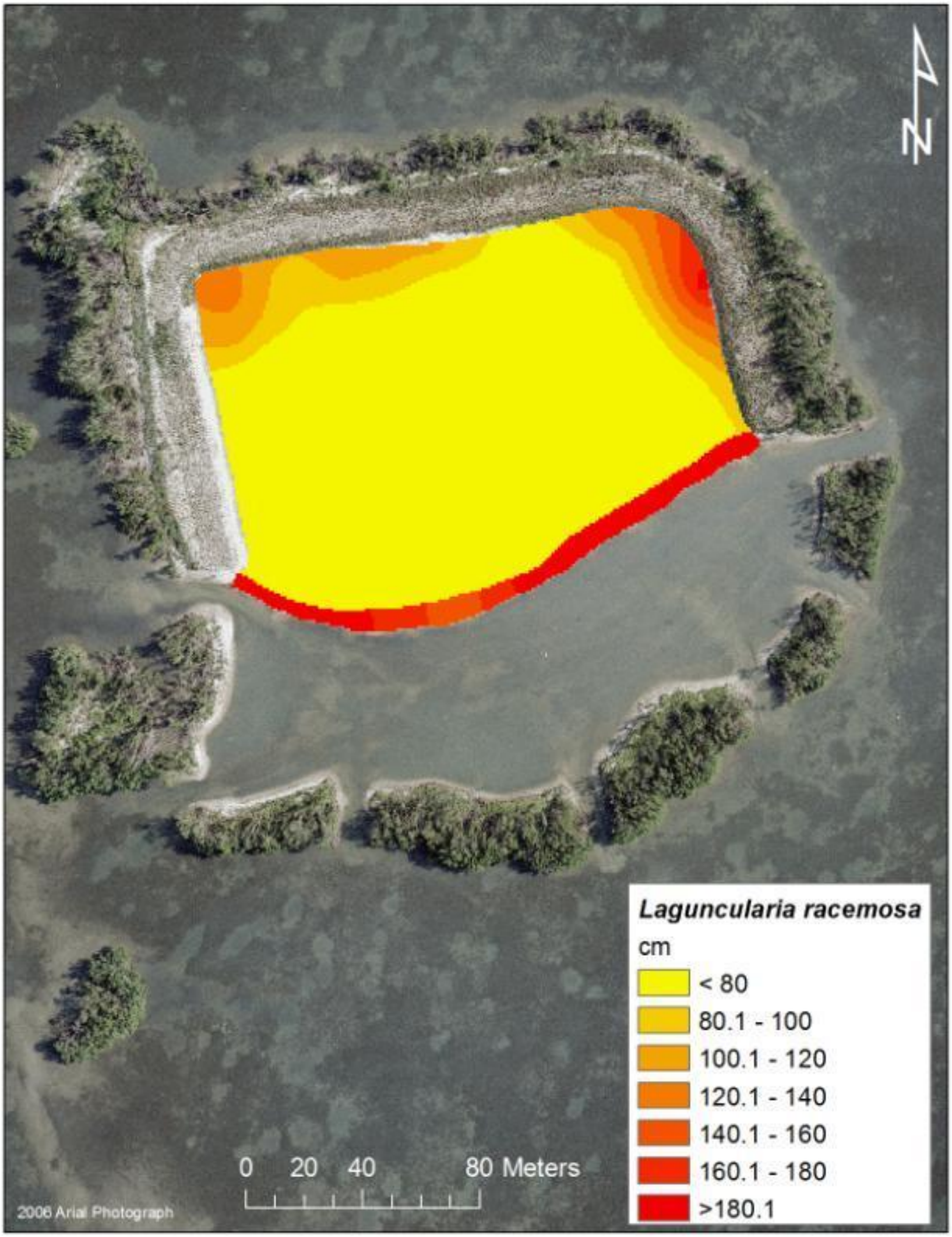


Figure A62. *L racemosa* maximum height for summer 2011.

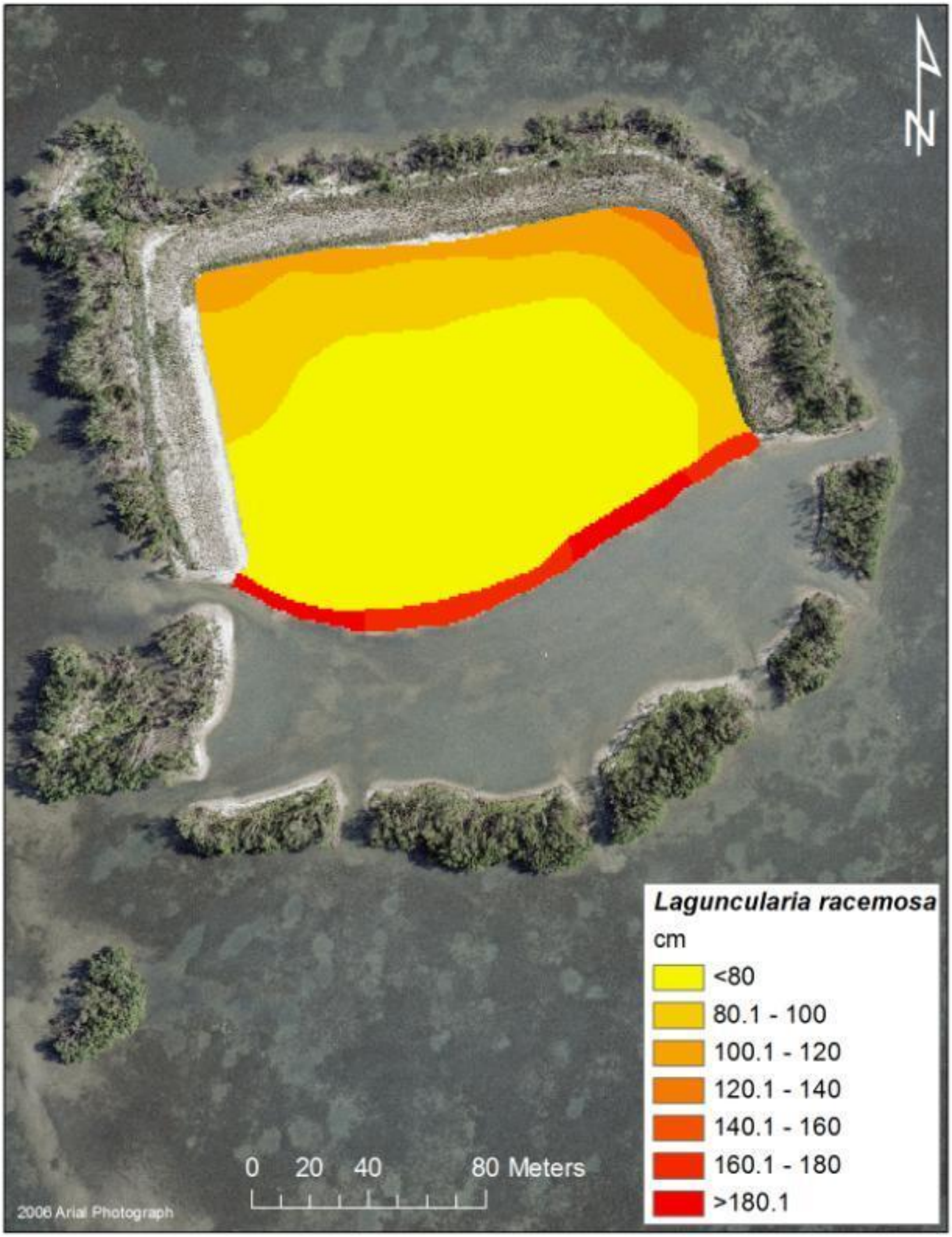


Figure A62. *L racemosa* maximum height for summer 2011.

Figure A63. *L racemosa* calculated canopy area/m2 summer 2011.

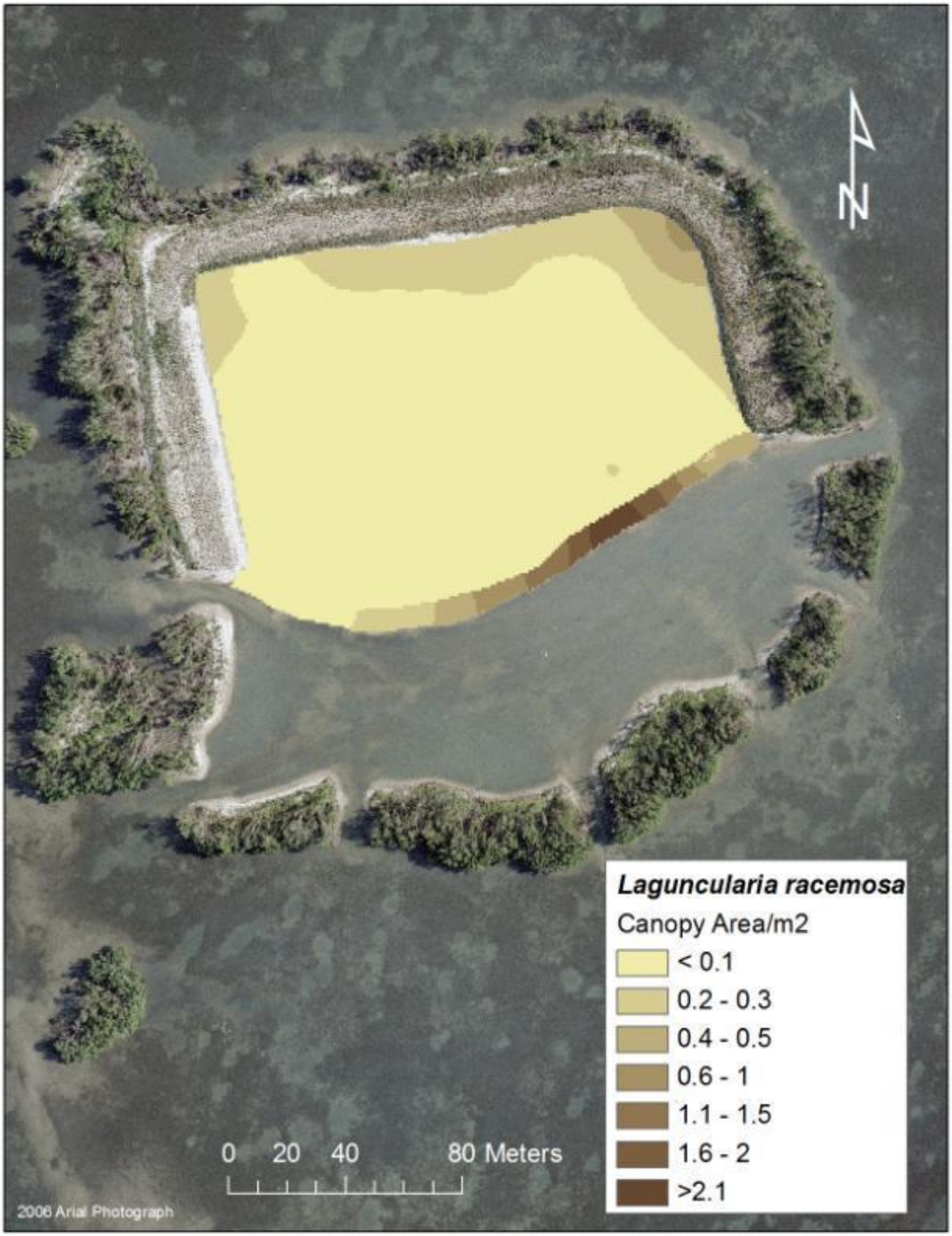


Figure A64. *L racemosa* calculated volume/m3 summer 2011.

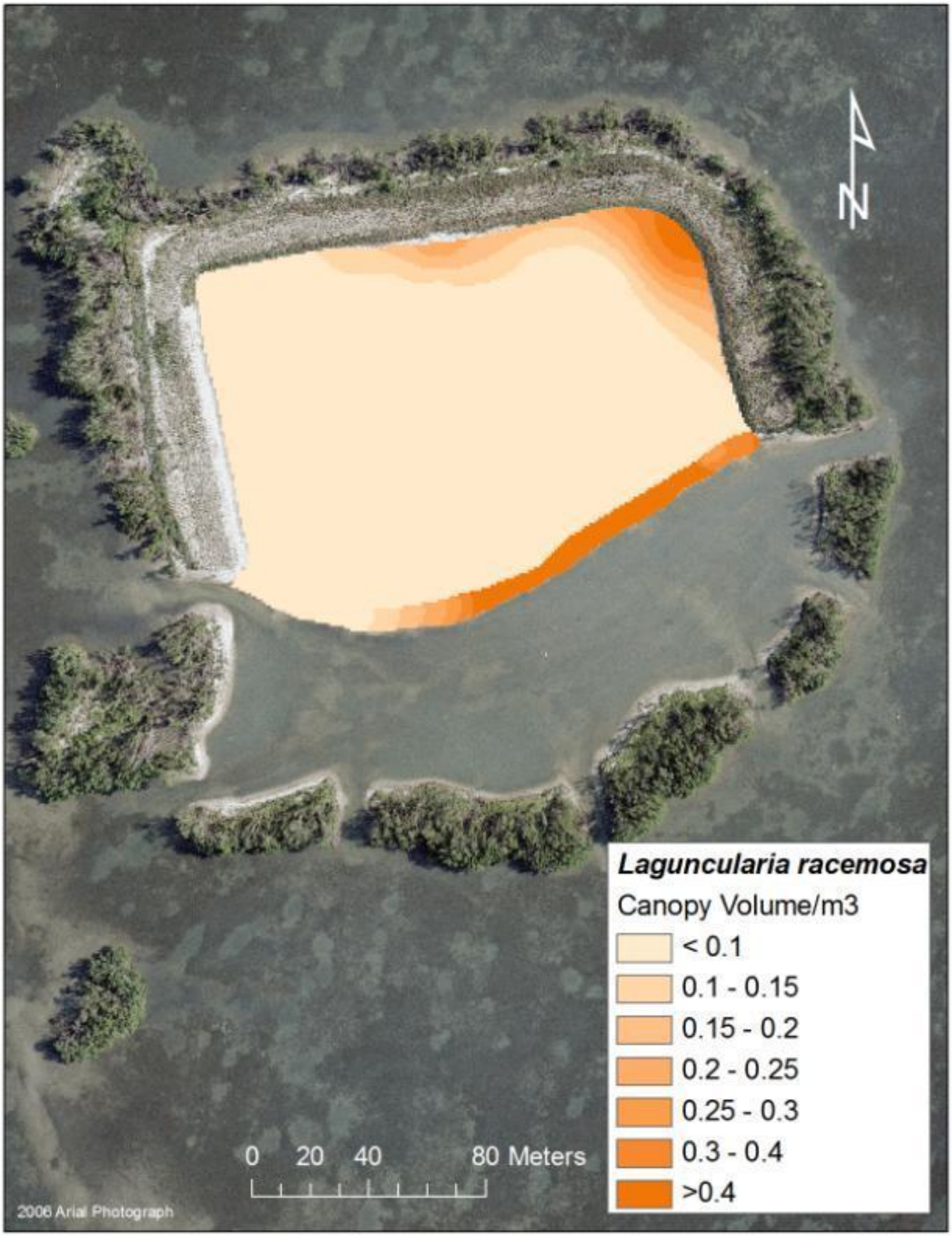


Figure A64. *L racemosa* calculated volume/m3 summer 2011.

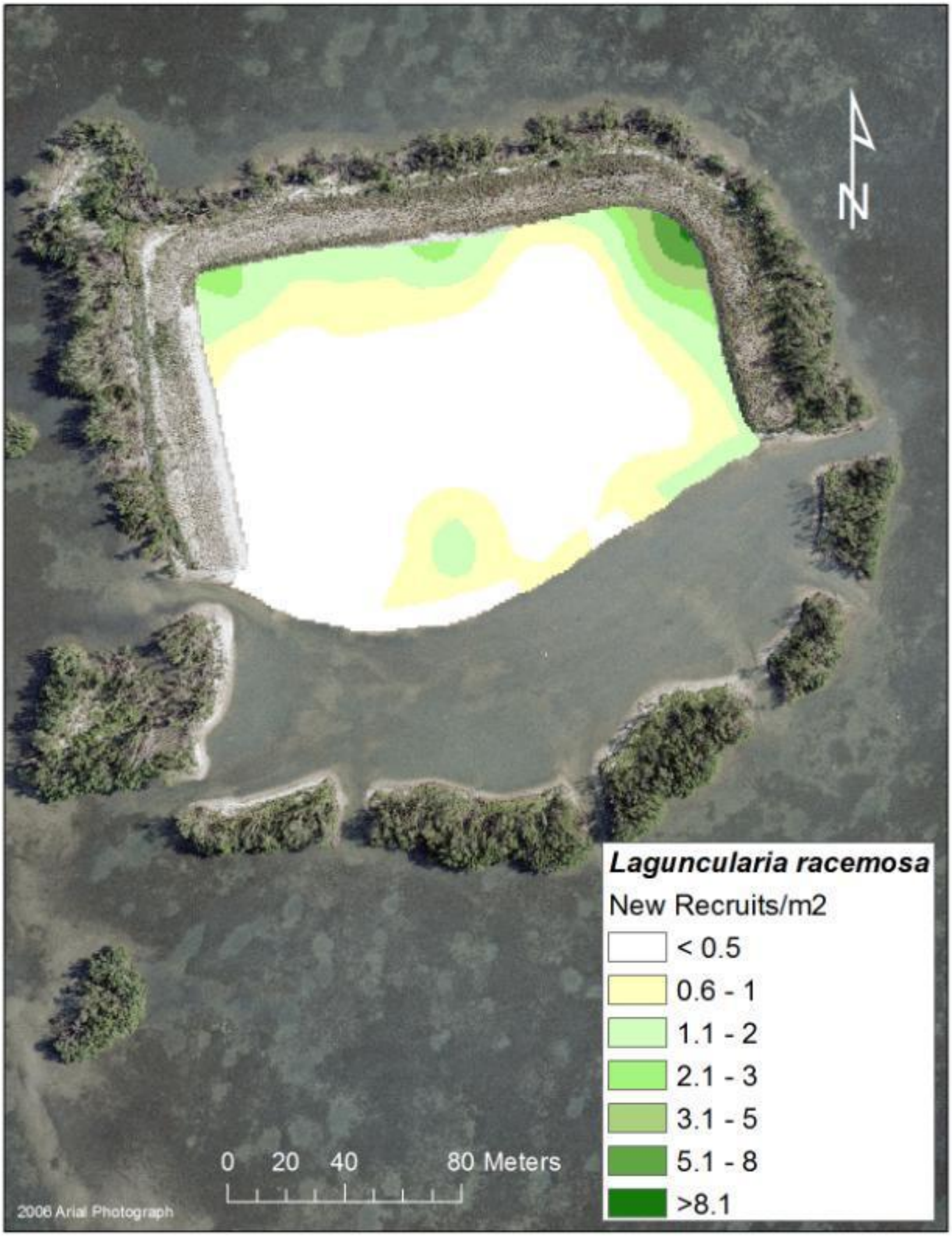


Figure A65. *L racemosa* juvenile mangrove recruits in summer 2011.

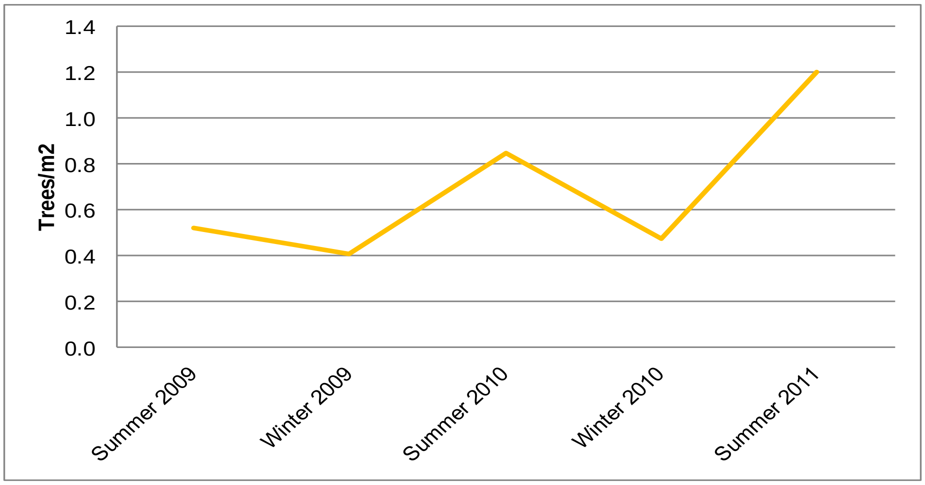


Figure A66. Average *L racemosa* density from summer 2009 to summer 2011.

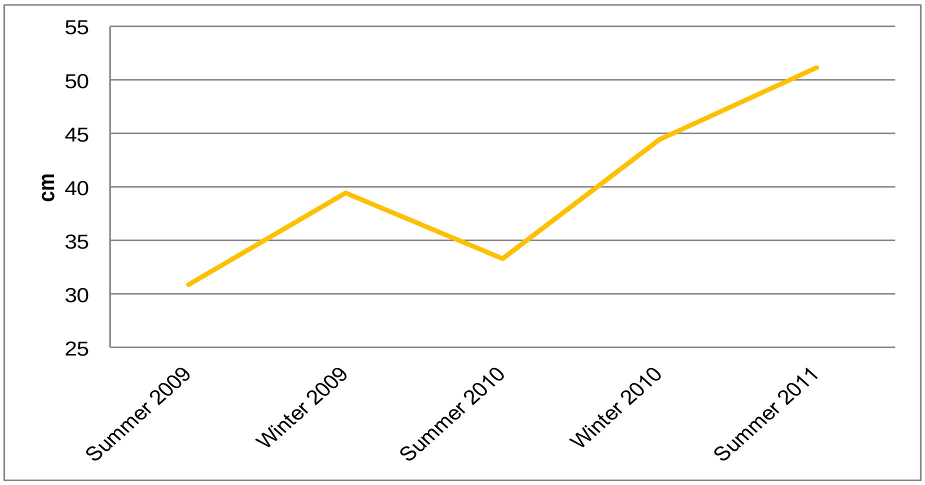


Figure A67. Average *L racemosa* height from summer 2009 to summer 2011.

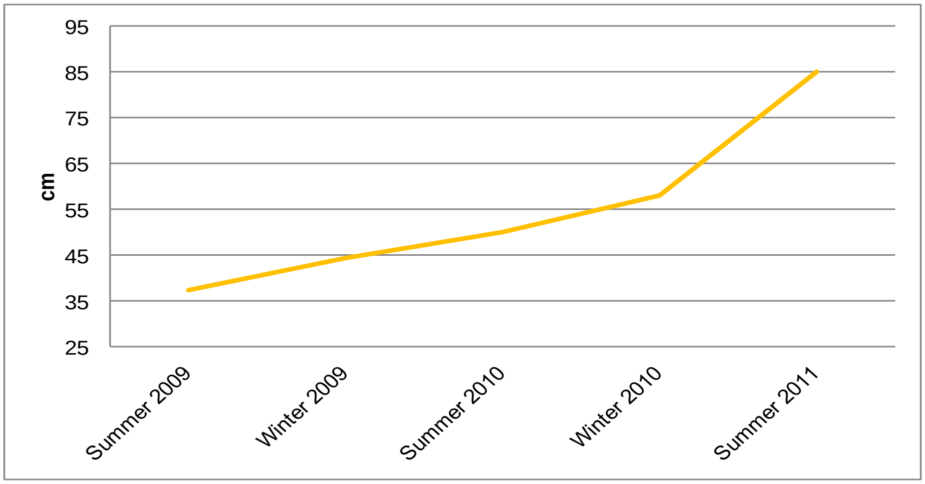


Figure A68. Average *L racemosa* maximum height from summer 2009 to summer 2011.

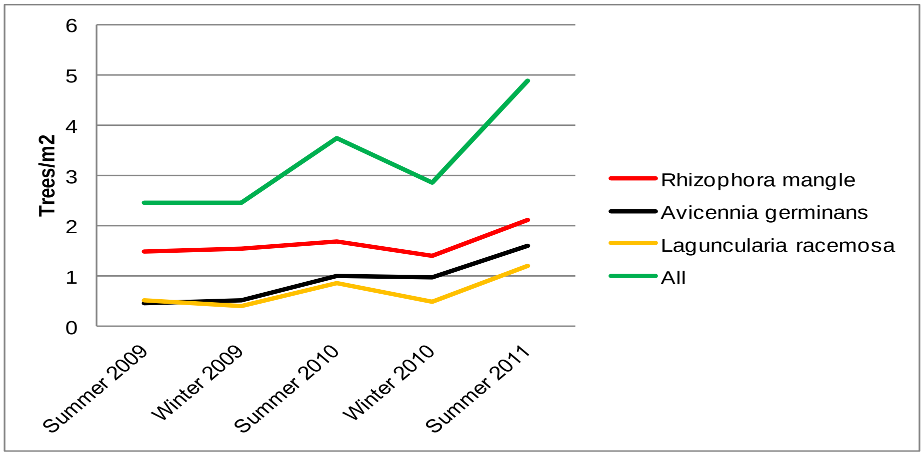


Figure A69. Average mangrove density for all species of mangrove from summer 2009 to summer 2011.

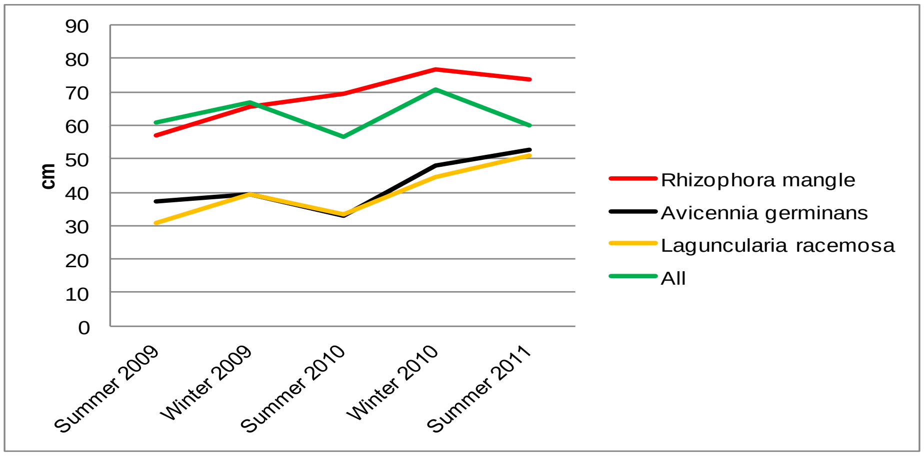


Figure A70. Average mangrove height for all species of mangroves from summer 2009 to summer 2011.

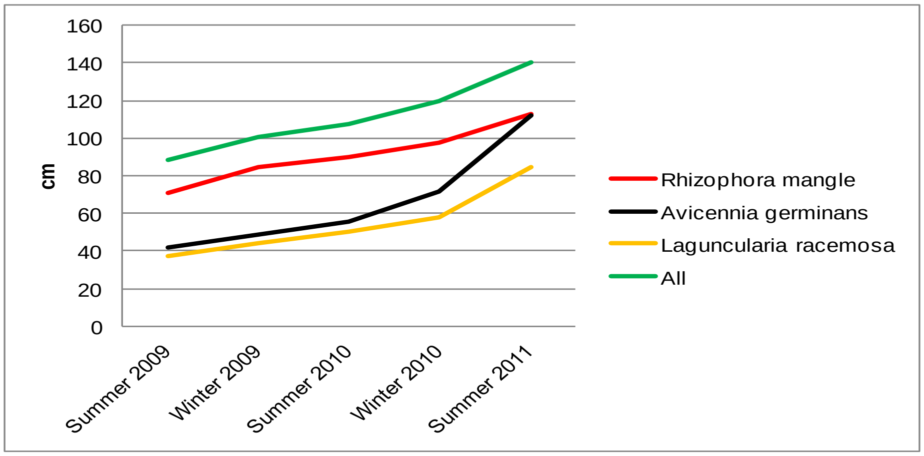
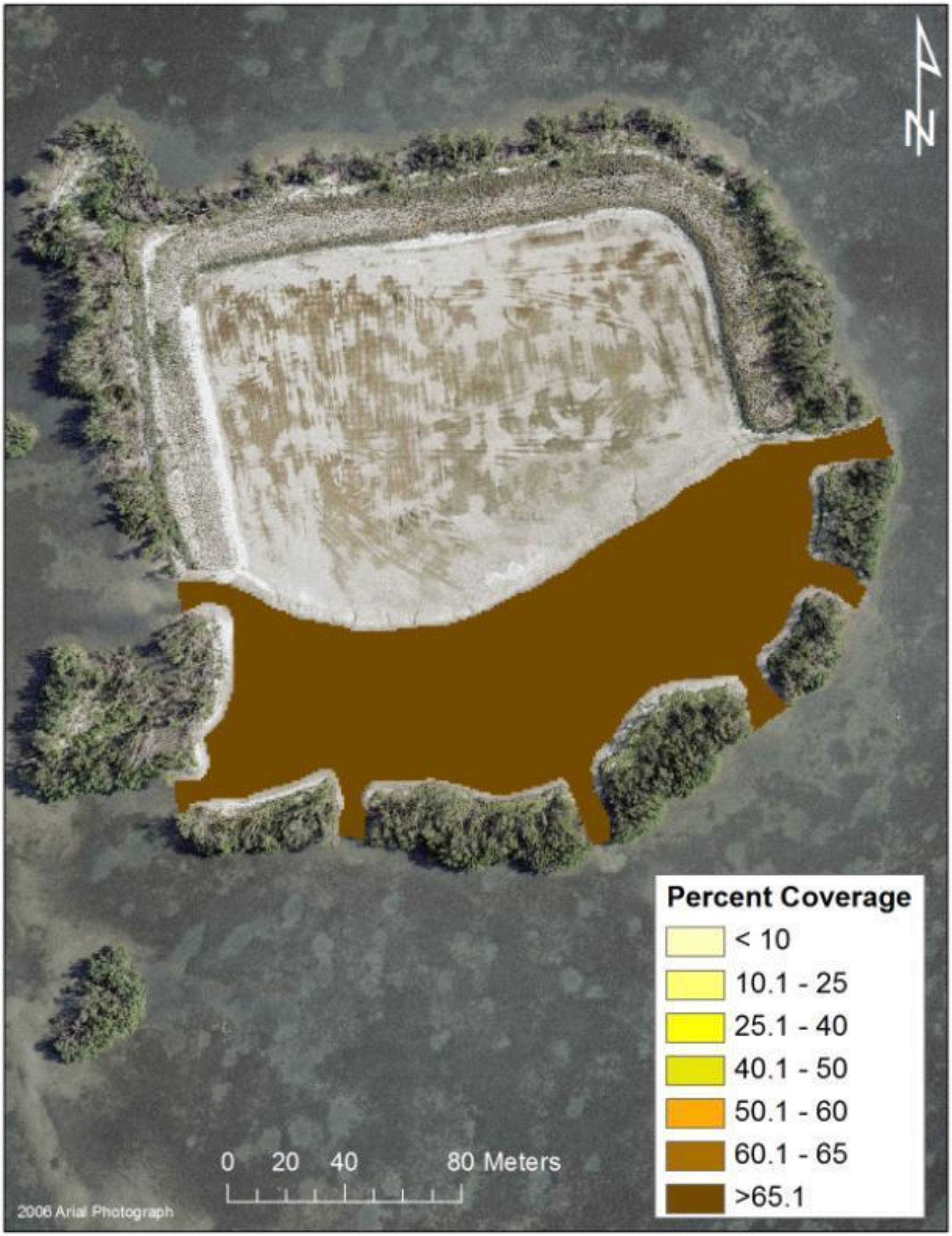


Figure A71. Average mangrove maximum height for all species of mangroves from summer 2009 to summer 2011.

Figure A72. Drift algae coverage of seagrass area (A) and an example depicting percent cover estimation of the algae (B).

Figure A73. Algae coverage in the seagrass recruitment area during winter 2008.



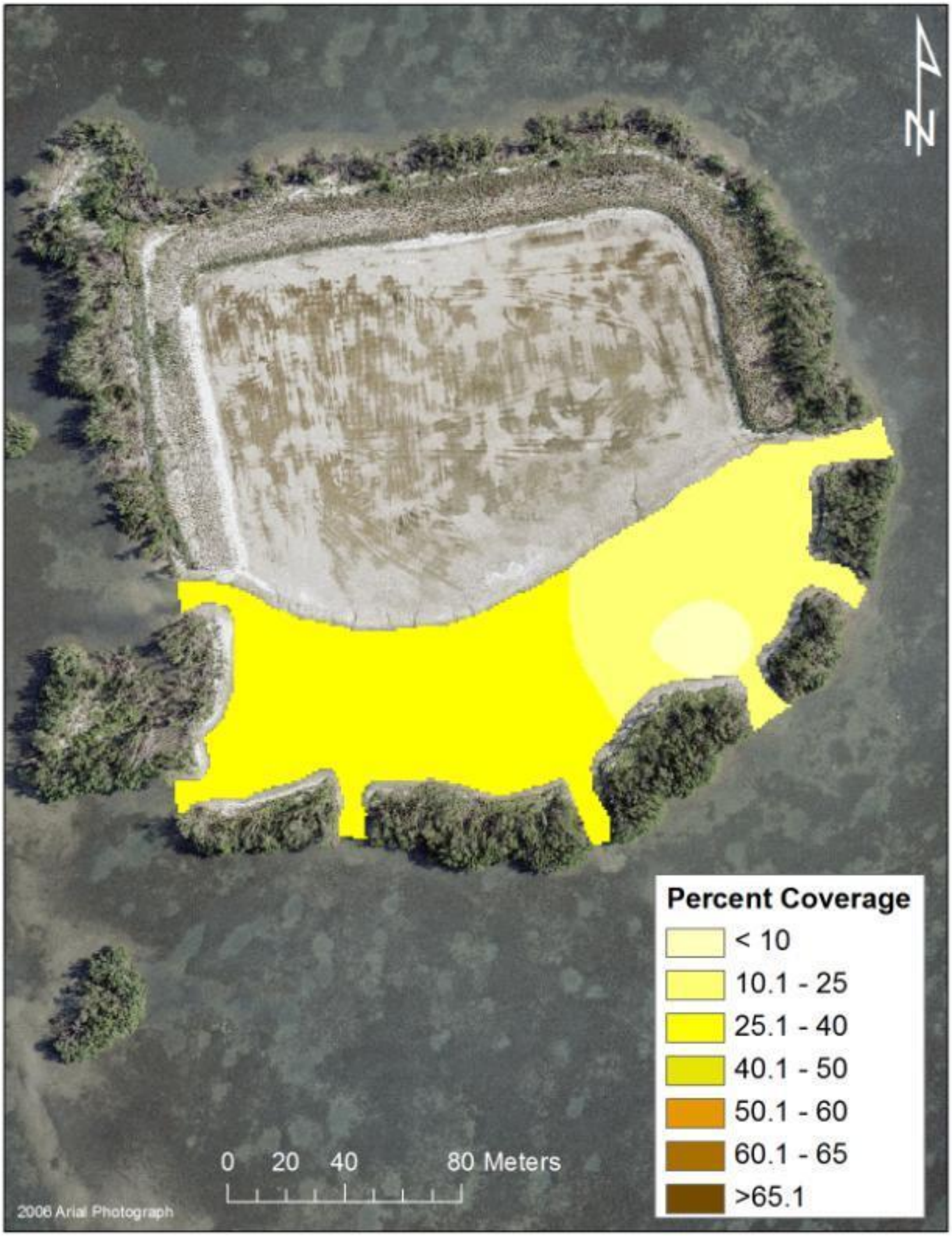


Figure A74. Algae coverage in the seagrass recruitment area during summer 2009.

Figure A75. Algae coverage in the seagrass recruitment area during winter 2009.

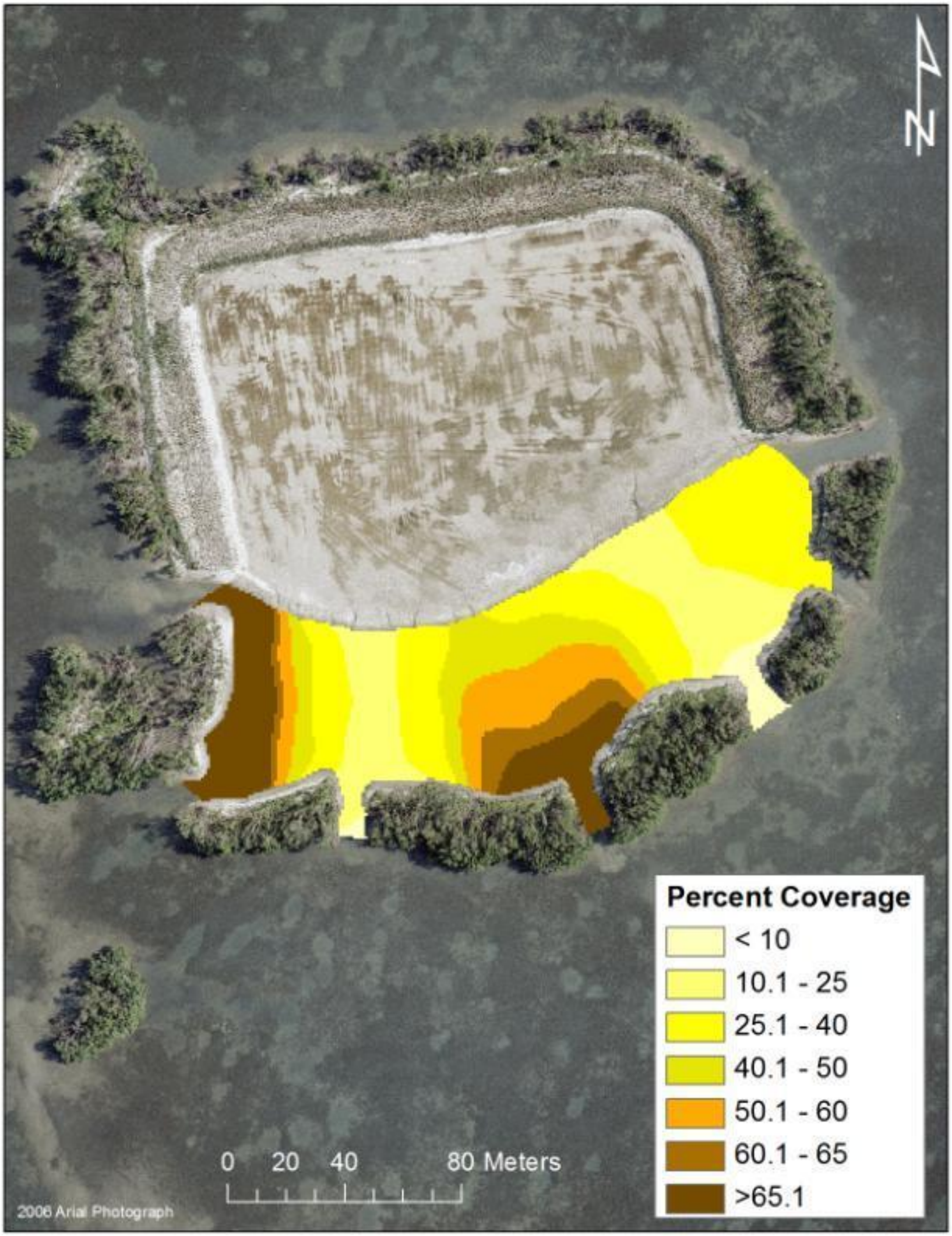


Figure A75. Algae coverage in the seagrass recruitment area during winter 2009.

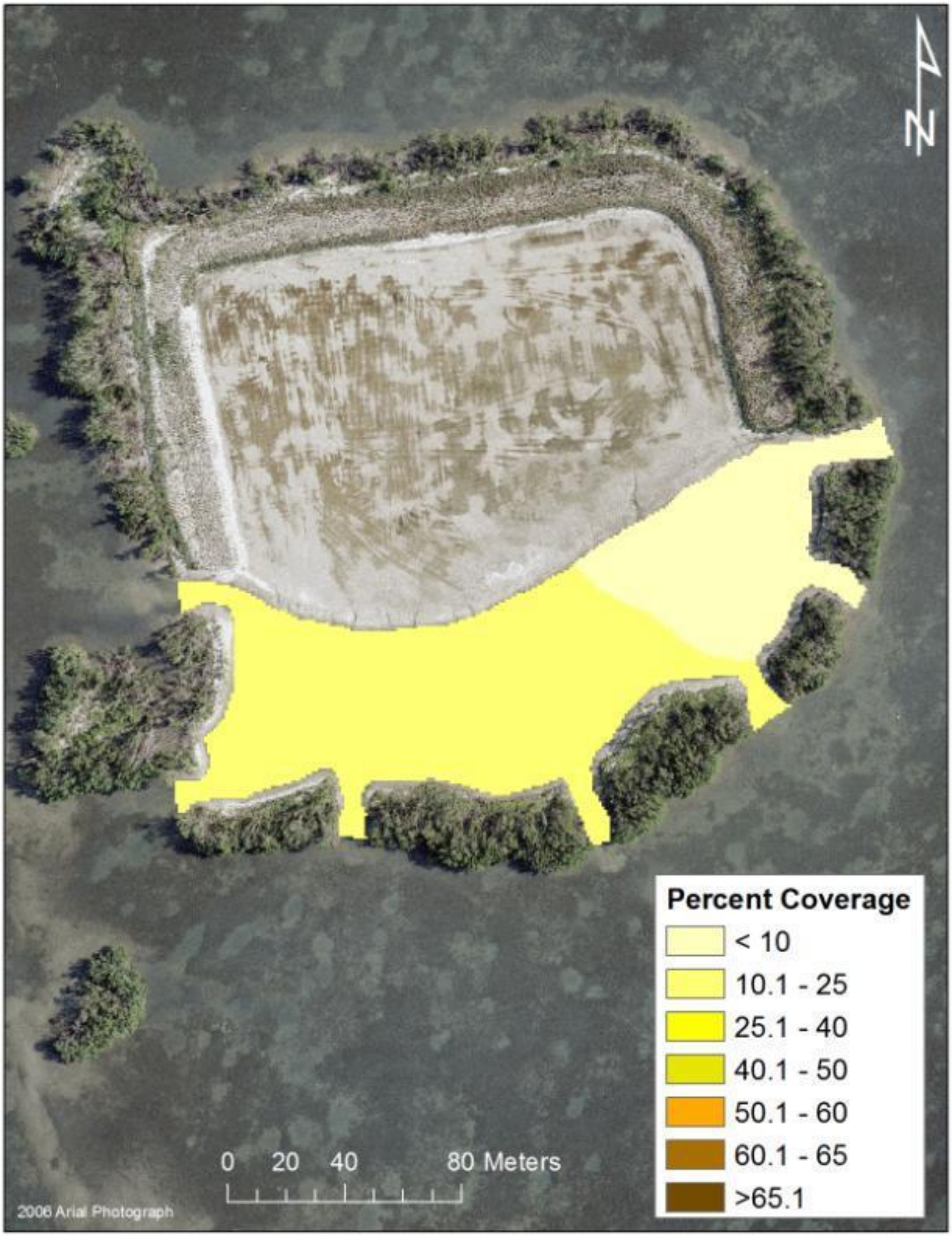


Figure A76. Algae coverage in the seagrass recruitment area during summer 2010.

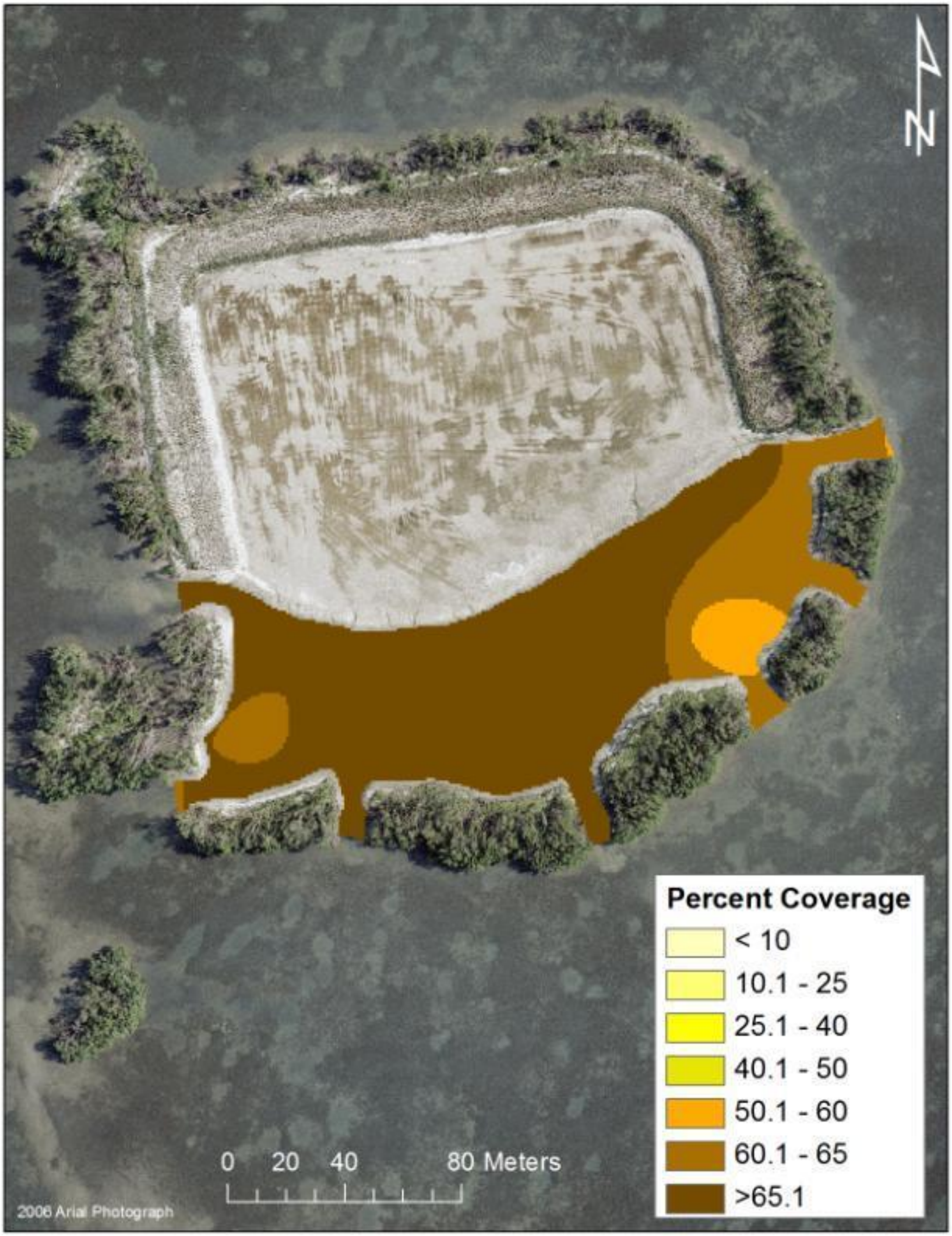


Figure A77. Algae coverage in the seagrass recruitment area during winter 2010.

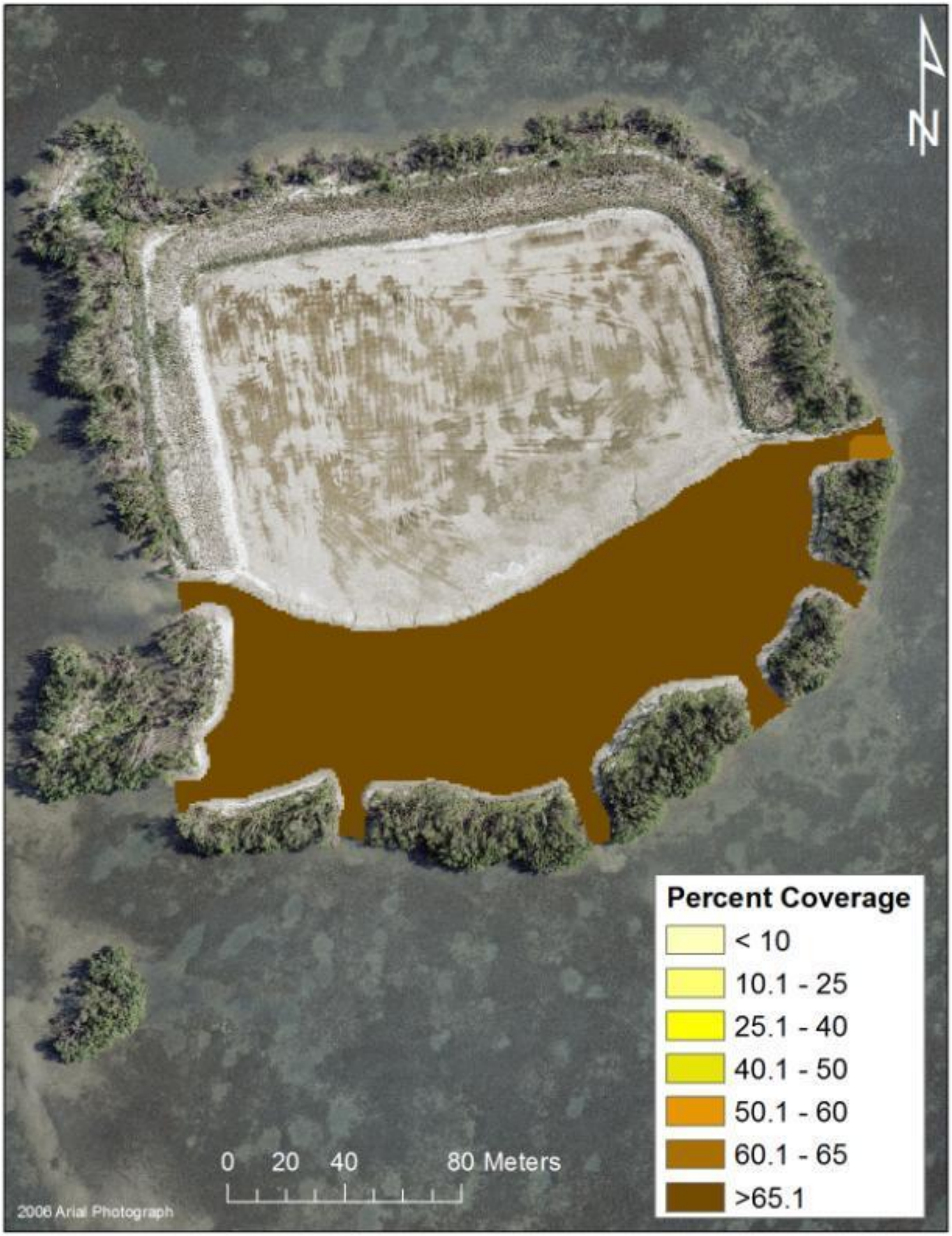


Figure A78. Algae coverage in the seagrass recruitment area during summer 2011.

Figure A79. Seagrass coverage in the seagrass recruitment area for winter 2008.

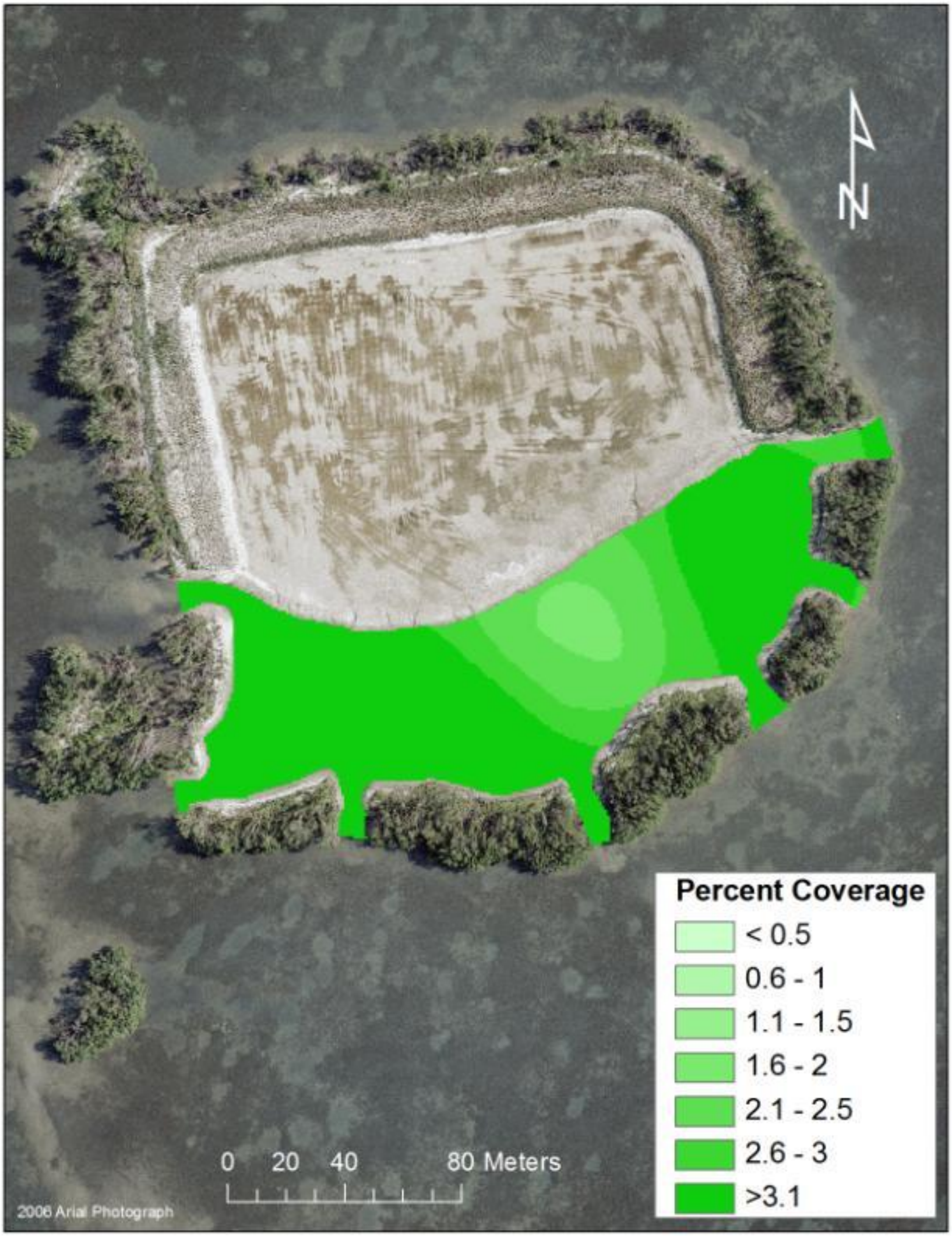


Figure A80. Seagrass coverage in the seagrass recruitment area for summer 2009.

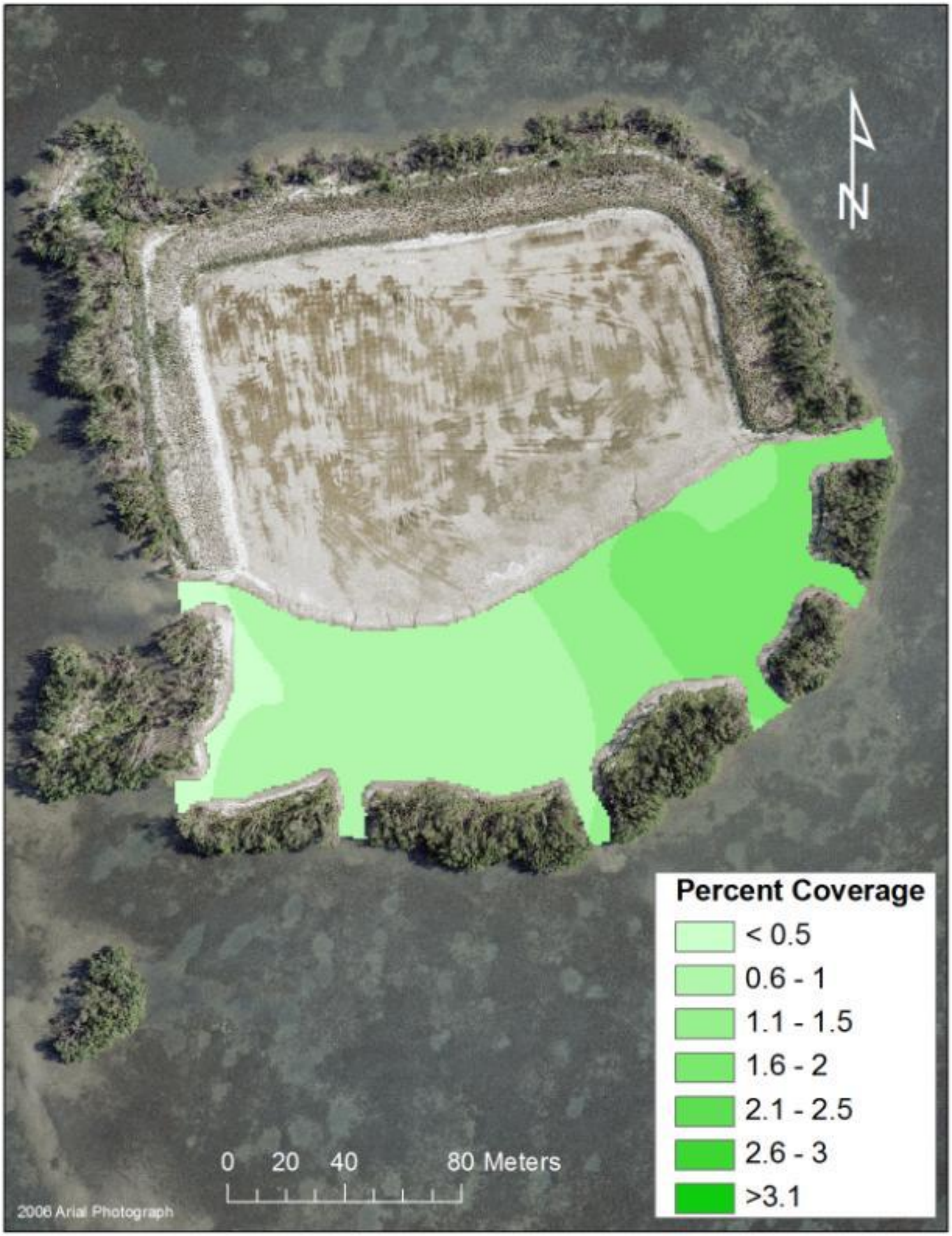


Figure A81. Seagrass coverage in the seagrass recruitment area for winter 2009.

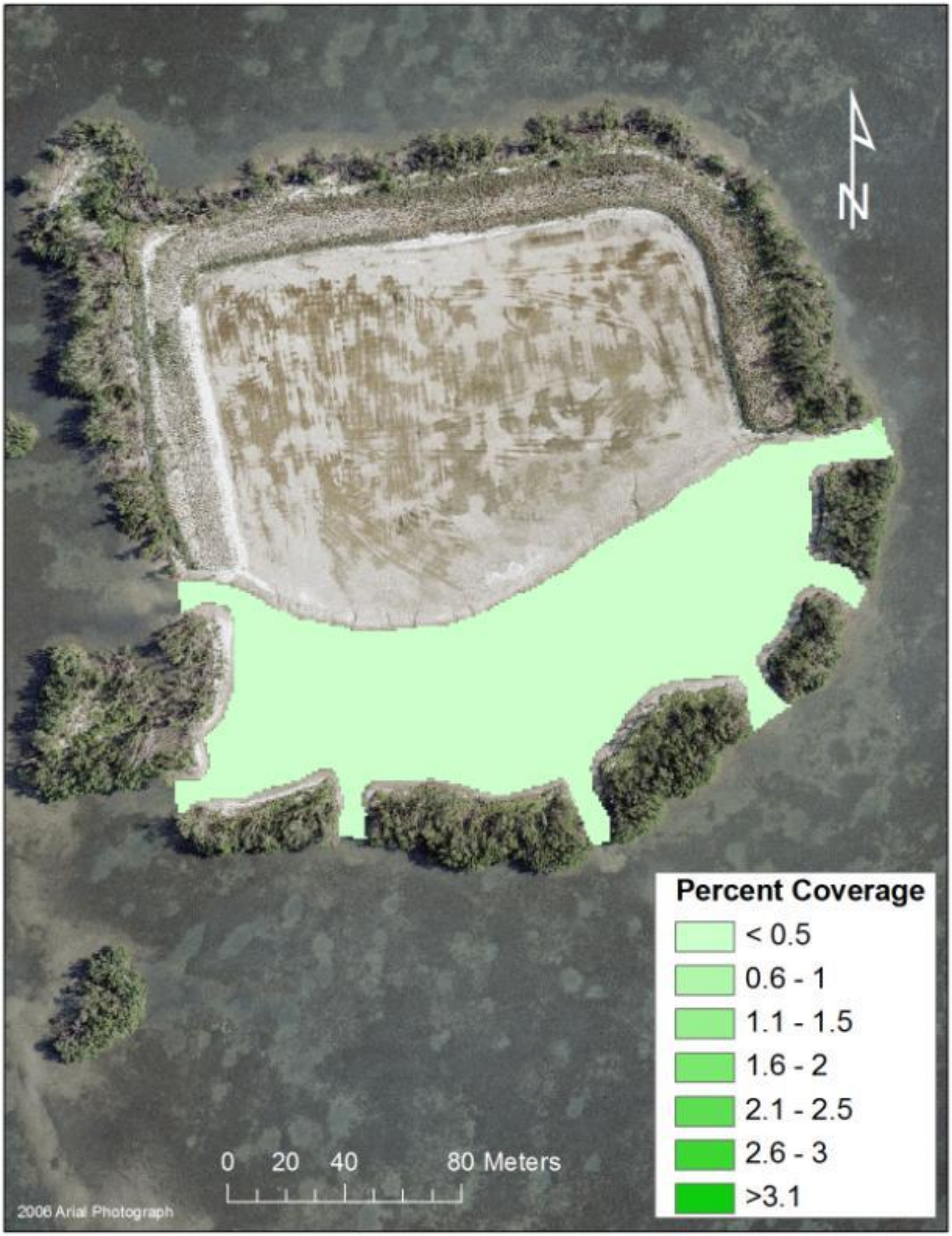


Figure A81. Seagrass coverage in the seagrass recruitment area for winter 2009.

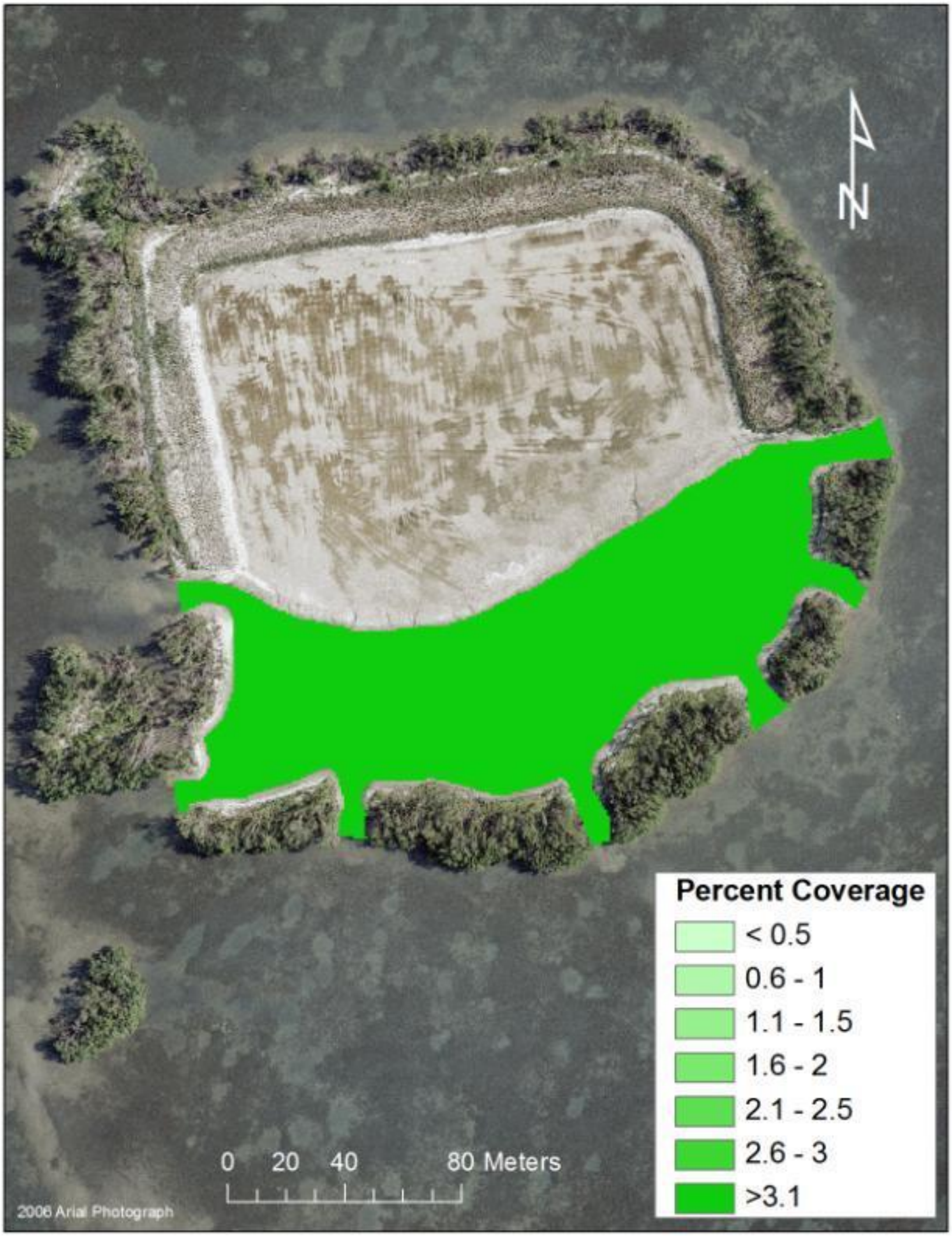


Figure A82. Seagrass coverage in the seagrass recruitment area for summer 2010.

Figure A83. Seagrass coverage in the seagrass recruitment area for winter 2010.

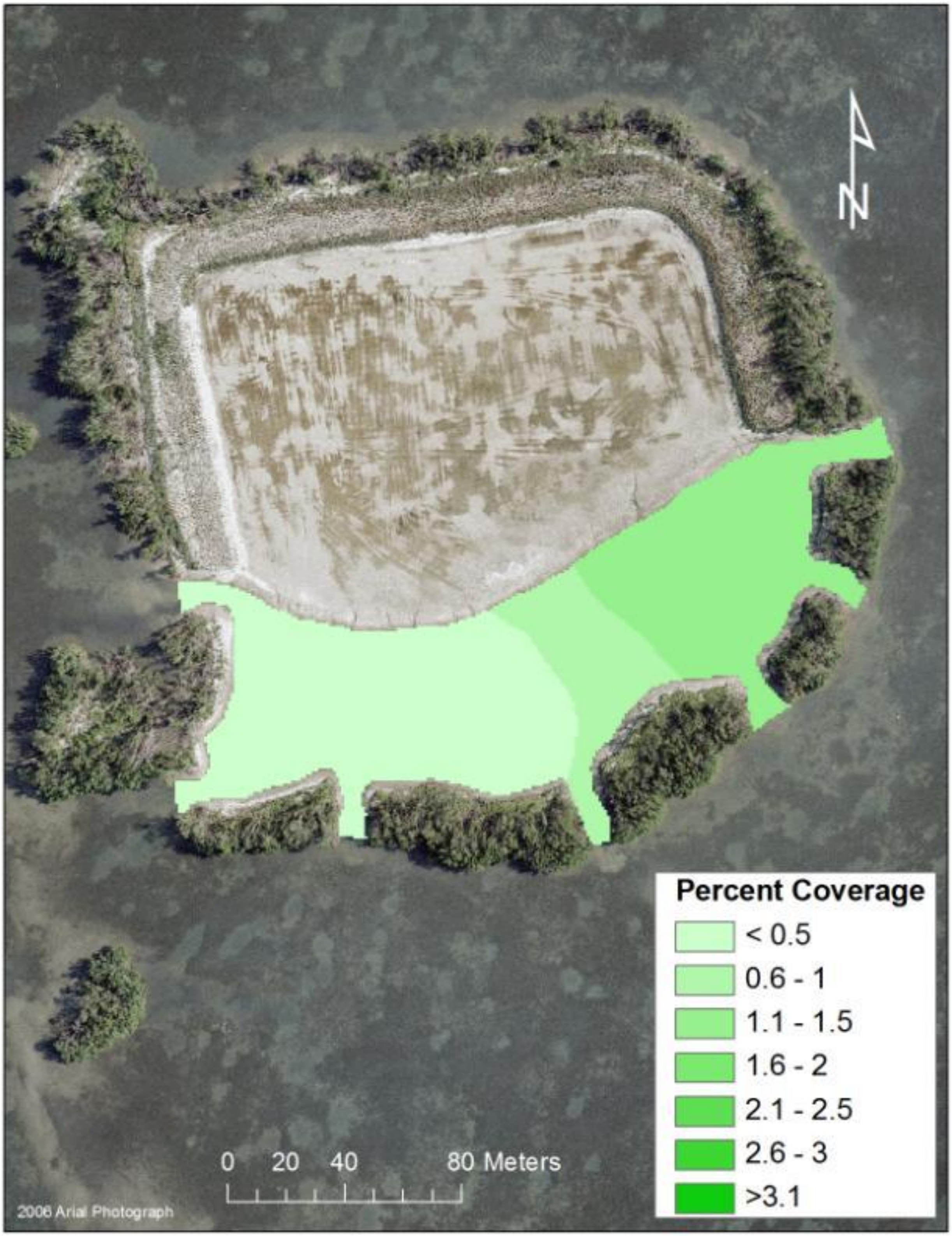


Figure A83. Seagrass coverage in the seagrass recruitment area for winter 2010.

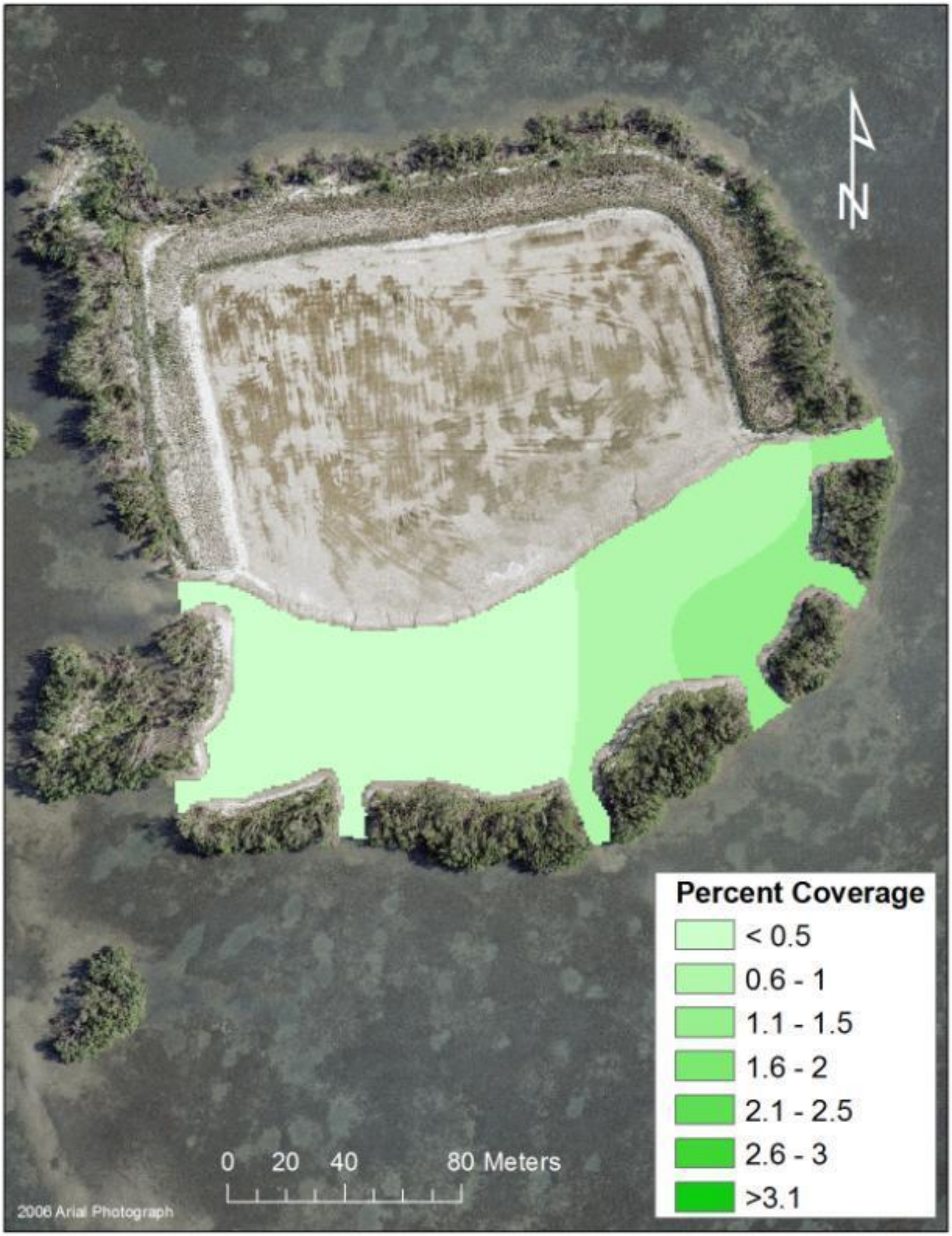


Figure A84. Seagrass coverage in the seagrass recruitment area for summer 2011.

Figure A85. Seagrass density (shoots/m2) in the seagrass recruitment area during winter 2008.

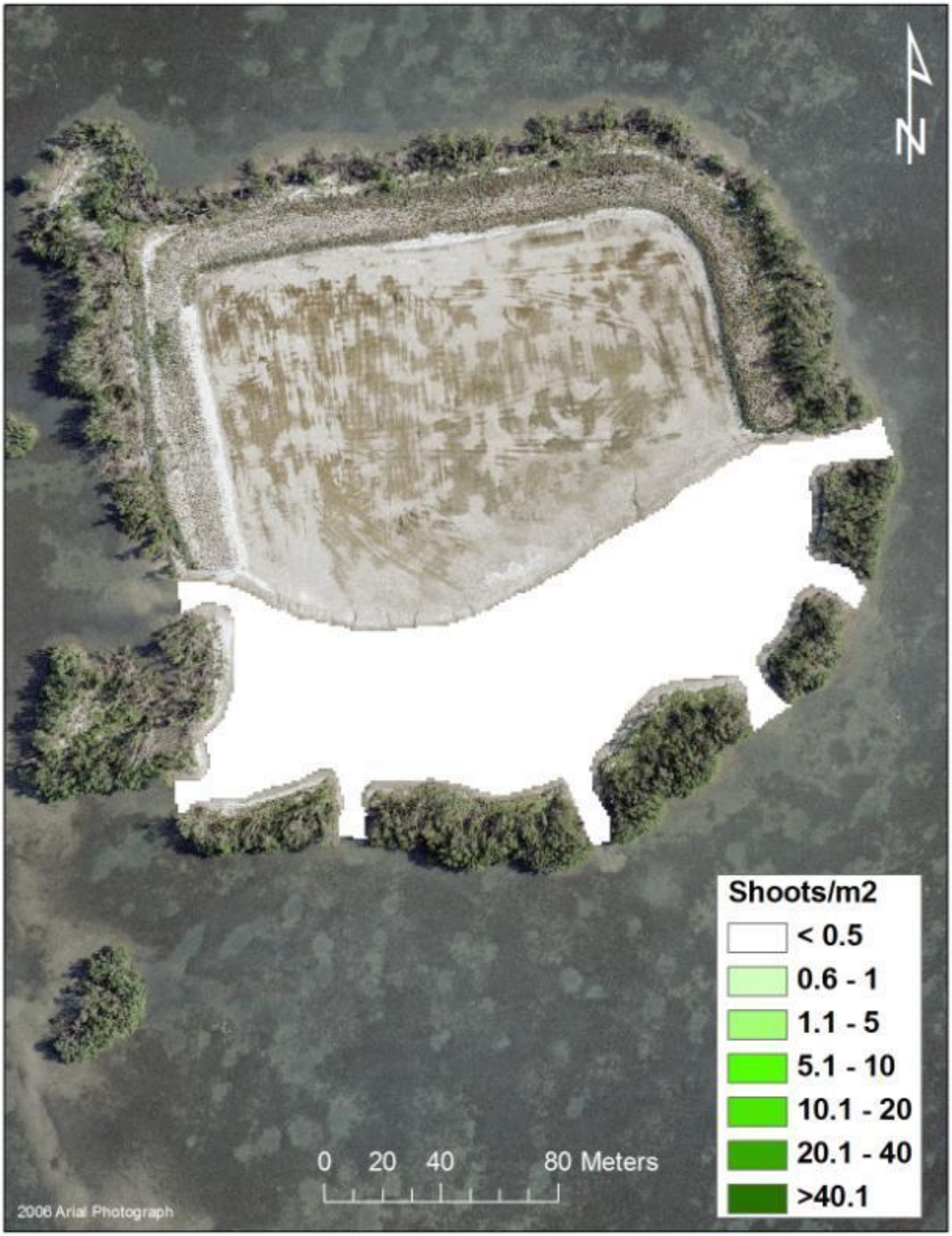


Figure A86. Seagrass density (shoots/m2) in the seagrass recruitment area during summer 2009.

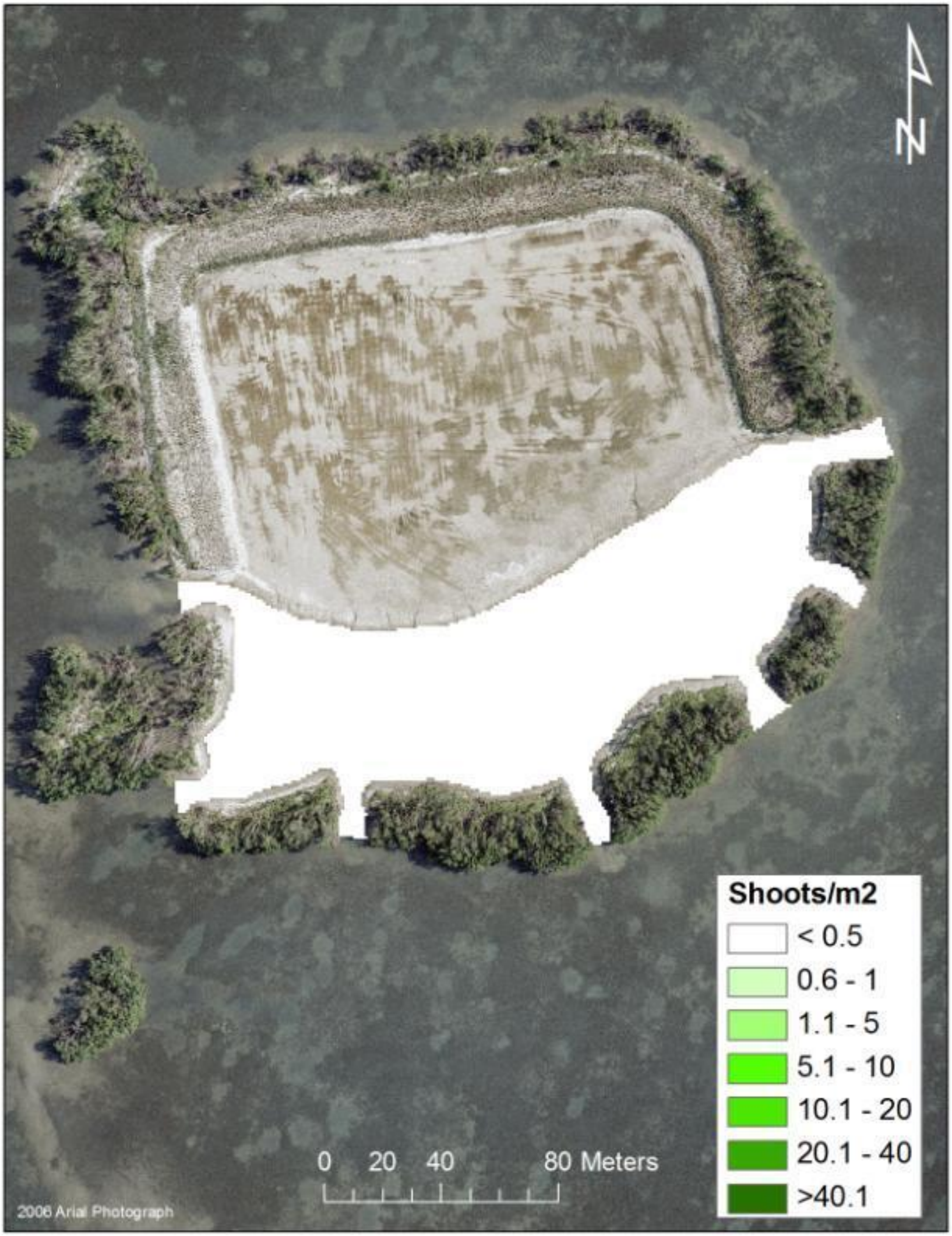


Figure A87. Seagrass density (shoots/m2) in the seagrass recruitment area during winter 2009.

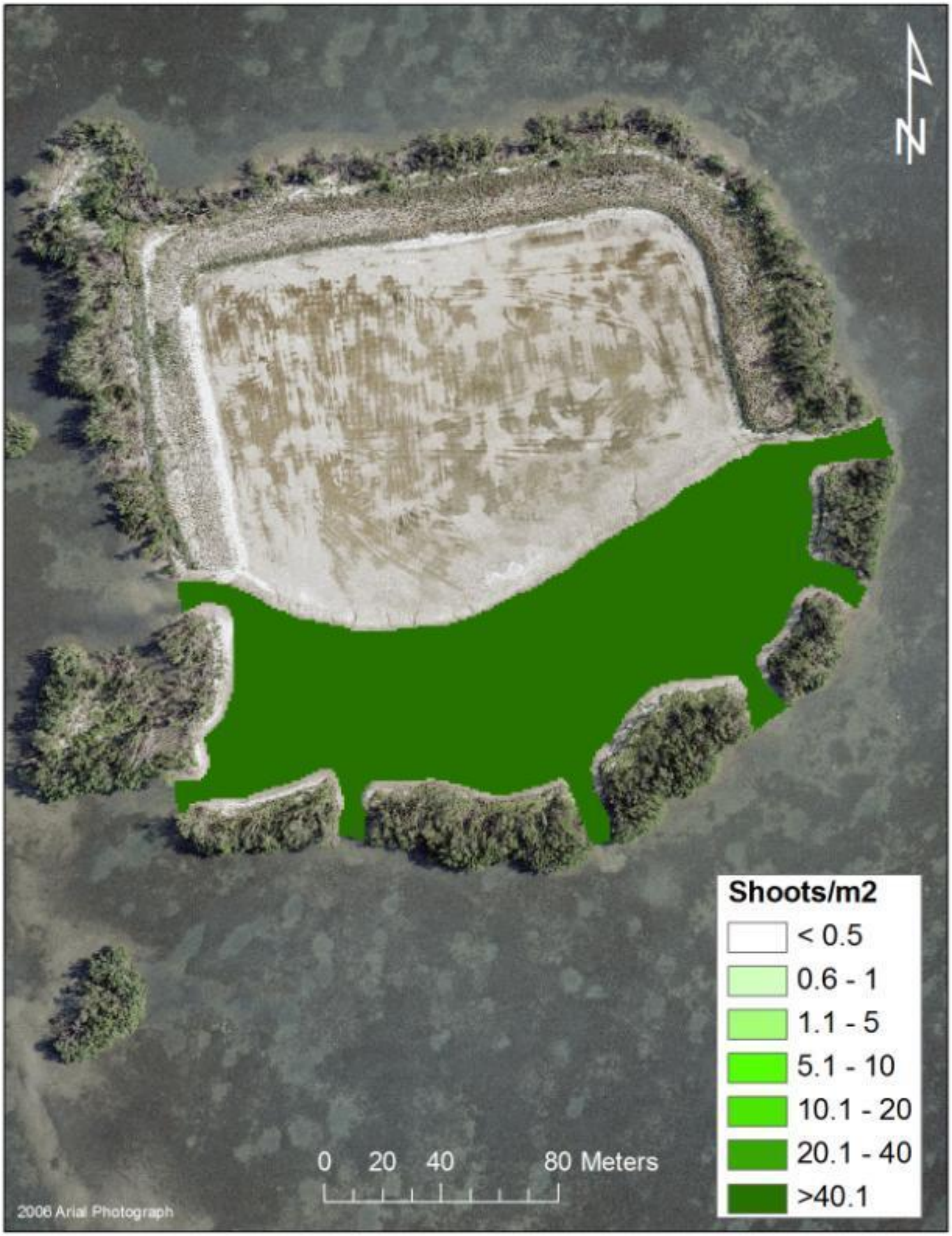
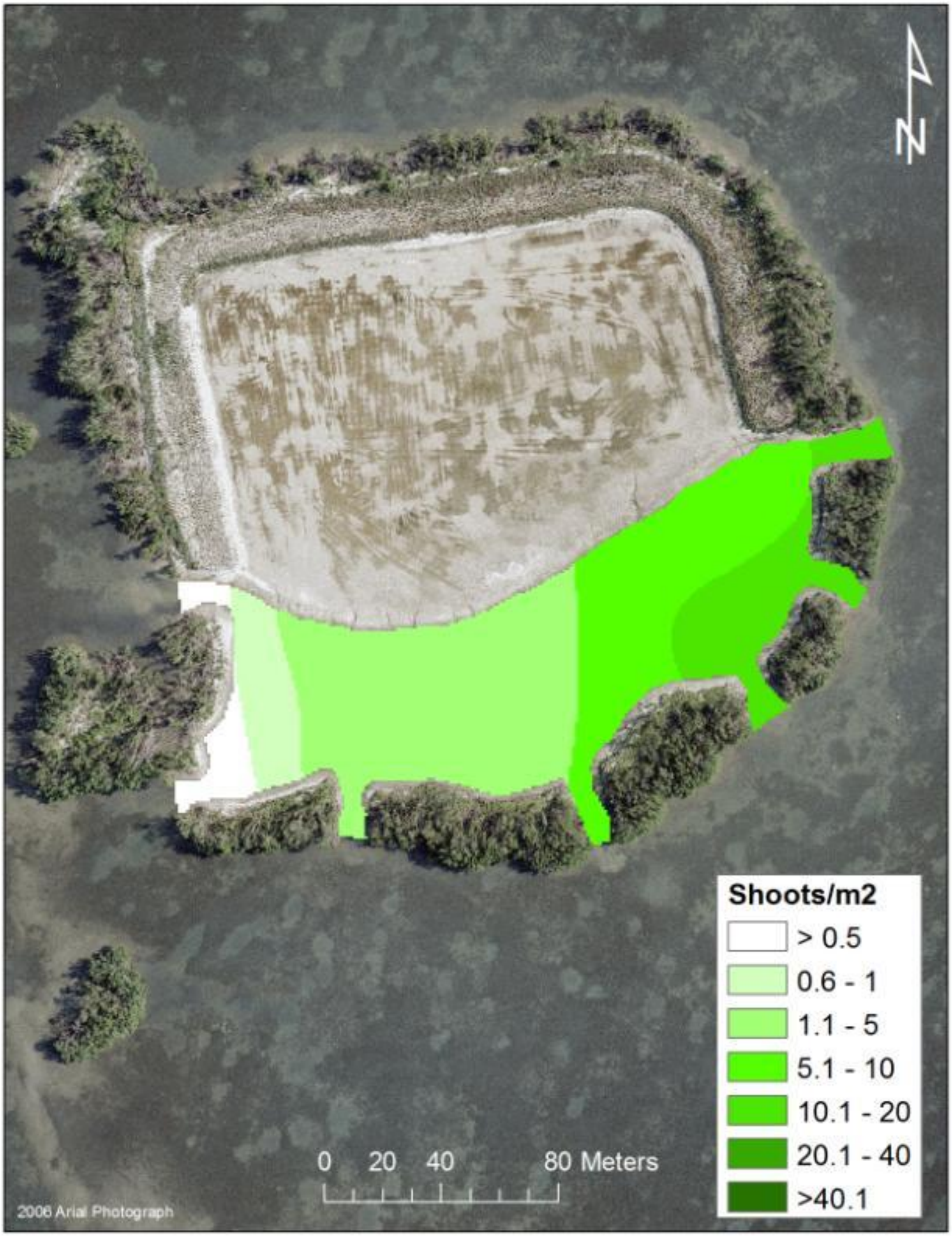


Figure A88. Seagrass density (shoots/m2) in the seagrass recruitment area during summer 2010.

Figure A89. Seagrass density (shoots/m2) in the seagrass recruitment area during winter 2010.

Figure A90. Seagrass density (shoots/m2) in the seagrass recruitment area during summer 2011.



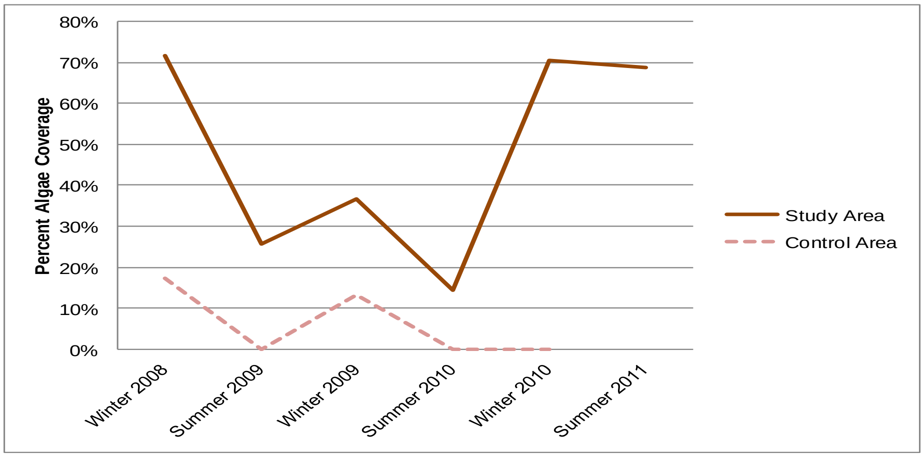


Figure A91. Average percent algae coverage for the seagrass recruitment area and the control area from winter2008 to summer 2011.

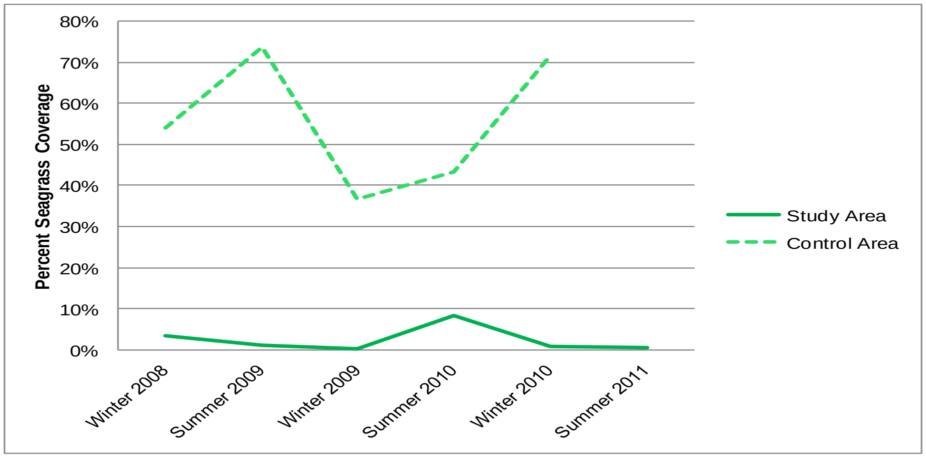


Figure A92. Average percent seagrass coverage for the seagrass recruitment area and the control area from winter2008 to summer 2011.

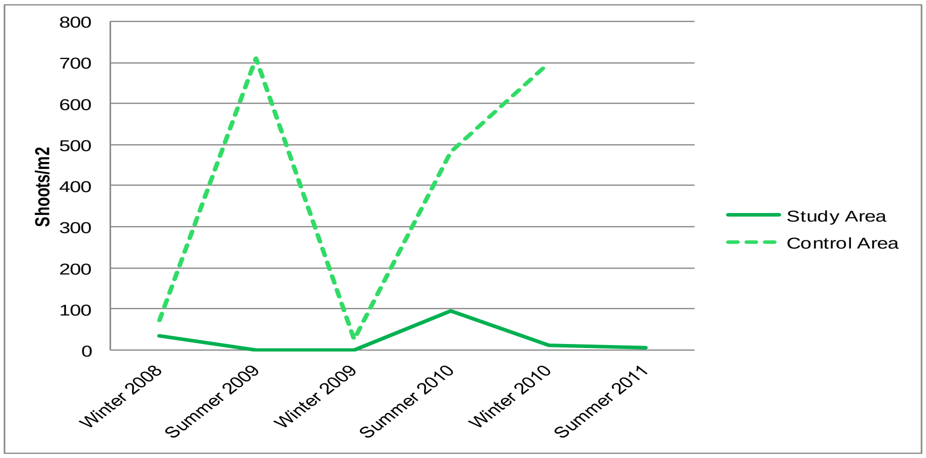


Figure A93. Average seagrass density for the seagrass recruitment area and the control area from winter 2008 to summer 2011.

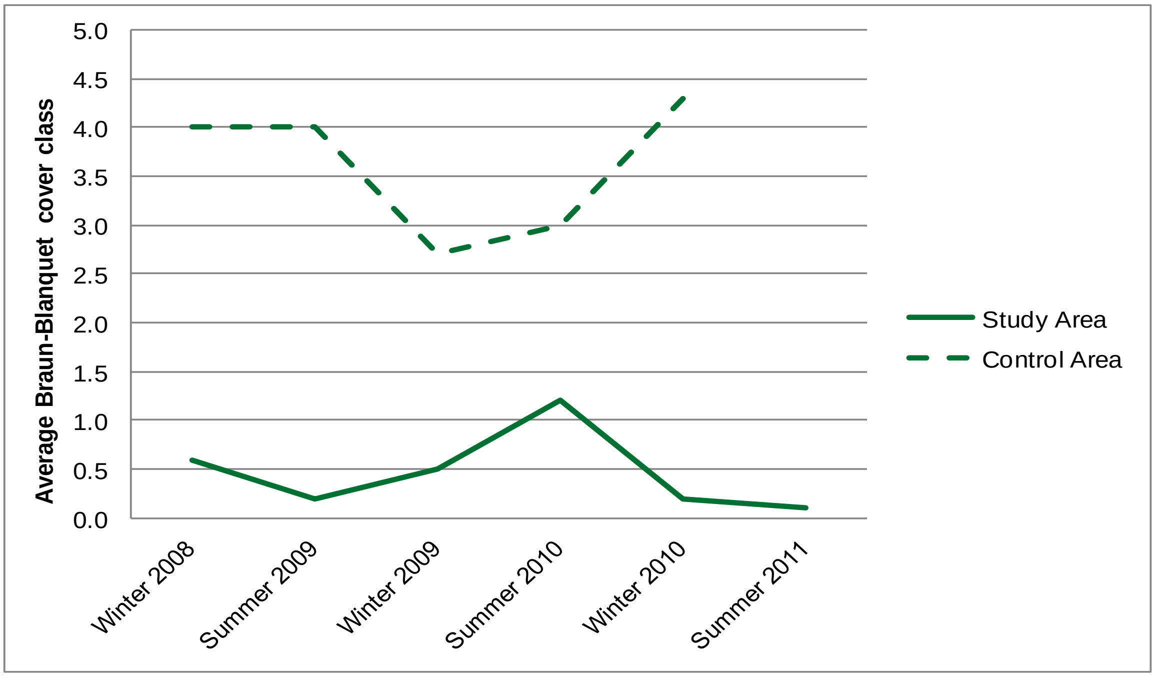


Figure A94. Average Braun-Blanquet cover class for the seagrass recruitment area and the control area from winter 2008 to summer 2011.

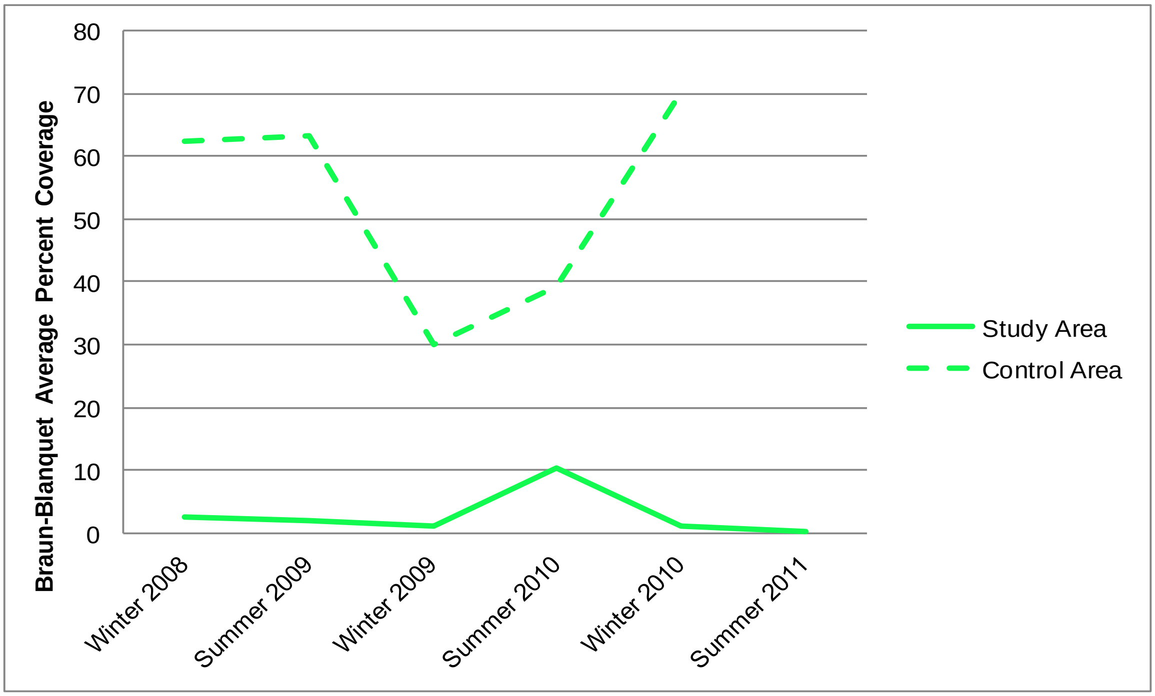


Figure A95. Average Braun-Blanquet percent coverage for the seagrass recruitment area and the control area from winter 2008 to summer 2011.

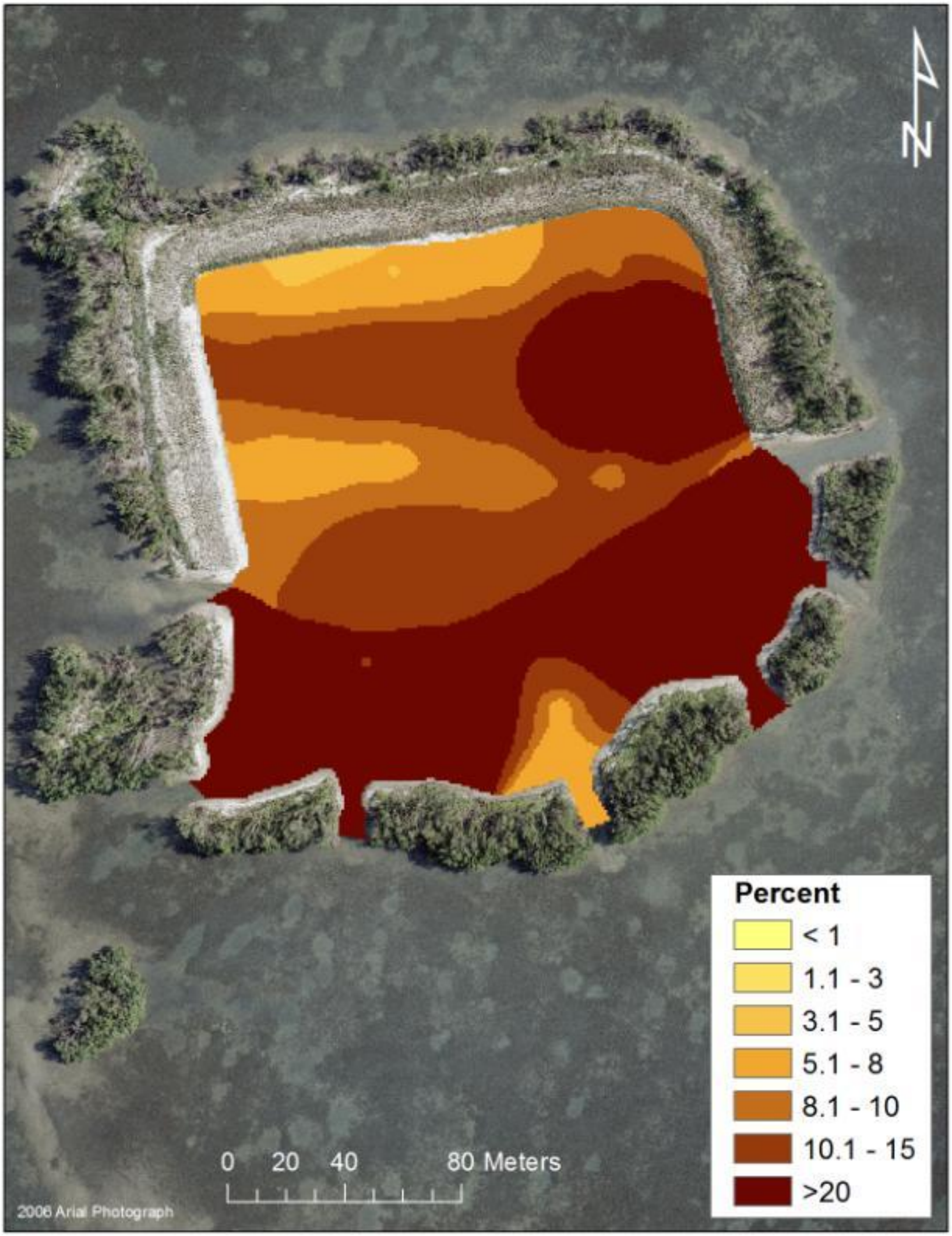
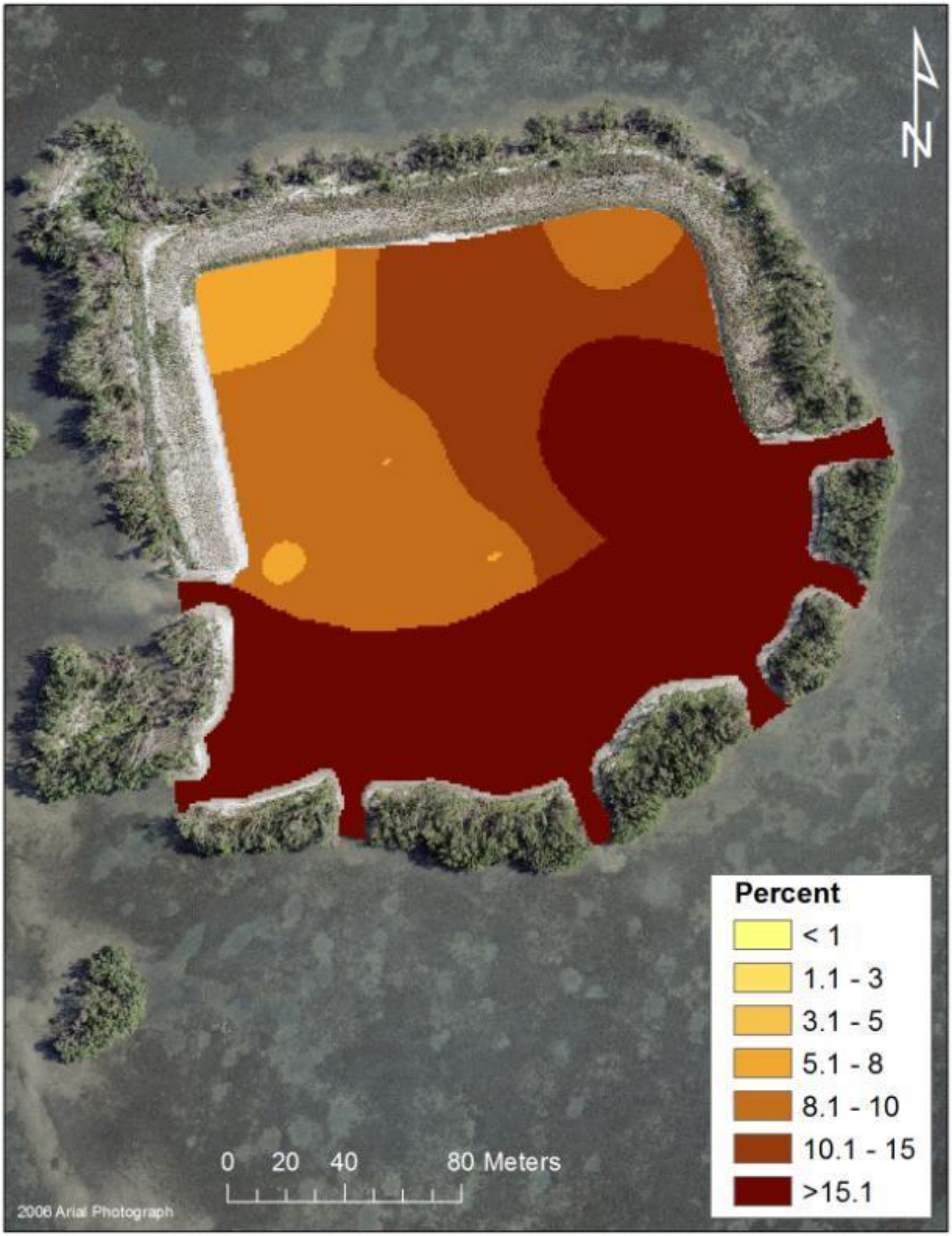


Figure A96. Percentage of soil sample with fine soil particles for winter 2008.

Figure A97. Percentage of soil sample with fine soil particles for summer 2009.



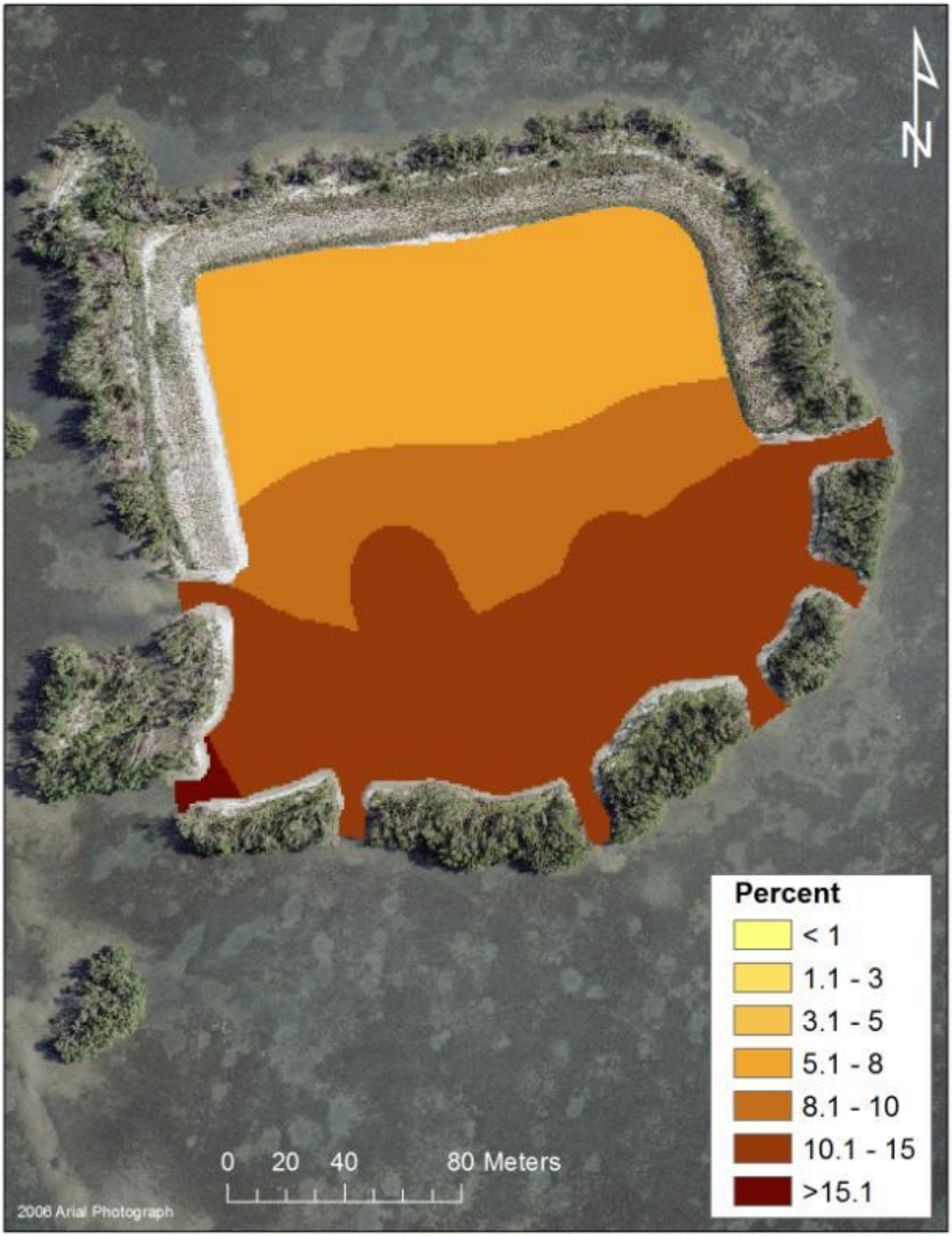


Figure A98. Percentage of soil sample with fine soil particles for winter 2009.

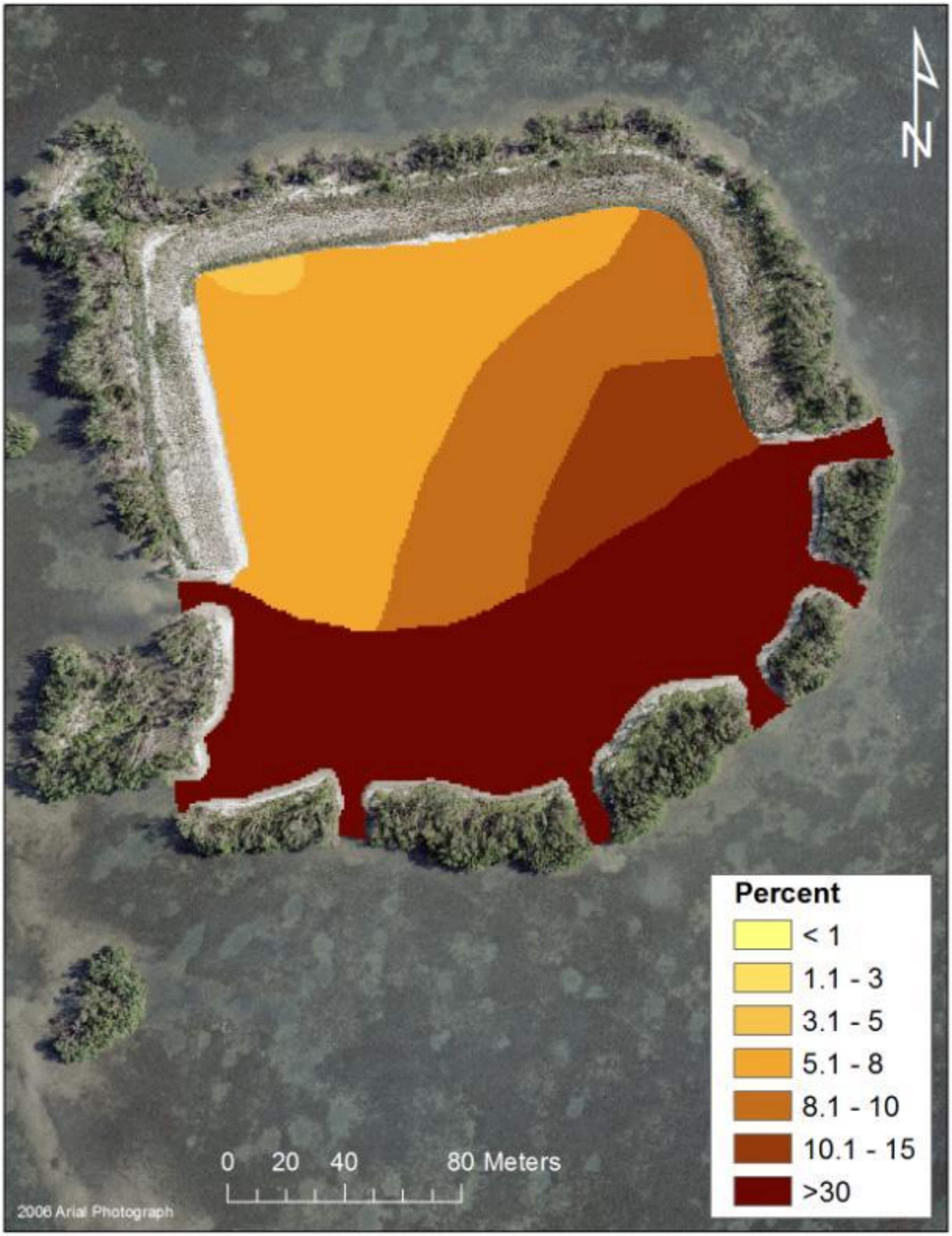


Figure A99. Percentage of soil sample with fine soil particles for summer 2010.

Figure A100. Percentage of soil sample with fine soil particles for winter 2010.

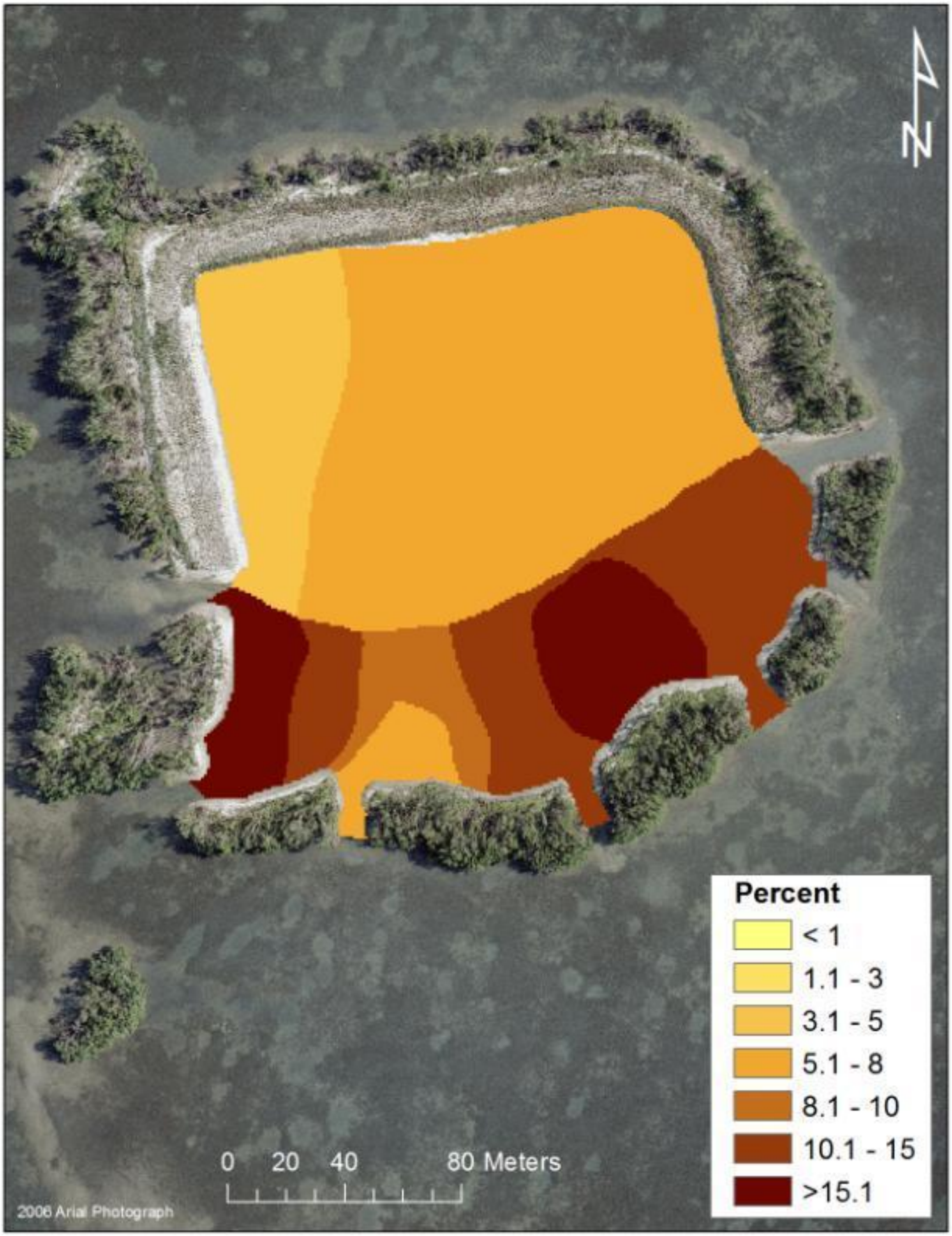


Figure A101. Percentage of soil sample with fine soil particles for summer 2011.

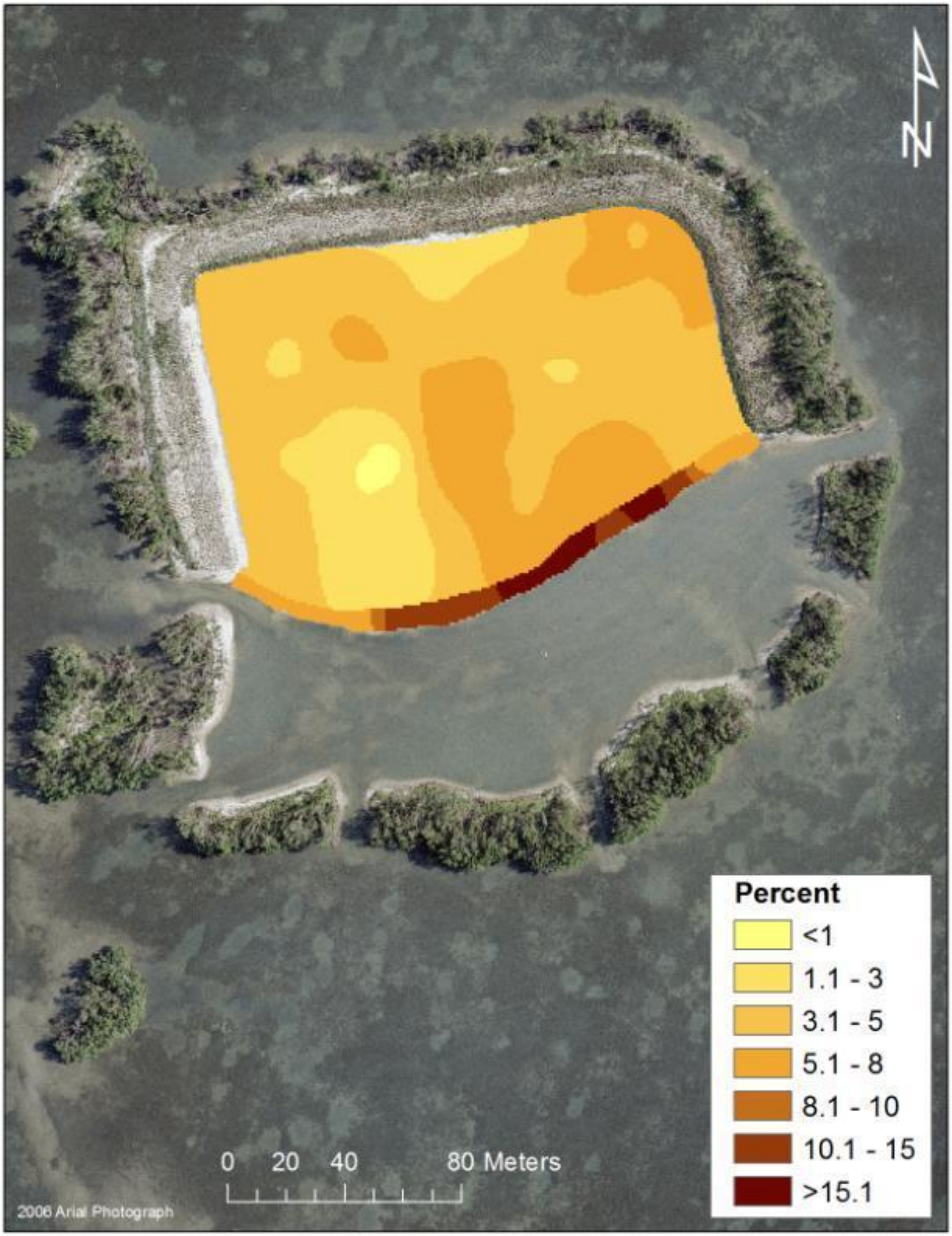
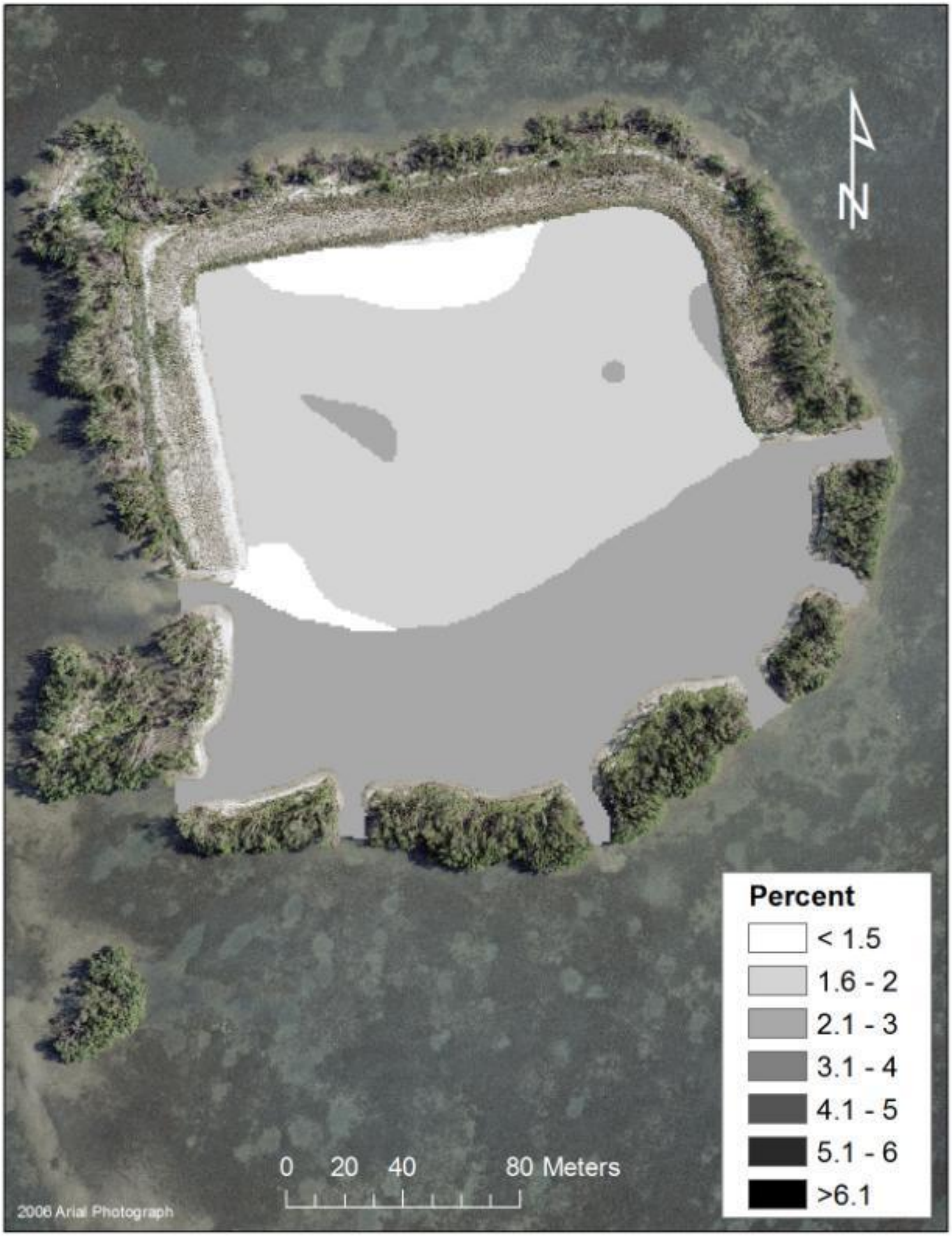


Figure A102. Percentage of organic matter within the soil for winter 2008.



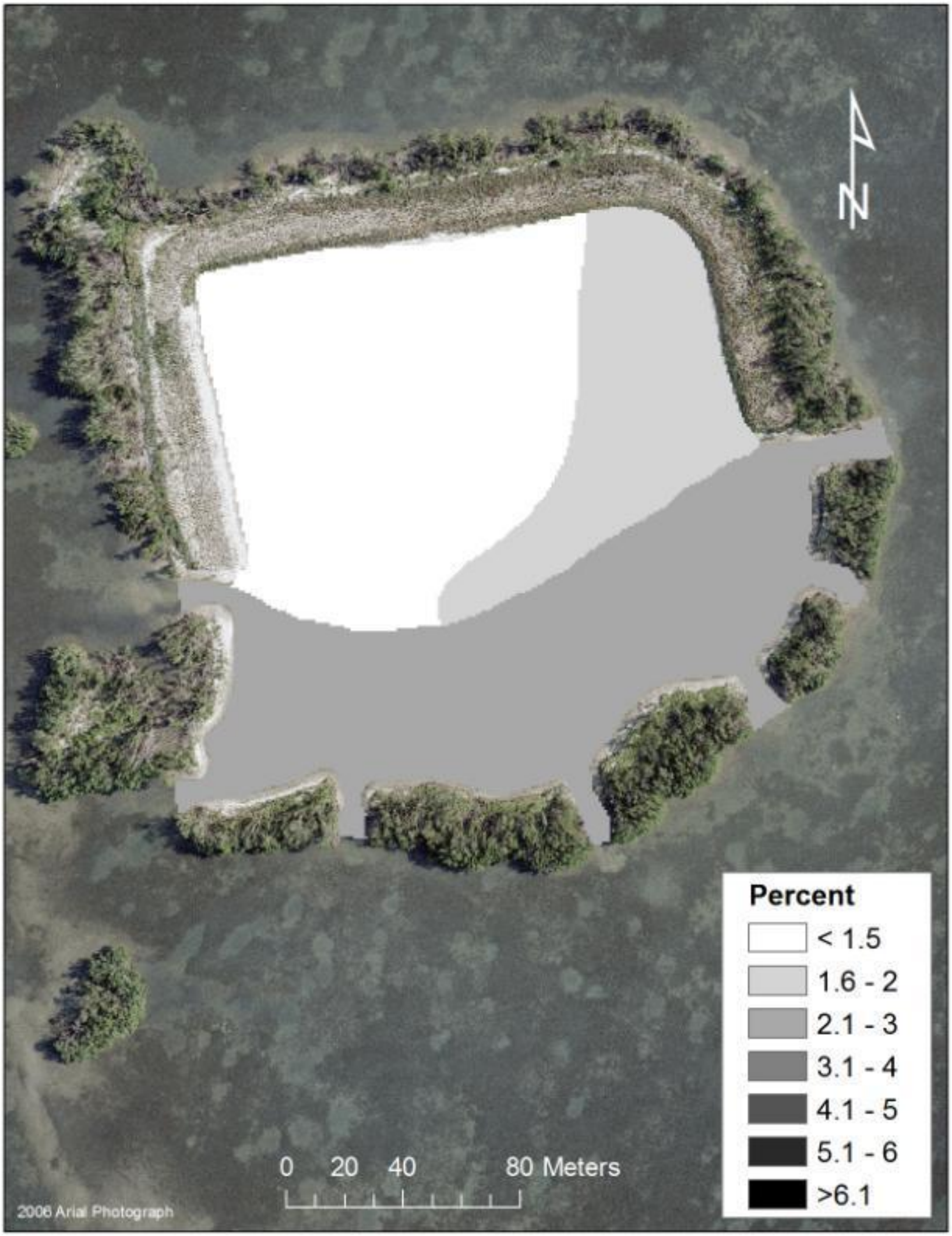
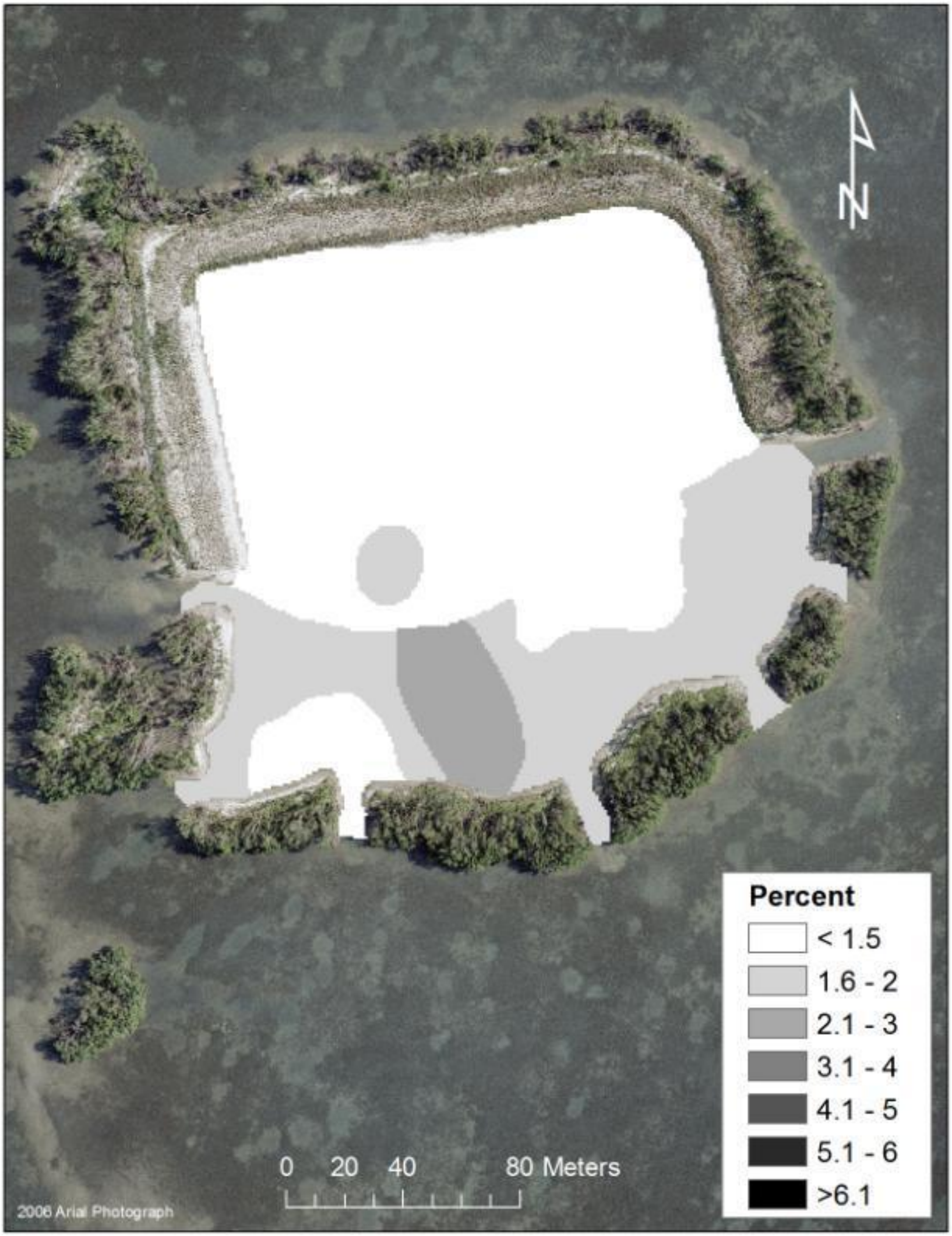


Figure A103. Percentage of organic matter within the soil for summer 2009.

Figure A104. Percentage of organic matter within the soil for winter 2009.



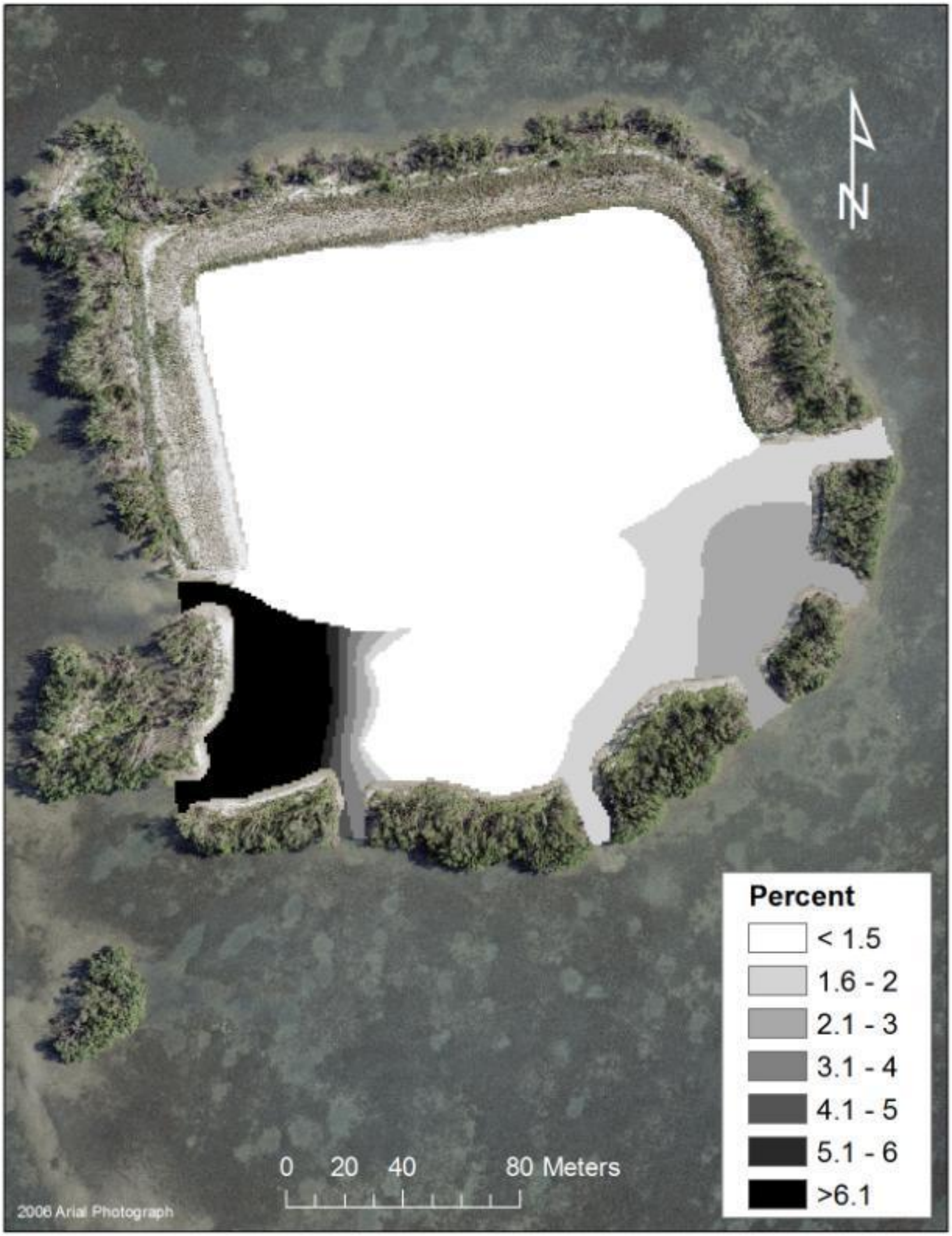


Figure A105. Percentage of organic matter within the soil for summer 2010.

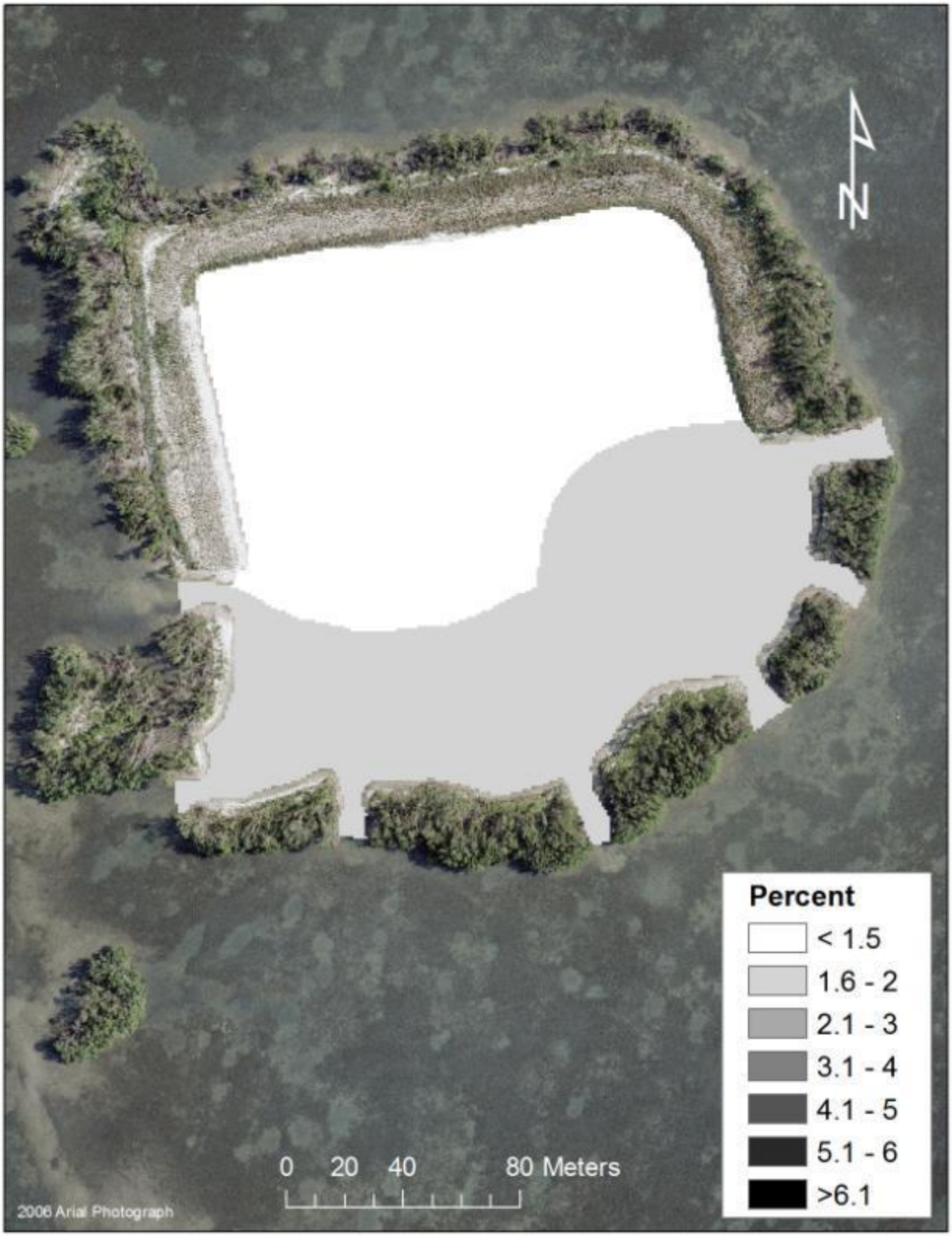


Figure A106. Percentage of organic matter within the soil for winter 2010.

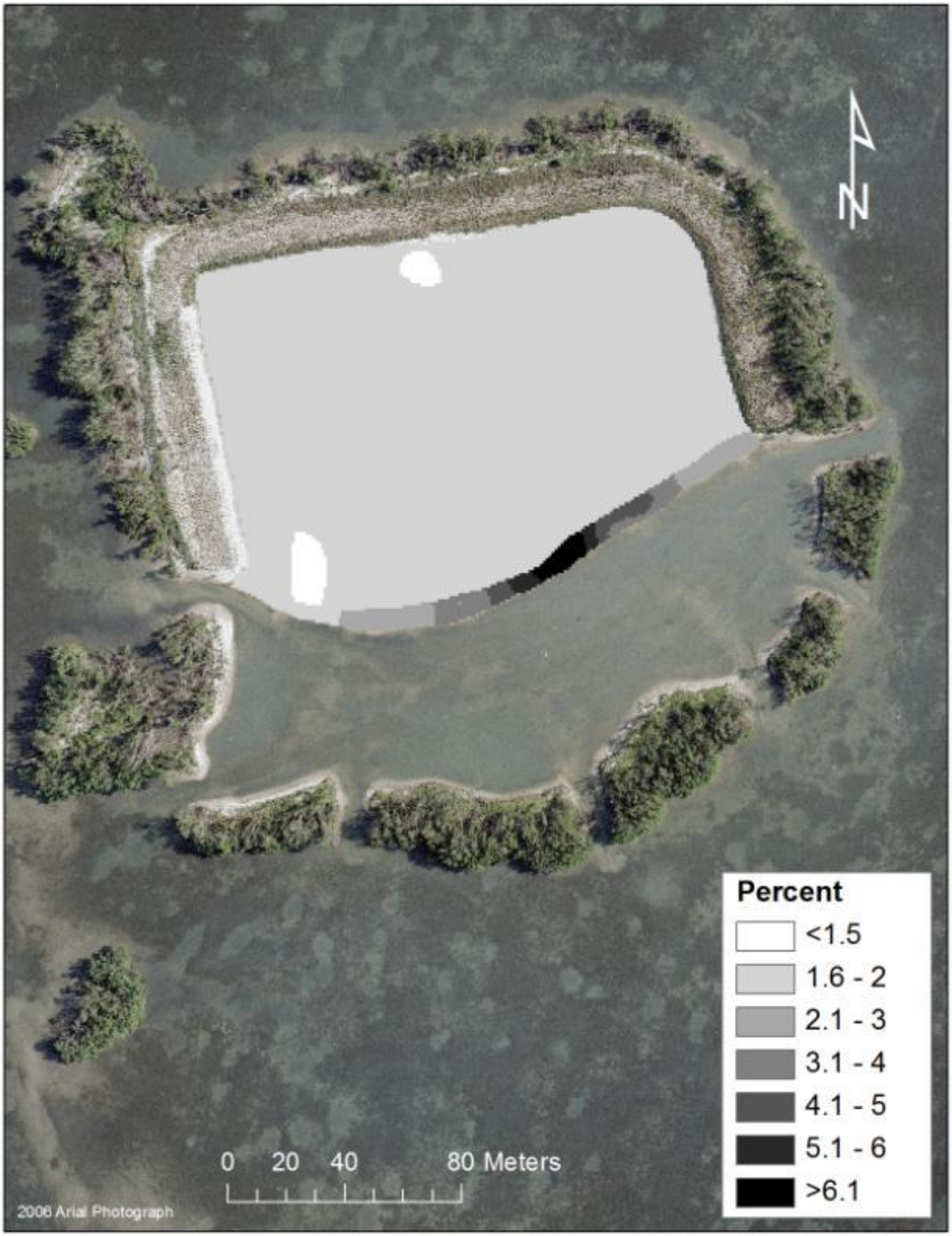


Figure A107. Percentage of organic matter within the soil for winter 2011.

Figure A108. Amount of phosphorus within the soil in winter 2008.

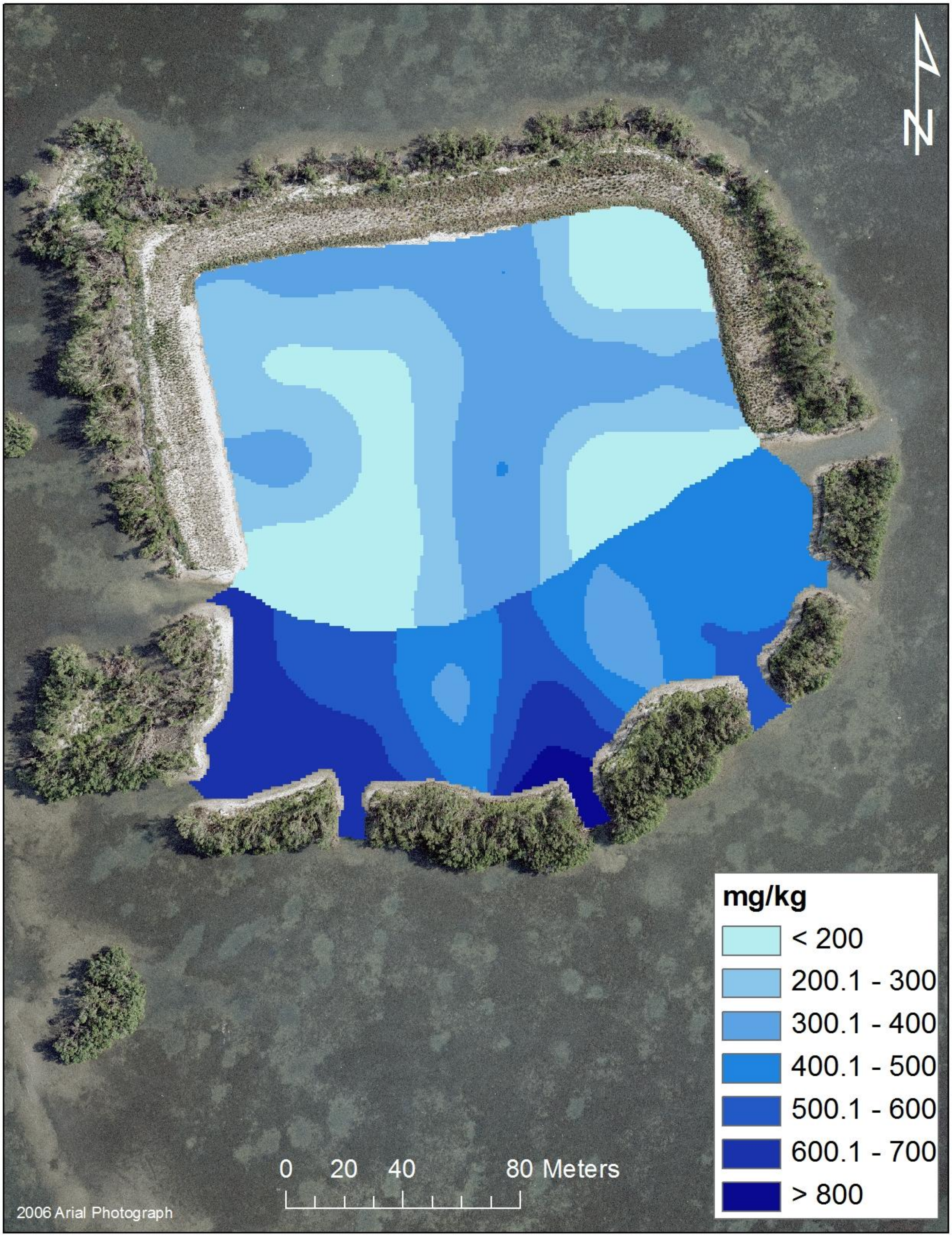


Figure A109. Amount of phosphorus within the soil in summer 2009.

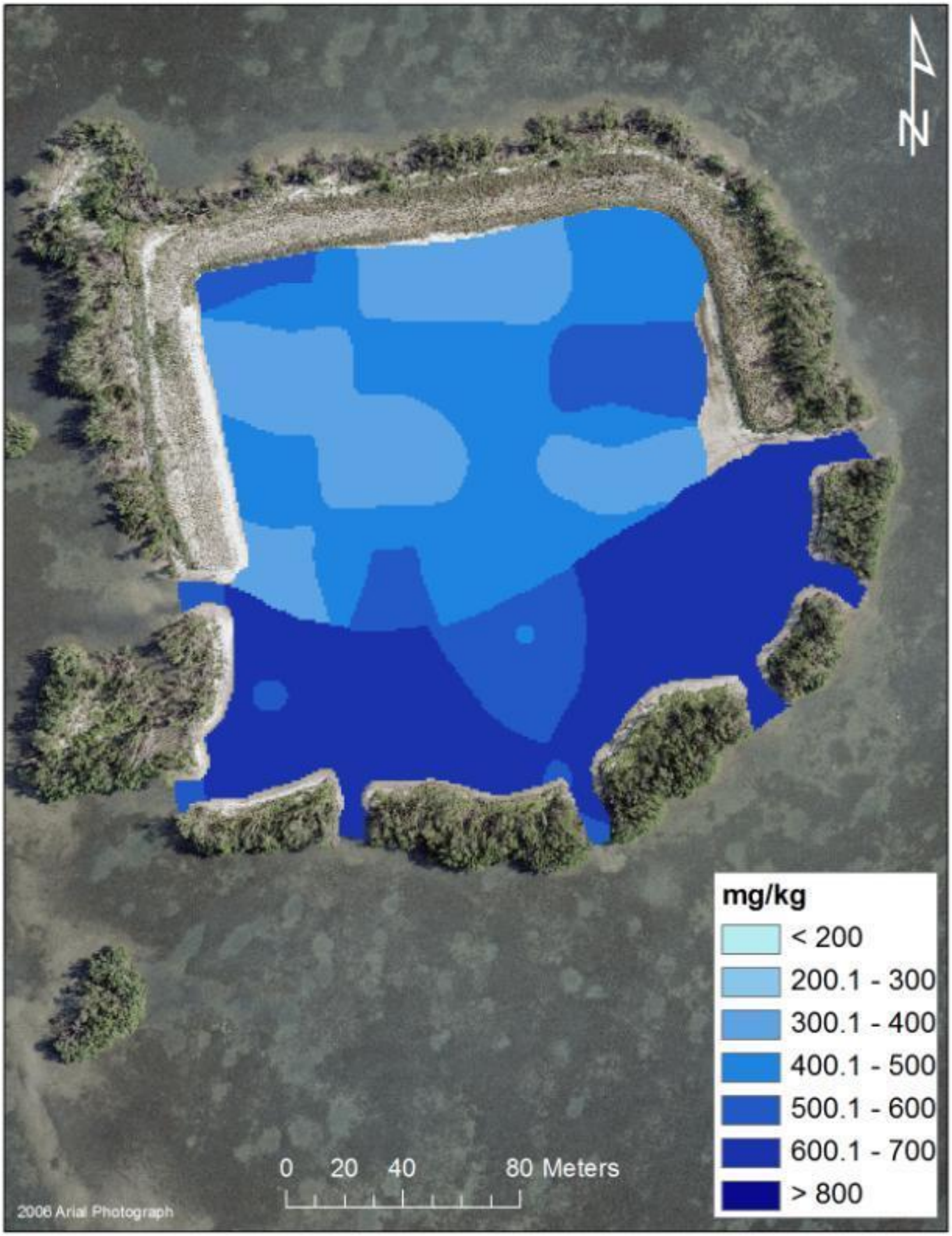


Figure A110. Amount of phosphorus within the soil in winter 2009.

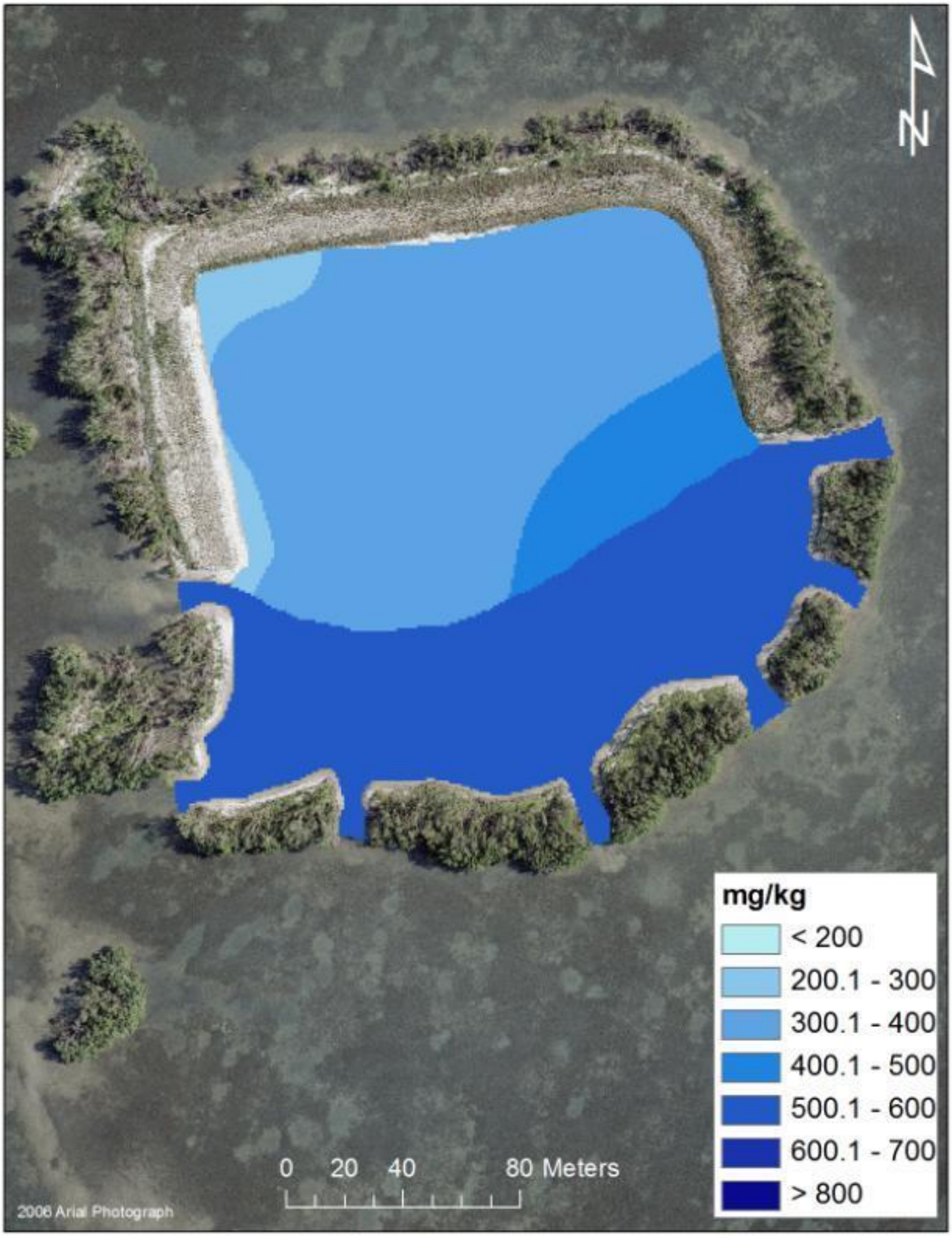


Figure A110. Amount of phosphorus within the soil in winter 2009.

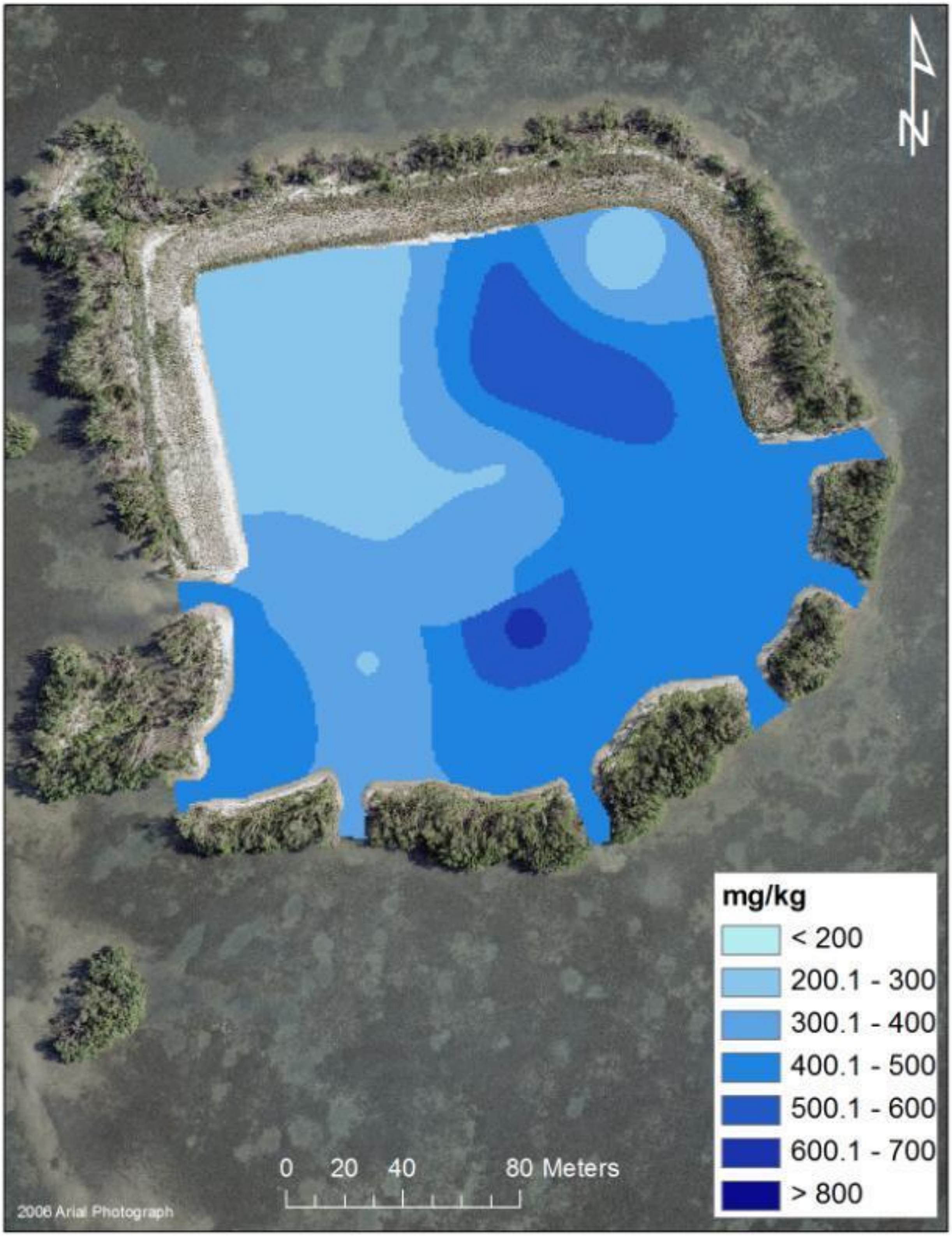


Figure A111. Amount of phosphorus within the soil in summer 2010.

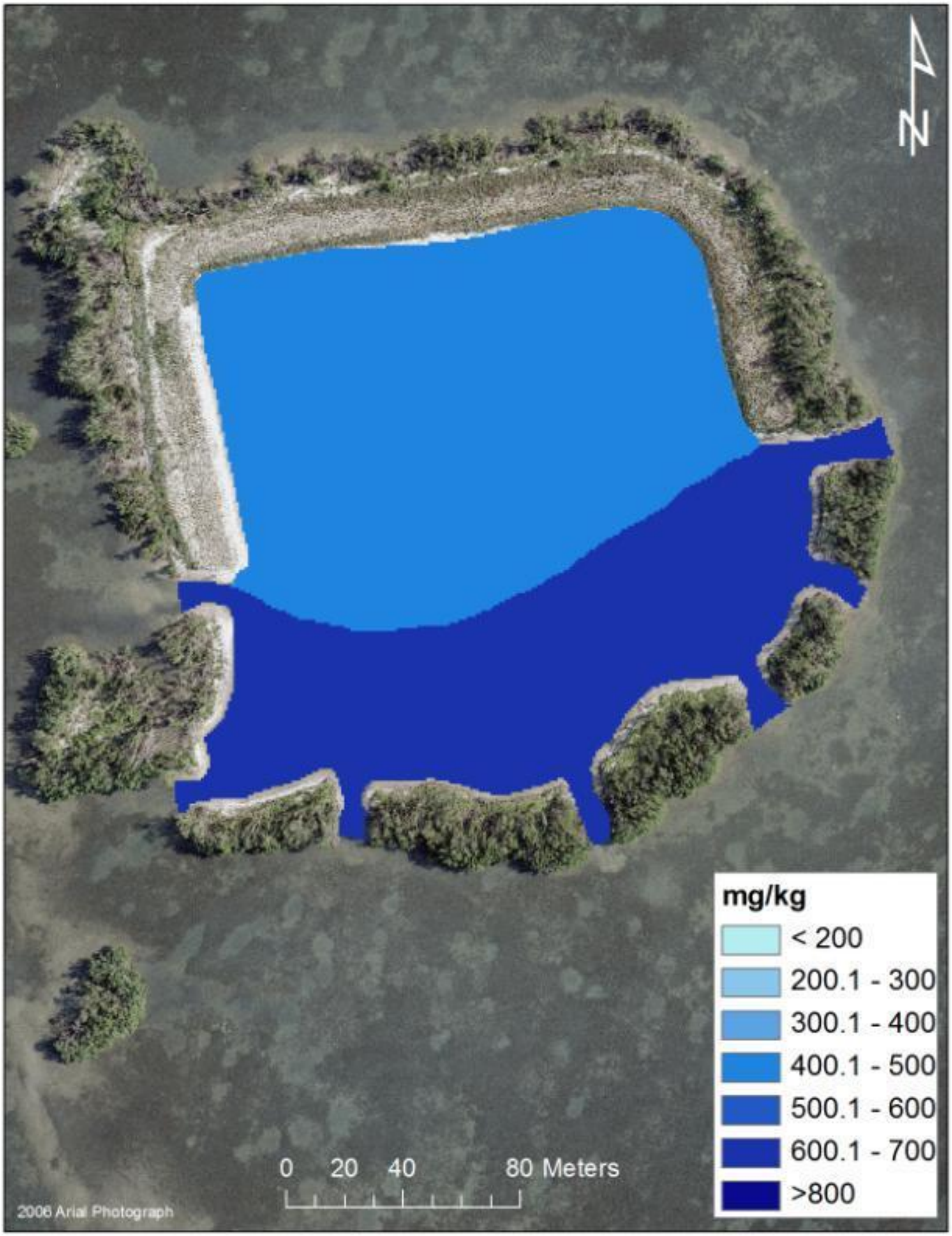


Figure A112. Amount of phosphorus within the soil in winter 2010.

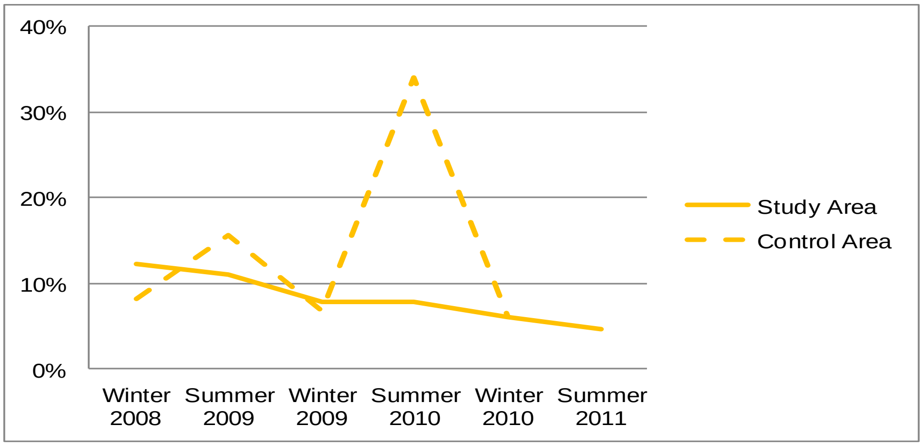


Figure A113. Average percent fine particles in the mangrove planter and upland control area form winter 2008 to winter 2010..

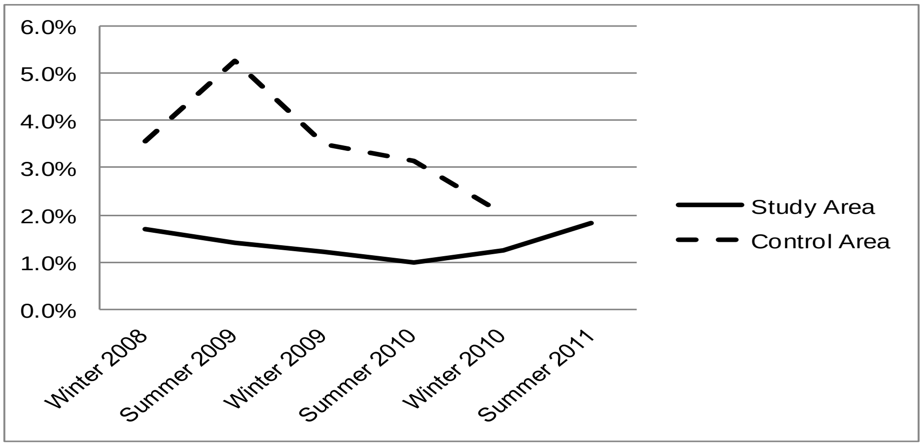


Figure A114. Average percent organic matter in the mangrove planter and upland control area form winter 2008 to winter 2010.

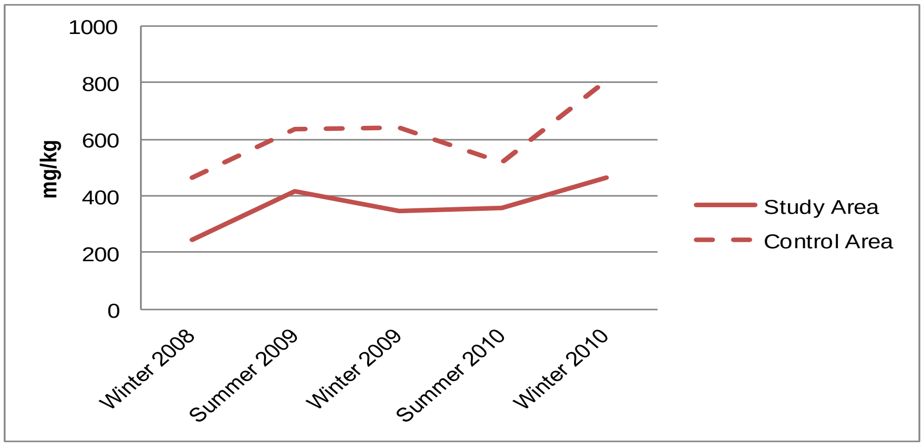


Figure A115. Average phosphorus in the mangrove planter and upland control area form winter 2008 to winter 2010.

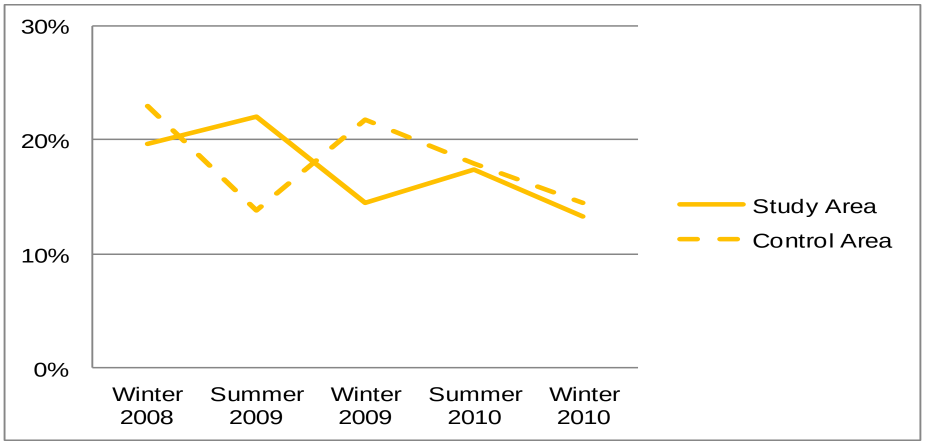


Figure A116. Average percent fine particles in the seagrass recruitment area and seagrass control area form winter 2008 to winter 2010.

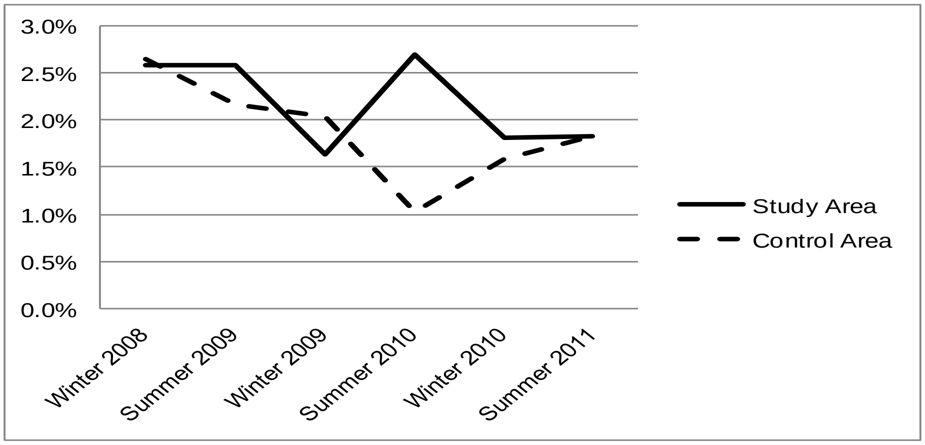


Figure A117. Average percent organic matter in the seagrass recruitment area and seagrass control area form winter 2008 to winter 2010.

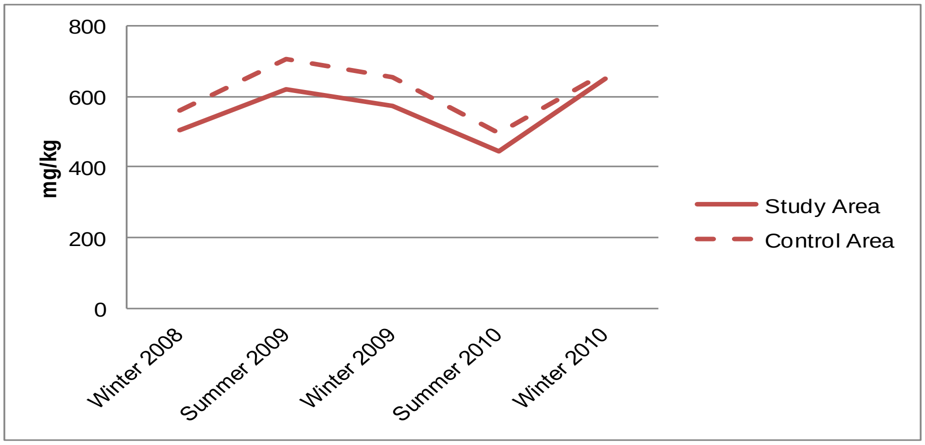


Figure A118. Average phosphorus in the seagrass recruitment area and seagrass control area form winter 2008 to winter 2010.

Braun Blanquet Density Scores	
Score	**Cover**
0	Taxa absent from quadrat
0.1	Taxa represented by a solitary shoot, <5% cover
0.5	Taxa represented by a few (<5) shoots, <5% cover
1	Taxa represented by many (>5) shoots, <5% cover
2	Taxa represented by many (>5) shoots, 5 - 25% cover
3	Taxa represented by many (>5) shoots, 25 - 50% cover
4	Taxa represented by many (>5) shoots, 50 - 75% cover
5	Taxa represented by many (>5) shoots, 75 - 100% cover

Table A1. Braun Blanquet classification system for determining score and percent cover.

Species	Season/Year	Average Density (Trees/m2)	Average Height (cm)	Average Maximum Height (cm)	Average Calculated Canopy Area m2/m2	Average Calculated Canopy Volume m3/m2	Average New Mangrove Recruit/m2
Rhizophora mangle	Summer 2009	1.5 (SD=1.7)	57.0 (SD=17.9)	71.0 (SD=26.2)	N/A	N/A	N/A
Rhizophora mangle	Winter 2009	1.5 (SD=2.5)	65.6 (SD=29.8)	84.6 (SD=39.2)	N/A	N/A	N/A
Rhizophora mangle	Summer 2010	1.7 (SD=2.8)	69.4 (SD=24.9)	89.6 (SD=36.5)	N/A	N/A	N/A
Rhizophora mangle	Winter 2010	1.4 (SD=1.3)	76.9 (SD=30.0)	97.3 (SD=38.0)	N/A	N/A	N/A
Rhizophora mangle	Summer 2011	2.1 (SD=4.2)	73.9 (SD=18.7)	112.6 (SD=32.2)	0.3 (SD=0.2)	0.1 (SD=0.1)	0.5 (SD=1.2)
Avicennia germinans	Summer 2009	0.4 (SD=0.6)	37.3 (SD=47.8)	42.1 (SD=53.2)	N/A	N/A	N/A
Avicennia germinans	Winter 2009	0.5 (SD=0.7)	39.3 (SD=47.2)	48.6 (SD=56.3)	N/A	N/A	N/A
Avicennia germinans	Summer 2010	1.0 (SD=1.6)	32.8 (SD=39.2)	55.2 (SD=59.4)	N/A	N/A	N/A
Avicennia germinans	Winter 2010	1.0 (SD=1.8)	48.1 (SD=41.7)	71.9 (SD=65.9)	N/A	N/A	N/A
Avicennia germinans	Summer 2011	1.6 (SD=2.1)	52.7 (SD=36.2)	112.1 (SD=60.6)	0.1 (SD=0.2)	0.1 (SD=0.2)	1.3 (SD=2.0)
Laguncularia racemosa	Summer 2009	0.5 (SD=1.3)	30.9 (SD=38.1)	37.2 (SD=47.2)	N/A	N/A	N/A
Laguncularia racemosa	Winter 2009	0.4 (SD=1.1)	39.3 (SD=51.3)	44.3 (SD=57.4)	N/A	N/A	N/A
Laguncularia racemosa	Summer 2010	0.8 (SD=1.8)	33.3 (SD=42.6)	50.0 (SD=59.2)	N/A	N/A	N/A
Laguncularia racemosa	Winter 2010	0.5 (SD=0.8)	44.5 (SD=55.1)	57.8 (SD=74.2)	N/A	N/A	N/A
Laguncularia racemosa	Summer 2011	1.2 (SD=3.3)	51.2 (SD=45.7)	84.9 (SD=61.2)	0.1 (SD=0.4)	0.1 (SD=0.4)	0.7 (SD=2.1)
All	Summer 2009	2.4 (SD=3.2)	60.8 (SD=19.5)	88.1 (SD=35.1)	N/A	N/A	N/A
All	Winter 2009	2.4 (SD=3.9)	66.9 (SD=27.7)	100.9 (SD=44.0)	N/A	N/A	N/A
All	Summer 2010	3.7 (SD=5.1)	56.6 (SD=26.7)	107.4 (SD=41.1)	N/A	N/A	N/A
All	Winter 2010	2.8 (SD=3.0)	70.7 (SD=27.0)	119.3 (SD=53.4)	N/A	N/A	N/A
All	Summer 2011	4.9 (SD=7.4)	60.1 (SD=24.8)	140.1 (SD=41.5)	0.5 (SD=0.5)	0.4 (SD=0.5)	2.6 (SD=4.3)

Table A2. Average mangrove density, height, maximum height, calculated canopy area, calculated canopy volume, and new recruit density of the study sites within the mangrove planting area.

Season/Year	Average Algae Coverage		Average Seagrass Coverage		Average Seagrass Desnity Shoots/m2	
	Study Area	Control Sites	Study Area	Control Sites	Study Area	Control Sites
Winter 2008	71.8 (SD=24.4)	17.3 (SD=14.2)	3.5 (SD=6.5)	54.0 (SD=5.3)	34.4 (SD=41.0)	71.7 (SD=25.7)
Summer 2009	25.7 (SD=11.7)	0.0 (SD=0.0)	1.0 (SD=1.2)	73.7 (SD=45.6)	0.0 (SD=0.1)	710.0 (SD=255.9)
Winter 2009	36.8 (SD=29.5)	13.3 (SD=23.1)	0.3 (SD=0.5)	36.7 (SD=23.1)	0.0 (SD=0.1)	24.0 (SD=24.8)
Summer 2010	14.5 (SD=13.0)	0.0 (SD=0.0)	8.3 (SD=10.7)	43.3 (SD=49.3)	95.0 (SD=144.7)	483.3 (SD=144.3)
Winter 2010	70.5 (SD=26.5)	0.0 (SD=0.0)	0.7 (SD=1.1)	71.7 (SD=36.2)	10.0 (SD=31.6)	700.0 (SD=204.6)
Summer 2011	68.7 (SD=27.3)	N/A	0.5 (SD=1.6)	N/A	5.0 (SD=15.8)	N/A

Table A3. Average algae coverage, seagrass coverage, and seagrass density for sites within the seagrass embayment and control.

Season/Year	Average Braun-Blanquet cover class		Braun-Blanquet Average Percent Coverage	
	Study Area	Control Sites	Study Area	Control Sites
Winter 2008	0.6 (SD=0.7)	4.0 (SD=0.0)	2.5 (SD=5.6)	62.5 (SD=0.0)
Summer 2009	0.2 (SD=0.2)	4.0 (SD=1.7)	2.0 (SD=1.1)	63.3 (SD=41.9)
Winter 2009	0.5 (SD=0.2)	2.7 (SD=0.6)	1.2 (SD=0.8)	30.0 (SD=13.0)
Summer 2010	1.2 (SD=1.1)	3.0 (SD=1.7)	10.3 (SD=11.9)	39.2 (SD=41.9)
Winter 2010	0.2 (SD=0.2)	4.3 (SD=1.2)	1.0 (SD=1.3)	70.1 (SD=28.9)
Summer 2011	0.1 (SD=0.2)	N/A	0.3 (SD=0.8)	N/A

Table A4. Average Braun-Blanquet cover class and percent coverage for sites within the seagrass embayment and control area.

Season/Year	Average *Halophila johnsonii* Denisty Shoots/m2		Average *Halodule wrightii* Denisty Shoots/m2		Average *Syringodium filiforme* Denisty Shoots/m2		Average *Thalassia testudinum* Denisty Shoots/m2	
	Study Area	Control Sites	Study Area	Control Sites	Study Area	Control Sites	Study Area	Control Sites
Winter 2008	30.6 (SD=40.8)	0.0 (SD=0.0)	3.75 (SD=7.9)	0.0 (SD=0.0)	0.0 (SD=0.0)	58.0 (SD=20.4)	0.0 (SD=0.0)	13.7 (SD=23.7)
Summer 2009	0.0 (SD=0.1)	0.0 (SD=0.0)	0.0 (SD=0.1)	0.0 (SD=0.0)	0.0 (SD=0.0)	698.0 (SD=203.9)	0.0 (SD=0.0)	12.0 (SD=20.8)
Winter 2009	0.0 (SD=0.1)	0.0 (SD=0.0)	0.0 (SD=0.1)	0.0 (SD=0.0)	0.0 (SD=0.0)	15.0 (SD=10.0)	0.0 (SD=0.0)	9.0 (SD=15.6)
Summer 2010	87.5 (SD=143.5)	0.0 (SD=0.0)	7.5 (SD=16.9)	0.0 (SD=0.0)	0.0 (SD=0.0)	450.0 (SD=86.6)	0.0 (SD=0.0)	33.3 (SD=57.7)
Winter 2010	0.0 (SD=0.0)	0.0 (SD=0.0)	10.0 (SD=31.6)	0.0 (SD=0.0)	0.0 (SD=0.0)	683.3 (SD=200.5)	0.0 (SD=0.0)	16.7 (SD=28.9)
Summer 2011	0.0 (SD=0.0)	N/A	5.0 (SD=15.8)	N/A	0.0 (SD=0.0)	N/A	0.0 (SD=0.0)	N/A

Table A5. Seagrass composition density of sites within the seagrass embayment and the control areas.

Season/Year	Average Percent Sand Soil Particles		Average Percent Fine Soil Particles		Average Percent Orangic Soil Matter		Average Bulk Density mg/cm3		Average Total Phophorus mg/kg	
	Mangrove Planter	Upland Control	Mangrove Planter	Upland Control	Mangrove Planter	Upland Control	Mangrove Planter	Upland Control	Mangrove Planter	Upland Control
Winter 2008	87.8 (SD=10.8)	91.8 (SD=2.6)	12.2 (SD=10.8)	8.2 (SD=2.6)	1.7 (SD=0.5)	3.6 (SD=1.2)	1.1 (SD=0.2)	0.8 (SD=0.0)	247.4 (SD=131.9)	463.7 (SD=378.4)
Summer 2009	89.1 (SD=4.1)	84.5 (SD=10.5)	10.9 (SD=4.1)	15.5 (SD=10.5)	1.4 (SD=0.5)	5.3 (SD=2.9)	1.3 (SD=0.2)	1.1 (SD=0.1)	418.0 (SD=74.3)	636.0 (SD=98.4)
Winter 2009	92.2 (SD=3.5)	93.3 (SD=4.6)	7.8 (SD=3.5)	6.7 (SD=4.6)	1.2 (SD=0.3)	3.5 (SD=3.4)	1.6 (SD=0.1)	1.0 (SD=0.5)	348.7 (SD=137.6)	644.3 (SD=61.1)
Summer 2010	92.1 (SD=3.2)	66.0 (SD=25.2)	7.9 (SD=3.2)	34.0 (SD=25.2)	1.0 (SD=0.2)	3.1 (SD=1.5)	1.6 (SD=0.2)	0.4 (SD=0.2)	356.1 (SD=123.9)	519.3 (SD=261.8)
Winter 2010	94.0 (SD=3.0)	93.8 (SD=1.7)	6.0 (SD=3.0)	6.2 (SD=1.7)	1.2 (SD=0.3)	2.0 (SD=1.2)	1.4 (SD=0.2)	1.7 (SD=0.0)	463.4 (SD=117.4)	807.1 (SD=250.5)
Summer 2011	95.3 (SD=3.5)	N/A	4.7 (SD=3.5)	N/A	1.8 (SD=0.8)	N/A	1.5 (SD=0.1)	N/A	N/A	N/A

Table A6. Average percent sand, percent fine, percent organic matter, bulk density, and total phosphorus for soil samples within the mangrove planter and the upland control sites.

Season/Year	Average Percent Sand Soil Particles		Average Percent Fine Soil Particles		Average Percent Orangic Soil Matter		Average Bulk Density mg/cm3		Average Total Phophorus mg/kg	
	Seagrass Recruitment Area	Seagrass control Sites	Seagrass Recruitment Area	Seagrass control Sites	Seagrass Recruitment Area	Seagrass control Sites	Seagrass Recruitment Area	Seagrass control Sites	Seagrass Recruitment Area	Seagrass control Sites
Winter 2008	80.4 (SD=7.8)	77.1 (SD=9.8)	19.6 (SD=7.8)	22.9 (SD=9.8)	2.6 (SD=0.7)	2.7 (SD=1.4)	0.8 (SD=0.2)	0.6 (SD=0.2)	503.3 (SD=128.7)	560.6 (SD=172.6)
Summer 2009	77.9 (SD=6.1)	86.2 (SD=6.1)	22.1 (SD=6.1)	13.8 (SD=6.1)	2.6 (SD=0.8)	2.2 (SD=1.0)	1.1 (SD=0.5)	1.0 (SD=0.1)	619.8 (SD=52.7)	706.7 (SD=25.9)
Winter 2009	85.4 (SD=5.2)	78.2 (SD=9.8)	14.6 (SD=5.2)	21.8 (SD=9.8)	1.6 (SD=0.5)	2.0 (SD=0.8)	1.3 (SD=0.3)	1.0 (SD=0.3)	572.2 (SD=52.8)	655.8 (SD=9.5)
Summer 2010	82.7 (SD=6.3)	82.1 (SD=1.5)	17.3 (SD=6.3)	17.9 (SD=1.5)	2.7 (SD=4.1)	1.0 (SD=0.3)	1.2 (SD=0.3)	1.2 (SD=0.2)	443.6 (SD=93.2)	496.2 (SD=175.9)
Winter 2010	86.7 (SD=7.3)	85.5 (SD=4.3)	13.3 (SD=7.3)	14.5 (SD=4.3)	1.8 (SD=0.7)	1.6 (SD=0.2)	1.2 (SD=0.3)	1.2 (SD=0.1)	649.9 (SD=128.7)	666.8 (SD=8.5)
Summer 2011	N/A	N/A	N/A	N/A	1.8 (SD=0.7)	1.8 (SD=0.7)	1.4 (SD=0.1)	N/A	N/A	N/A

Table A7. Average percent sand, percent fine, percent organic matter, bulk density, and total phosphorus for oil samples within the seagrass embaymeny and the control sites.