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Development of a Mangrove Quality Index in Tampa Bay, Florida

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by

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To Mommy, may you always fuel my fire.

Acknowledgments

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Table of Contents

List of Tables

List of Figures

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ABSTRACT

Mangroves are an important resource. They provide a breeding ground for commercially and recreationally important fish, protect shorelines from erosion and improve coastal water quality. Historically, mangroves were undervalued, leading to a loss of 35% of mangroves worldwide and 44% in Tampa Bay due to anthropogenic stressors. Efforts to protect and restore mangroves have led to a variety of management programs. In Tampa Bay the main management program is the Tampa Bay Estuary Program (TBEP). The program has identified the need for simple and easy to use assessment tools to track mangrove quality and aid in mangrove quality. There are several types of assessment methods recommended for measuring habitat quality. Among these approaches, environmental indices are favorable because they are simple and easy to use as well as objective measures of habitat quality. Indices are most effective when configured to a specific habitat. Although similar assessment methods have been developed for several habitats, there are none specifically for estuarine wetlands in peninsular Florida. This study aims to fill this gap and create an index to assess the quality of mangroves in Tampa Bay and measure the impact of human activities on the habitat.

The index was created by measuring a variety of physical characteristics in three reference wetlands of varying quality. Cockroach Bay was the highest quality wetland in the most pristine condition, Weedon Island moderately impacted and Feather Sound the most highly impacted and lowest quality. Metrics for the index were determined by performing simple correlation analysis of the physical characteristics and condition. The characteristics strongly correlating to conditions were selected as metrics. Based on this analysis, a mangrove quality index (MQI) was recommended for Tampa Bay. This index contains three categories: biota, vegetation and water. The resulting MQI is recommended for use by mangrove managers and policy makers to ensure the protection and restoration of Tampa Bay's mangroves.

Introduction

Mangroves are an ecological group of halophytic tree species. The term mangrove also refers to a complex plant community fringing sheltered tropical shores. These communities are also referred to as mangrove swamps or mangrove forests (Hogarth, 2007; Lacerda et al., 2002). Mangroves grow in tropical and subtropical coastal environments. In the United States, most mangrove forests are found in southern Florida with occurrences in Texas and Louisiana (Spalding et al., 1997). In Florida, mangrove forests extend north to Cedar Key on the Gulf Coast and St. Augustine on the Atlantic Coast, with some small areas possibly occurring further north (Lewis et al., 1985) (figure 1). The forests consist of four main mangrove species occurring in various patterns of assemblage. They are *Rhizophora mangle* known as the red mangrove, *Avencia germinans* known as the Black Mangrove, *Laguncularia racemosa* known as White Mangrove and *Conocarpus erecta* known as Buttonwood (Lewis et al., 1985). The buttonwood is not considered to be a true mangrove species and may be referred to as an associate species (Lewis et al., 1985).

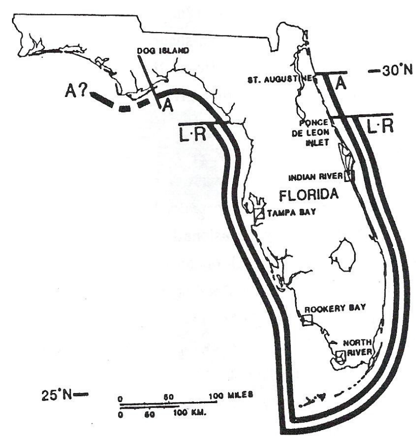


Figure 1. Geographical extent of mangroves in Florida (Lewis et al., 1985)

The development and structure of mangrove forests result from an interaction of many physical factors and environmental variables (Hogarth, 2007; Lacerda et al., 2002). As a result, the species of trees in a mangrove forest often occur in discrete and monospecific zones (Hogarth, 2007). In the United States and the rest of the Americas, mangrove forests are classified into three main types based on the structure of the community (Lacerda et al., 2002). They may be classified as basin, fringe or riverine forests or combination of these three main types (Hogarth, 2007; Lacerda et al., 2002).

Mangroves have many important functions that are beneficial to humans. Some of these are coastal protection, nutrient and sediment filtration, nurseries and feeding ground for fishes and crustaceans (Sharitz and Pennings, 2006). Mangroves stabilize coasts and act as a buffer for destructive winds and waves that can occur during storms, protecting shores from erosion (Tomlinson, 1986; Sharitz and Pennings, 2006). This function is especially important in Florida because of its susceptibility to hurricanes and the presence of highly developed coastal communities. Mangroves also contribute to water quality by removing large amounts of inorganic nutrients, heavy metals and other pollutants from the water and trapping them in the sediment (Bossi and Cintron, 1990). Florida's mangroves are vital to many recreationally and commercially important fisheries (Lewis, 1977). In Florida, approximately 90% of commercial fisheries and 70% of recreational fisheries are dependent on mangroves for part of their life cycle (Lewis et al., 1985). Mangroves are a habitat for juvenile fish and provide food to fish though the rich supply of detritus to the detritus-based food web (Lewis et al., 1985). Finally, mangroves are home to many species of wildlife such as crabs, frogs, lizards and migratory birds (Hogarth, 2007).

In many places, the benefits of mangroves are not fully understood and this has led to mismanagement and destruction (Lacerda, 2002). Worldwide, an estimated 35% of mangrove forests have been lost in the past two decades (Valiela et al., 2001). In Florida, the estimated losses range from 20% in some locations to 80% in others (Lewis, 1985). Tampa Bay lost 44% of its mangroves over a 100-year period as a result of pollution and other anthropogenic stressors. These losses are because of human activities such as urbanization, forestry and aquaculture (Sharitz and Pennings 2006). Mangroves can also be displaced by the dumping of fill and conversion to other uses for economic gain (Valiela et al., 2001; Spalding et al., 1997; Bossi and Cintron, 1990). Mangroves have also been affected indirectly by human activities. These include loss of habitat from pollution of water inputs and nutrient enrichment, as well as changes that alter hydrologic flow in the mangrove (Lewis, 1977; Valiela and Cole, 2002).

In order to prevent further losses, a wide range of legislation has been enacted to protect mangroves - notably wetlands regulations. These mostly restrict the activities that can take place within a forest. In the United States these include compensatory mitigation under the Clean Water Act, Section 404, and the National Estuary Program. Section 404 requires a permit before dredged or fill material may be discharged into wetlands (EPA, undated). Permit applicants must show that they have taken steps to avoid wetland impacts, minimized potential impacts on wetlands, and provided compensation for any remaining unavoidable impacts (EPA, undated). The permitting is administered by the Environmental Protection Agency, US Army Corps of Engineers and various state and local agencies (FDEP, 2007). The National Wetlands Mitigation Action Plan aims to improve the ecological performance and results of compensatory mitigation under Section 404 (NOAA, 2006). The goal of the National Estuary Program is to improve the quality of estuaries of national importance (EPA, 1999). It encourages local communities to manage their own estuaries (EPA, 1999). There are four Florida estuaries that are part of this program: Tampa Bay, Sarasota Bay, Charlotte Harbor and Indian River Lagoon (EPA, 1999).

In addition to general wetlands regulations, there are also regulations specifically for mangroves. In Florida, the Mangrove Trimming and Preservation Act, administered by local authorities, protects and preserves mangroves by allowing only professional trimmers to trim mangroves (Mangrove, 1996). The aforementioned pieces of legislation led to the creation of specific programs put in place to preserve and maintain the remaining mangrove habitat in Tampa Bay (Holland et al., 2006). The largest is the Tampa Bay Estuary program. It aims to preserve the current mangrove habitat and has restored a large amount of the mangrove forest in the region (Holland et al., 2006). There is a need for efficient and adequate management and monitoring of these mangrove forests in Tampa Bay (Holland et al., 2006).

In order to properly manage wetlands and make informed decisions concerning mangroves, managers and policy makers should be able to quickly assess their state. There are several methods currently used to assess wetlands, but none that specifically address mangrove forests. Managers should be provided with a simple, easy tool that adequately measures mangrove condition. This tool can then be used to determine the best course of action to follow with regards to that particular mangrove forest. An adequate assessment tool not only tells the user whether any degradation is taking place but also points toward the stressor causing the degradation.

Environmental indices or assessment methods have been used to successfully manage wetlands and other habitats. The hydrogeomorphic (HGM) approach measures wetland function as part of the regulatory, planning and management situations (Bartoldus, 1999). The estuarine rapid assessment procedure is used by the Southwest Florida Water Management District as a regulatory tool to assess estuarine wetlands (Bartoldus, 1999). In Tampa Bay a benthic habitat index is used to assess the severity of toxic contamination and identify priority areas for remediation (Holland et al., 2006). Environmental indices are attractive because they are objective, quick and easy to use.

Of the available assessment methods, there are no methods that are specifically for assessing mangrove forests. Current methods such as HGM are either broadly based or have been adapted for other types of wetlands. Other methods such as the benthic habitat index or the estuarine rapid assessment procedure do not asses all aspects of the forest or simply categorize mangrove forests for regulatory purposes. The mangrove quality index, developed in this study, attempts to fill the gap left by current assessment methods by providing a tool to help managers with the effective and efficient management of one of Florida's valuable resources - mangroves.

The development of a mangrove assessment tool proposed here can be used to measure the state of the mangroves in Tampa Bay in an effort to understand the impact of human activities on the habitat and to allow its management in a manner that minimizes that impact. I hypothesize that mangrove forests in Tampa Bay have been negatively impacted by human development in the region. The following objectives will be used to address this hypothesis:

1. To determine the impact of human activities on mangroves in the Tampa Bay.

2. To develop a mangrove quality index for measuring mangrove quality.
3. To refine the index by applying it to mangroves in Tampa Bay.

Literature Review

Much of the world's population lives in the coastal environment and depends on its resources for survival. Research has been conducted into many aspects of the marine terrestrial interface, some of which involve coastal zone management. Further research has been conducted to identify the biological and physical properties of mangroves, some specifically in Florida. These studies, in part, document the state of mangroves and the impact of human activities on mangrove quality.

Current literature identifies integrated management as a means of effective sustainable coastal zone management (Gallagher et al., 2004). Integrated management is defined as a continuous decision making process aimed at maintaining, restoring or improving specified qualities of ecosystems and the associated human societies (Zagonari, 2007). This approach has been found to improve coastal environmental quality and can be used to establish a coastal sustainability standard (Gallager et al., 2004; Zagonari, 2007). Furthermore, effective coastal management requires clear goals, a conceptual model and a decision framework in addition to strong leadership and oversight maintaining coastal environmental quality.

The importance of mangroves as part of the coastal environment has been well documented. Alongi and McKinnon (2005) explored the cycling of nutrients and sediments in the coastal zone of the Great Barrier Reef shelf and found that mangroves and tidal flats are very effective at reducing the sediment and nutrient load to the coral reefs. In addition, they play an important role in protecting seagrass from land derived nitrogen loads by removing nitrogen before it can stress the seagrass (Valiela and Cole, 2002). Florida's mangroves are vital to many recreationally and commercially important fisheries (Lewis, 1977). Species such as shrimp, lobster, sea trout and snapper are dependent on mangroves for part of their life cycle (Lewis et al., 1985). Mangroves are also useful as shoreline stabilizers. In Florida *Avicennia* and *Rhizophora* are the most useful genera for this purpose (Savage, 1972).

Knowledge of the properties of mangroves is crucial to understanding the quality and benefits of the resource. Spalding et al. (1997) created a mangrove atlas documenting the location and coverage of mangroves worldwide. Figure 2 shows the distributions of mangroves in the Americas. Mangroves are found mostly along tropical coastlines although they can also be found in subtropical climates of Bermuda, Japan,

Figure 2. Distribution of Mangroves in the West (Spalding et al., 1997). Mangroves are represented by the green areas.

Australia, New Zealand and South Africa in the South (Spalding et al., 1997). The geographical distribution of mangroves is limited by the 20°C winter isotherm, with a few exceptions (Hogarth, 2007). In addition, global mangrove distribution is also affected by rainfall because rainfall decreases salinity in an otherwise hypersaline environment (Spalding et al., 1997).

Mangrove forests occur in various forms determined largely by the physical characteristics of the environment (Hutchings, 1987). In the United States and the rest of the Americas, there are three main types of forests based on the structure of the community: basin, fringe and riverine (Hogarth, 2007; Lacerda et al., 2002; Lewis et al., 1985; Lugo and Snedaker, 1974). Basin forests occur inland in drainage depressions that channel terrestrial runoff to the coast (Lacerda et al., 2002; Lewis et al., 1985; Lugo and Snedaker, 1974). This type of forest receives little to no tidal influence and is a sink for nutrients rather than a source for export into the coastal environment (Hogarth, 2007; Lacerda et al., 2002; Lewis et al., 1985; Lugo and Snedaker, 1974). Fringe forests are found along protected shorelines at elevations above high tides (Lacerda et al., 2002; Lewis et al., 1985, Lugo and Snedaker, 1974). These forests are flooded periodically by tides and develop dense prop root and pneumatophore systems that trap litterfall and other debris (Lacerda et al., 2002; Lewis et al., 1985, Lugo and Snedaker, 1974). Riverine forests are often the most developed with the tallest red mangrove trees in Florida (Lewis et al., 1985). These occur along river and creek systems and are flushed by daily tides (Lewis et al., 1985).

While there are over 70 species of mangroves worldwide, only four species are found in American forests (Hogarth, 20007; Lacerda, 2002). They are *Rhizophora* *mangle* (Red mangrove), *Avencia germinans (*Black Mangrove), *Laguncularia racemosa* (White Mangrove) and *Conocarpus erecta* (Buttonwood) –an associate species (Lewis et al., 1985). The identifying characteristics of each species such as leaf shape, bark appearance and the presence of salt glands are well documented in the literature (Carlton, 1975; Lacerda et al., 2002; Lewis et al., 1985; Tomlinson, 1986).

Researchers have studied the characteristics of Florida's mangroves, their location, physical properties, ecological functions, community structure, and energy pathways as well as threats to the forests (Carlton, 1974; Lugo and Snedaker, 1974). The results of these studies explain the functions and typical characteristics of forests. They are finely tuned systems that respond to outside forcing (Lugo and Snedaker, 1973). Environmental conditions such as fresh water input, evaporation and topography have a significant impact on forest structure because they affect hydrology and soil salinity (Pool et al., 1977). In Florida, mangroves can be found from Cedar Key on the Gulf Coast to St. Augustine on the Atlantic Coast, however they tend to vary in constituency and structure from one location to the next (Carlton, 1974). Measurements of the rates of photosynthesis respiration and transpiration in mangrove forests of south Florida showed zonation in the rates that help the plants take advantage of available energy sources (Lugo et al., 1973).

Nutrients in the form of nitrogen and phosphorus are very important in estuarine systems as their relative availability has the potential to limit growth of the community. In Florida's mangroves, nutrient limitation is complex and varies between specific forests (Feller et al., 2002). Nitrogen does not appear to be the limiting nutrient while phosphorus has been identified as the major factor in limiting mangrove growth, particularly in low nutrient carbonate soils (Feller et al., 2002; Koch, 1997).

Mangroves are the most threatened ecosystem worldwide due to human use and interaction (Valiela et al., 2001). Worldwide, an estimated 35% of mangrove forests have been lost in the past two decades (Valiela et al., 2001). 44% of the mangroves in Tampa Bay were lost from 1876-1976 due to the impact of dredging in the surrounding area (Lewis, 1977). Other human activities that threaten mangroves include reclamation, charcoal production, timber production, paper production, conversion to agriculture, coastal development, pollution and oil spills amongst others (Bossi and Cintron, 1990; Spalding et al., 1997). In addition, mangroves are threatened by natural factors. For example, Maxwell and Li (2006) found that biofouling in the form of barnacle infestation on the bark of mangroves can be problematic, especially on seedlings less than two years old. To compensate for the loss from anthropogenic stressors, mangroves need to be adequately and effectively managed (Ellison and Farnsworth, 1996).

Several approaches have been taken to mangrove management. Some of these include approaches that are used generally for wetlands. Aksornkoae (2004) recorded the use of a two zone approach in Thailand. The mangroves were divided into a conservation zone and a development zone (Aksornkoae, 2004). Activity in the conservation zone was highly restricted while economic activities were allowed in the development zone, allowing for preservation of the resource at the same time as sustainable economic exploitation by the people who rely on the resource to make a living (Aksornkoae, 2004). Blasco (2004) developed a Mangrove Action Plan to promote the sustainable management of mangroves. The plan identifies the major impediments to sustainable management and makes recommendations for addressing these issues (Blasco, 2004). These are examples of approaches that led to the successful management of mangroves by addressing local needs.

In Zanzibar, Tanzania, mangroves were managed as part of an integrated coastal area management program in an effort to balance the needs of all those utilizing the resources while improving its quality (Masoud and Wild, 2004). Lacerda et al. (2002) recognized the need for site-specific flexibility in mangrove management policies. In the Philippines, mangroves are managed according to a co-management arrangement where partners agree on the management role they play (Pomeroy and Katon, 2004). In Tampa Bay, strong local direction and commitment, coupled with good science and significant support from state and federal programs, resulted in an integrated coastal management approach with measureable goals for restoration (Lewis et al., 1998). Ewel et al. (1998) advocated making management decisions based on the goods and services provided by a mangrove. These include goods such as paper and timber, and services such as fisheries habitat and reduction of nutrient load. They also recognized the need for understanding the impacts of human activities on the ecosystem services provided by mangroves. Parikh and Dayte (2003) documented the need for functional and ecological assessment as part of mangrove management.

Functional and ecological assessment is a popular management tool for wetland management. They are sometimes referred to as assessment methods or wetlands indices. A scientifically sound assessment method is very useful as a cornerstone for a wetland protection program (Fennessy et al., 2004). Some assessment methods use physical and chemical attributes to diagnose potential sources of degradation (USEPA, 2002). These are often in the form of environmental indices. Indices use biological indicators of ecosystem integrity to give an objective quantitative value for the quality of the ecosystem (Lopez and Fennessy, 2002). Indices are powerful tools for making management decisions related to wetlands and wetland health (USEPA, 2002a). Some of these assessment methods are highlighted in Table 1.

Table 1. Summary of Indices and Rapid Assessment Methods

Index	Description
Rapid Appraisal Index	Used to determine the condition of wetlands in south-eastern Australia (Spencer et al., 1998).
Floristic Quality Index	Uses a disturbance gradient to rank the level of human impact to characterize depressional wetlands (Lopez and Fennessy, 2002).
Wetland Fish Index	Used to detect degradation in wetlands in the Laurentian great lakes (Seilheimer and Chow Fraser, 2006).
California Rapid Assessment Method	Used to assess wetlands in California not including riparian wetlands (Collins et al., 2007).

One of the most popular assessment methods is the Hydrogeomorphic Approach for Assessing Wetland Functions (HGM). It is based on a hydrogeomorphic classification of wetlands (Brinson et al., 1995; Smith et al., 1995). Federal policy states that all federal agencies will use HGM through the development of regional guidebooks (NIIT, 1997). These include guidebooks for the application of HGM to riverine wetlands and tidal fringe wetlands (Brinson et al. 1995; Shafer and Yozzo, 1998). These were refined for specific geographical areas such as Northwest Gulf of Mexico and another for the wetlands of the Mississippi and Alabama Gulf Coasts (Shafer et al., 2002; Shafer et al., 2007). In these, a large number of characteristics of the wetland are measured ranging from vegetative cover to measurement of the stocks of macrobenthic invertebrates. One of the main criticisms of HGM is that it requires a large amount of resources to implement (Hatfield et al., 2004). This includes a large time commitment, extensive equipment and well qualified teams of experts.

There are many guides for creating wetland indices or assessments methods. Smith and Wakeley (2001) proposed guidelines for developing regional guidebooks for the application of HGM. They identified the steps for developing the initial model (figure 3), and the need to verify, field test and validate the model (Smith and Wakeley, 2001).

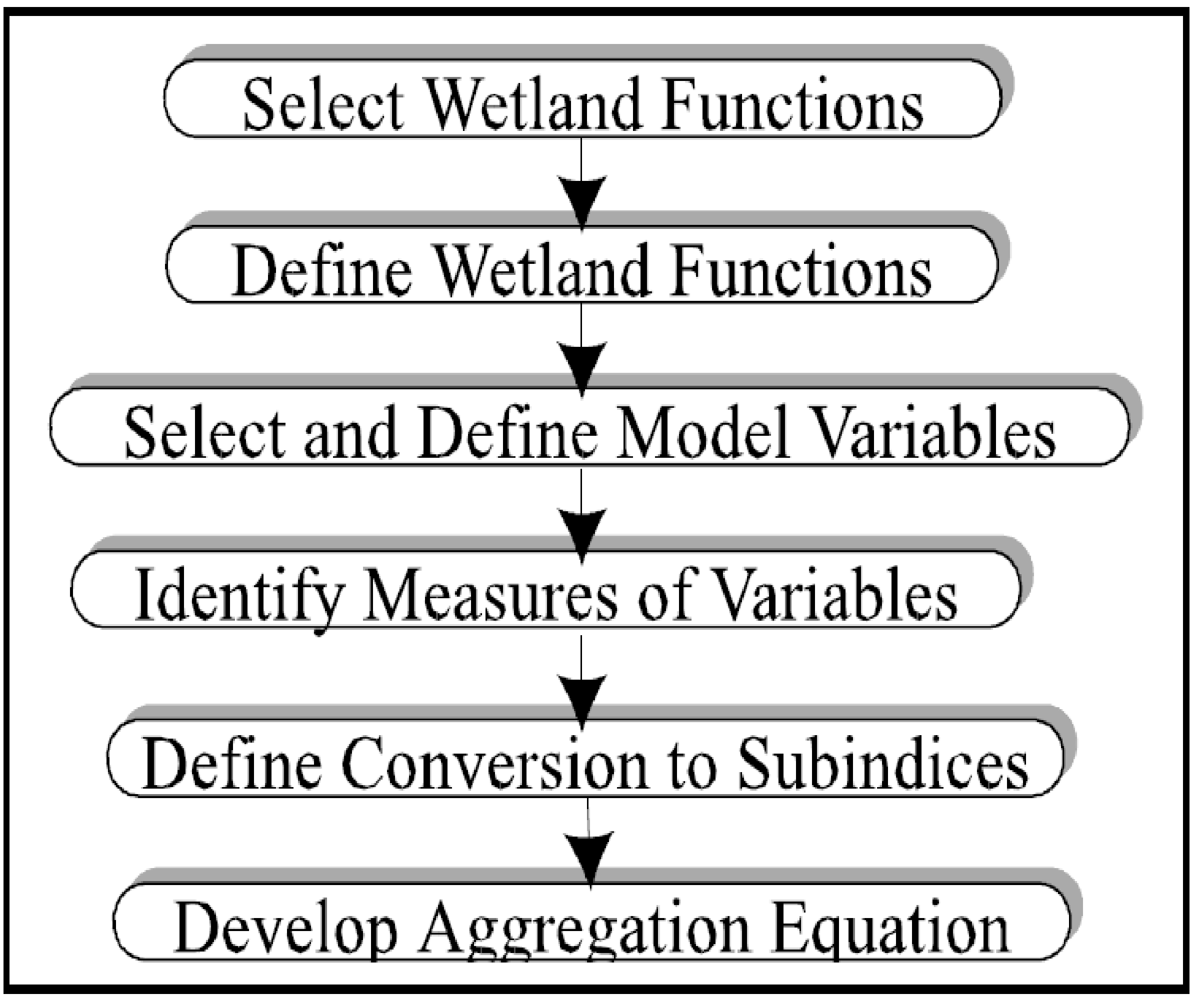


Figure 3 Suggested steps for field testing assessment method (Wakely and Smith, 2001)

They described the process for verifying, field testing and validating assessment methods (Table 2, Table 3). Reference wetlands play a very important role in this process (Smith, 2001). They are benchmarks against which other wetlands can be compared to for assessment (Brinson, 1993). They form standards against which to compare wetlands being assessed in the future. Sutula et al. (2006) created a guide for creating a wetland assessment method based on the creation of the California Rapid Assessment Method (CRAM) (Table 4).

Based on these methods the main steps for developing a sound assessment method are:

1. Set assessment goals
2. Build a scientific foundation
3. Determine metrics
4. Field test and verify the method
5. Calibrate and validate the method.

Table 2. Suggested steps for field testing assessment method (Wakely and Smith, 2001)

Step	Description
1	Select at least 10 to 20 reference wetlands representing a range of conditions for the function of interest and for each of the variables in the model.
2	Select as least three to five wetland field sites representing a range of condition relative to reference standards.
3	Provide the draft guidebook (including models, instructions, and data forms) and background site information to testers in advance of site visits.
4	Schedule site visits by each tester independently, if possible. In any case, testers should not be influenced by other test participants. Consider scheduling two or more rounds of tests to evaluate seasonal or annual bias.
5	Ask testers to record the amount of time to apply the model at each field site and, after completion of all field visits, to provide a written critique of the model instructions, sampling procedures, and calculations.
6	Combine field results from all testers. Evaluate consistency of FCI scores across testers for each wetland function considered.
7	If model output is inconsistent, modify the model, instructions, or sampling recommendations to reduce variability. If necessary, schedule a new field test using some of the same and some different participants.

Table 3. Suggested procedure for validating assessment method (Wakely and Smith, 2001)

Step	Description
1	Select at least 10 to 20 reference wetlands representing a range of conditions for the function of interest and for each of the variables in the model.
2	Apply the morel and calculate FCI for each site. At the same time collect any variable being considered for alternative versions of the model.
3	Make independent measures of function, reevaluate assumptions made during model development and calibration about reference standard wetlands and the level of function that corresponds with FCI=1.0
4	Based on independent measures of function, re-evaluate assumptions made during model development and calibration about reference standard wetlands and the level of function that corresponds with FCI=1.0.
5	Examine plots and coefficients of determination r^2 of FCI versus independent measure of function. The expected relationship is linear.
6	Examine plots of the relationships between the measure (x-axis) for each variable in the model and the independent measure of function (y-axis). The plots should resemble the curves or histograms given in the model, except for the effects of other variables in the model output.
7	If needed modify the variable measure/subindex relationships, add or drop variables, or adjust the model aggregation equation to improve the correlation between FCI and the independent measure of function. Also test and compare the performance of any alternative version of the model.
8	If possible, return to Step 1 and initiate a new validation study on the modified model using a different set of field sites.

Table 4. Summary of Six Basic Stages and Key Questions in the Development of a Wetland Rapid Assessment Method (Stutula et al., 2006)

Stage	Elements	Questions
Organize RAM development	Assemble RAM Development Team	• What range of expertise is needed, given intended application and geographic scope of RAM? • Who are the targeted users, and how should they be included [in the] development process?
	Identify RAM Target Applications	• Is there one or more intended application of the RAM? • How will the intended application influence the type of method and specific metrics selected?
	Identify Assessment Endpoints	• What are the tradeoffs between choosing a single ecological endpoint (i.e., ecological condition) versus several assessment endpoints (i.e., multiple wetland functions) • How does broadening the method geographic scope affect method sensitivity and cost of method development?
Build a scientific foundation for the RAM development	Review RAM Existing Methods	• What existing literature, methods, and guidance are useful or relevant for RAM development? • What attributes or metrics are commonly used in RAMs? • What are common pitfalls in RAM development or implementation that can be avoided?
	Identify Wetland Classes	• Should the RAM have a single method applicable to all wetland types, focus on one wetland class or customize the method by wetland class? • How does increasing the number of wetland classes affect sensitivity of the RAM versus cost to develop and calibrate method for each class? • If multiple wetlands classes will be used, will attributes and metrics be standardized across wetland classes? • What wetland classification system will be used and are mapping data available to support its use?
	Specify Conceptual Models	• What are the kinds of wetland structure that relate to the assessment endpoint? • Is the relationship between stress and condition or function articulated? • What are the assumptions underlying the use of the conceptual models constructed?
Assemble the Method	Select RAMs Attributes and Metrics	• Should RAM metrics be selected to measure condition, stress or both? • Should RAM metrics be readily visible or require some degree of quantification? • What is the level of expertise that will be required to use RAM, and what does it imply for the selection of metrics? • What are the tradeoffs in using metrics that are customized for a wetland class or standardized across wetland classes?

Table 4 (Continued). Summary of Six Basic Stages and Key Questions in the Development of a Wetland Rapid Assessment Method (Stutula et al., 2006)

Stage	Elements	Questions
	Defining the Reference Network	• How will the reference be defined? • What are the tradeoffs of using a culturally unaltered versus best attainable reference standard condition?
	Creating Narrative Ratings and Scales	• What are the implications of using ordinal versus continuous data for aggregating results into a final score?
	Determine How Assessment Area Boundary will be determined	• Can the definition of assessment area be applied with consistency and ease during RAM use? • Given the definition of assessment area, how ecologically meaningful are the results of the assessment? • Given the assessment area, how will the results contribute to addressing the management information needs?
Verification	Verify that RAM is measuring assessment endpoints as intended	• Are RAM attributes and metrics comprehensive and appropriate? • Is RAM sensitive to disturbance gradient? • Does RAM produce repeatable results among different practitioners? • What steps can be taken to provide end users with an opportunity for feedback before method calibration?
Calibration and Validation	Determine that method is Scientifically sound through calibration and validation	• Does RAM correlate to more intensive measures of condition? • What metrics and data sources should be used as independent variables for calibration and validation? • What are the tradeoffs of using existing data versus collecting new data for calibration and validation?
Outreach and implementation	Conduct outreach	• Has a clear system been established for regular communication, update, and feedback? • Is additional guidance (i.e., beyond a user's manual) required for specific application? • How can pilot projects be used to demonstrate and stimulate interest in RAM applications?
	Manage information	• How will data collected from different sources be compiled? • What are the tradeoffs of central versus distributed data management? • How will the data be made available to the public?
	Train users	• Who are the intended users of RAM? Are they currently involved in its development? • What kinds of materials will be most useful to these groups? • Are there systems in place to assess the repeatability of results among RAM users?

Some measures of wetland quality have been developed for Florida wetlands. The estuarine rapid assessment procedure has been developed by the Southwest Florida Water Management District as a regulatory tool to assess estuarine wetlands (Bartoldus, 1999). This procedure is used to assess mitigation banks in Florida. Reiss and Brown (2005) developed an index for forested stand and floodplain wetlands. They identified the need for accounting for seasonal variability and validation of the index through testing on a different set of wetlands as the areas for future research (Reiss and Brown, 2005).

The research needs for Tampa Bay have been documented in the literature. Lewis et al. (1998) outlined the need for continued monitoring in order to maintain habitat quality. Holland et al. (2006) documented the research needs outlined by a large group of stakeholders. These include the need for a monitoring program to track the quantity and quality of mangrove forests. This program is needed because the managers in Tampa Bay aim to improve the quantity and quality of mangrove forests as part of conservation efforts. The literature clearly establishes the need for an assessment method that can be applied to Tampa Bay and that such a method would be highly effective as a management tool. This will be addressed through the creation of the Mangrove Quality Index (MQI) created as a result of this study.

The best assessment methods are those that are developed for a specific habitat type. This is because wetlands vary according to the type and by region. This is one of the main reasons why a variety of HGM methods specific to location and type has been developed. HGM was not applied in this situation mainly because of the large amount of resources needed to develop an HGM method for a specific category of wetlands.

Further many HGM methods do not include important aspects of wetland characteristics such as biogeochemistry, biota and other wetland functions. Currently there are no methods specifically for mangroves (Bartoldus, 1999). Current methods cannot be applied to mangroves because of the many characteristics unique to mangrove forests. These include the wildlife, the unique plant species and the characteristics of the water found in mangrove forests. For example, crabs play an important role in the ecology of mangrove forests, yet they are not included in current methods (Hogarth, 2007). Crabs affect the chemical composition of soil as well as the growth and productivity of tree species. Their burrows aerate the soil, help remove harmful chemicals and transport nutrients. The MQI- developed as a result of this study- addresses these shortcomings because it is developed specifically for mangrove forests and because it measures several characteristics of the forests.

Study Area

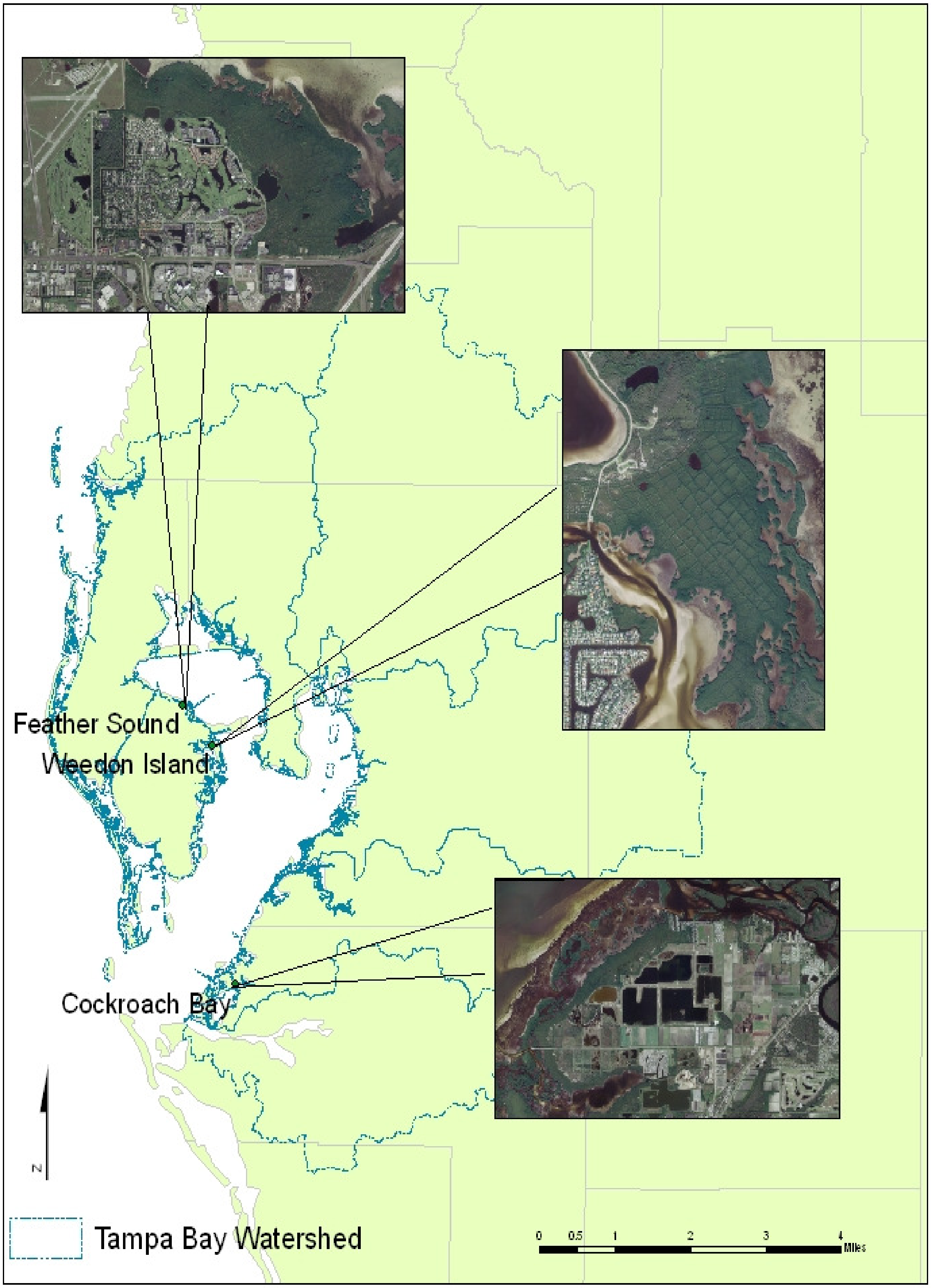
Tampa Bay, located on Florida's west coast, is Florida's largest open water estuary (Holland et al., 2006). It covers over 1000 km^2 and its watershed or drainage basin covers 5700 km^2. The bay was previously believed to be located on an in-filled valley system that becomes a shelf valley system offshore (Donahue et al., 2003). More recently it was discovered that Tampa Bay is actually a spatially-restricted, sediment filled karst paleopographic low (Hine et al., 2009). It is in the center of the Florida Platform and fed by a small streams and local upland drainage basins. Tampa Bay is very shallow with an average depth of three meters (Holland et al., 2006). Many shipping channels have been dredged to support the three commercially important ports located in the bay. The bay is directly bordered by three counties: Hillsborough, Manatee and Pinellas. The combined population of these counties is over two million people and a significant amount of growth is expected (Census, 2009). These counties all have subtropical climates with warm humid summers and mild winters. Tampa Bay and its surrounding areas have very few freezing days and rarely experience temperatures below -2^{o}C. The area is susceptible to tropical storms and hurricanes from June to November. The dry weather that occurs in the spring and fall can damage plants.

Tampa Bay is a part of the National Estuary Program and is managed by the Tampa Bay Estuary Program (TBEP) (Holland et al., 2006). The TBEP works with many partners to restore and protect the bay. Among the habitats present in Tampa Bay, mangrove forests provide a vital function.

Study Sites*:*

Three distinct locations in Tampa Bay were selected to conduct this study (figure 4). These are Feather Sound, Weedon Island and Cockroach Bay. Feather Sound and Weedon Island are part of the Weedon Island Preserve managed by the Pinellas County Department of Environmental Management's Land Division. Cockroach Bay is part of the Cockroach Bay Aquatic Preserve managed by the Florida Department of Environmental Protection.

These sites were selected because of their current level of human impact. Cockroach Bay has the least amount of human impact because it is relatively isolated and not highly used (figure 5). Weedon Island in the past experienced significant human alteration but now natural vegetation, including mangrove forests, is recovering (figure 6). Today, this location is currently protected and carefully managed. Feather Sound was chosen as the mangrove forest with the highest level of human impact (figure 7). Although it is part of the Weedon Island preserve, it is not actively managed and is in close vicinity to several sources of point and non-point source pollution. Together these three sites can show a range of human impact on mangroves.



Data source: SWFWMD

Figure 4. Study Sites in Tampa Bay

Cockroach Bay

Figure 5. Cockroach Bay mangroves with prop roots of red mangroves rising out of the estuarine waters

Cockroach Bay is located in Hillsborough County in lower Tampa Bay. The Cockroach Bay Preserve covers 2.49 km^2 and consists mostly of mangrove forests. It is one of the least impacted aquatic preserves in the region (DNR, 1987). It is adjacent to farms and a small number of residences. A large portion of the area surrounding Cockroach Bay has been modified from its natural state by channeling, mining or farming. Some of the previously mined area has been restored to mangrove forests. The area is managed by the Florida Department of Environmental Protection. It is used mainly for fishing, paddling and launching recreational vessels.

Weedon Island

Figure 6. Weedon Island mangroves showing extensive prop root system

Weedon Island is a nature preserve in Pinellas County in the western part of Tampa Bay. Public access to the preserve is restricted and activities are limited to recreational and educational activities. The park contains a canoe trail, an educational facility, elevated boardwalks and hiking trails. There are various natural habitats in the park in addition to mangrove forests, such as mudflats, salterns, scrub, pine flatwoods and maritime hammocks. Weedon Island also has a rich and varied history. Historically, Weedon Island has been moderately impacted by human activities. The preserve was once home to prehistoric people (Pinellas, 2008). At least four prehistoric cultures called Weedon Island home including the Weedon Island Culture, which created distinctive decorated pottery. There was a movie studio on the island in the 1930s as well as an airport, which left distinctive human footprints. Relics from this time can still be found throughout the mangrove forests, as well as changes in elevation and community structure. As with many other mangrove forests in Florida and the rest of the U.S., extensive mosquito ditching was conducted at Weedon Island, evidence of which can still be seen today in aerial photographs and field observations (figure 9). The mosquito ditching affected the hydrology of the habitat by changing the water flow and topography in the mangroves. Since 1974 the island has been designated as a preserve. Presently, the preserve is near various residential communities and a small portion of the park is under the control of Progress Energy as the Bartow Power Plant.

Feather Sound

Figure 7. Feather Sound mangroves showing dead trees and apparent damage

Located in Old Tampa Bay, Feather Sound is often thought of as the forgotten part of Weedon Island Preserve because it is not part of the park. It is part of the Gateway Tract, which covers 6.14 km^2. It is adjacent to highly developed residential, recreational and commercial properties in Pinellas County, which are part of the Feather Sound community. This is a collection of neighborhoods and businesses that have developed over the past twenty years with a golf course, playground and parking lot bordering the preserve. There is also evidence that some areas of the preserve have been used for some recreational activities. Feather Sound also underwent extensive mosquito ditching. In addition there is evidence of infilling in some areas and a lake at the landward extent of the forest.

Methodology

The mangrove quality index (MQI) was created based on the stages of developing a rapid assessment method outlined by Stutula et al. (2006) and Wakely and Smith (2001). In the first stage of the development of the MQI the assessment goals were set. The MQI will be developed for the assessment of the quality of mangroves in Tampa Bay, FL. It may be used by mangrove managers to monitor mangrove quality and make management decisions. The MQI will aim to measure multiple wetland functions. A scientific foundation for the MQI was built from an extensive review of the current scientific assessment methods. Based on this review of the physical properties of mangroves and existing assessment methods, the indicators outlined in Table 5 were suggested as possible metrics for the MQI.

These possible metrics were chosen because they are likely to show changes that correlate with mangrove forest conditions. They include physical properties suggested by Whigham (1999) as indicators of wetland function. Whigham (1999) suggests that characteristics such as absolute density, neighboring land use, hydrological modifications, and physical integrity of the soil affect the function and quality of wetlands. Whigham's variables were adapted based on the unique qualities of mangrove forest to determine the indicators used in this study.

The indicators measure the quality of four main attributes: hydrologic flow, water quality, soil and biota. Indicators that measure the hydrologic flow attribute reflect characteristics that may potentially alter the flow of water. Water quality indicators measure the physical properties in the mangrove water column. Similarly, soil indicators measure soil quality. Biota indicators rely on vegetation and animal indicators to categorize the overall health of the community. These indicators were then measured at three reference locations in order to field test the metrics.

The study locations were selected based on the varying levels of human impact and overall quality of the forests. These locations form the reference network because they represent mangroves of varying quality with regards to the spectrum of human impact. Using GIS, five transects were drawn at each location and five sampling sites were randomly generated along each transect (figure 8, 9, 10). The locations of the transects were determined by visual examination of the study area. One transect was drawn across the northernmost section, one across the southernmost and three in between with the aim of capturing as much as possible of the variety of conditions within that study area. Samples were collected from the sampling sites during the summer and fall of 2008.

Table 5. Description of Indicators

Attribute	Description	Indicators
Hydrologic	Measures the amount of hydrologic changes on site	To be determined later (to include factors such as roads, ditching, canals, boat basins etc)
Water	Measures physical properties of water in the mangroves	Turbidity, chlorophyll a
Soil	Characterizes the soil on site	organic content, sediment composition (size/type)
Biota	Determines species community characteristics.	Composition and abundance of mangrove species, neighboring land use, crab holes

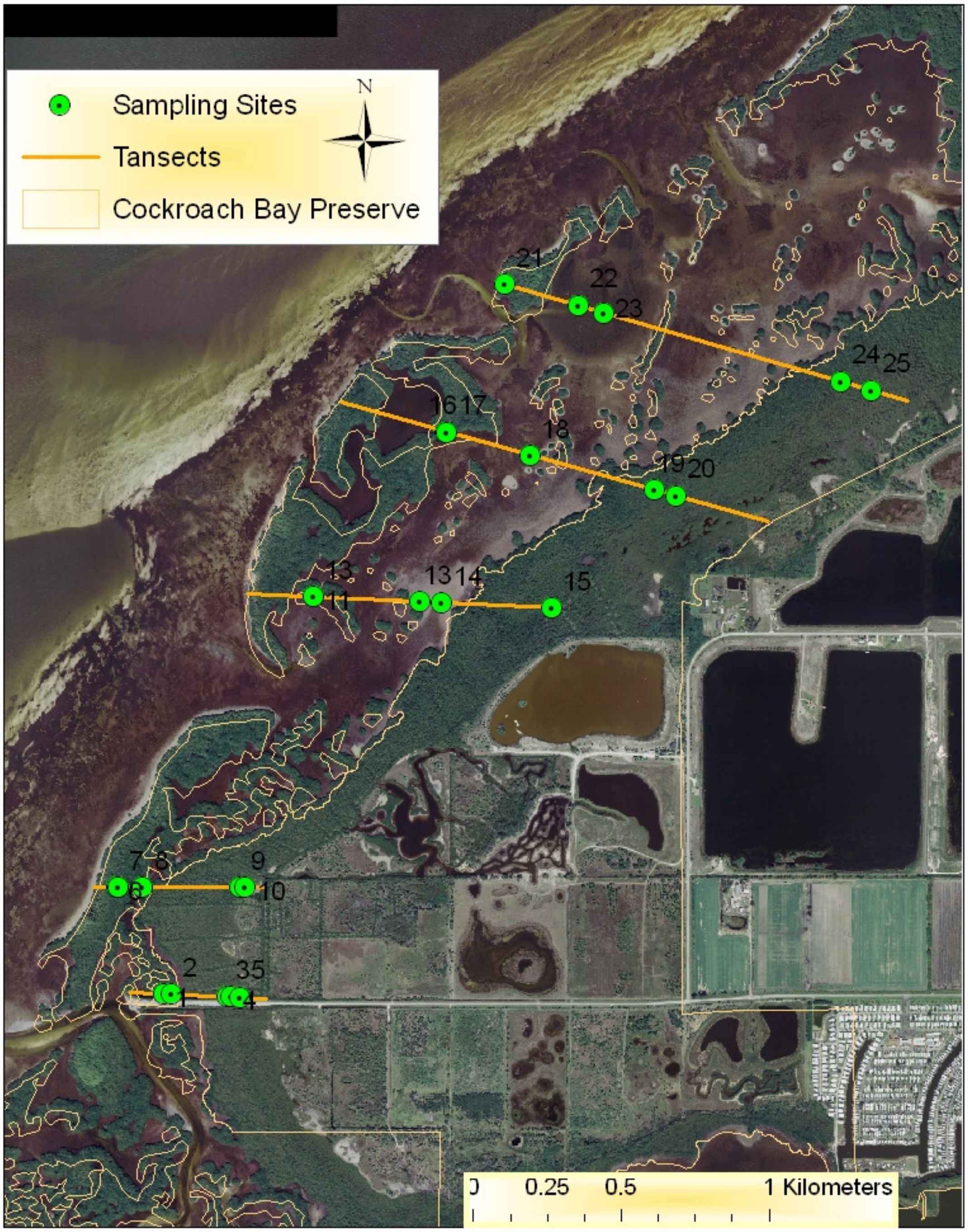


Figure 8. Transects and sampling sites in Cockroach Bay

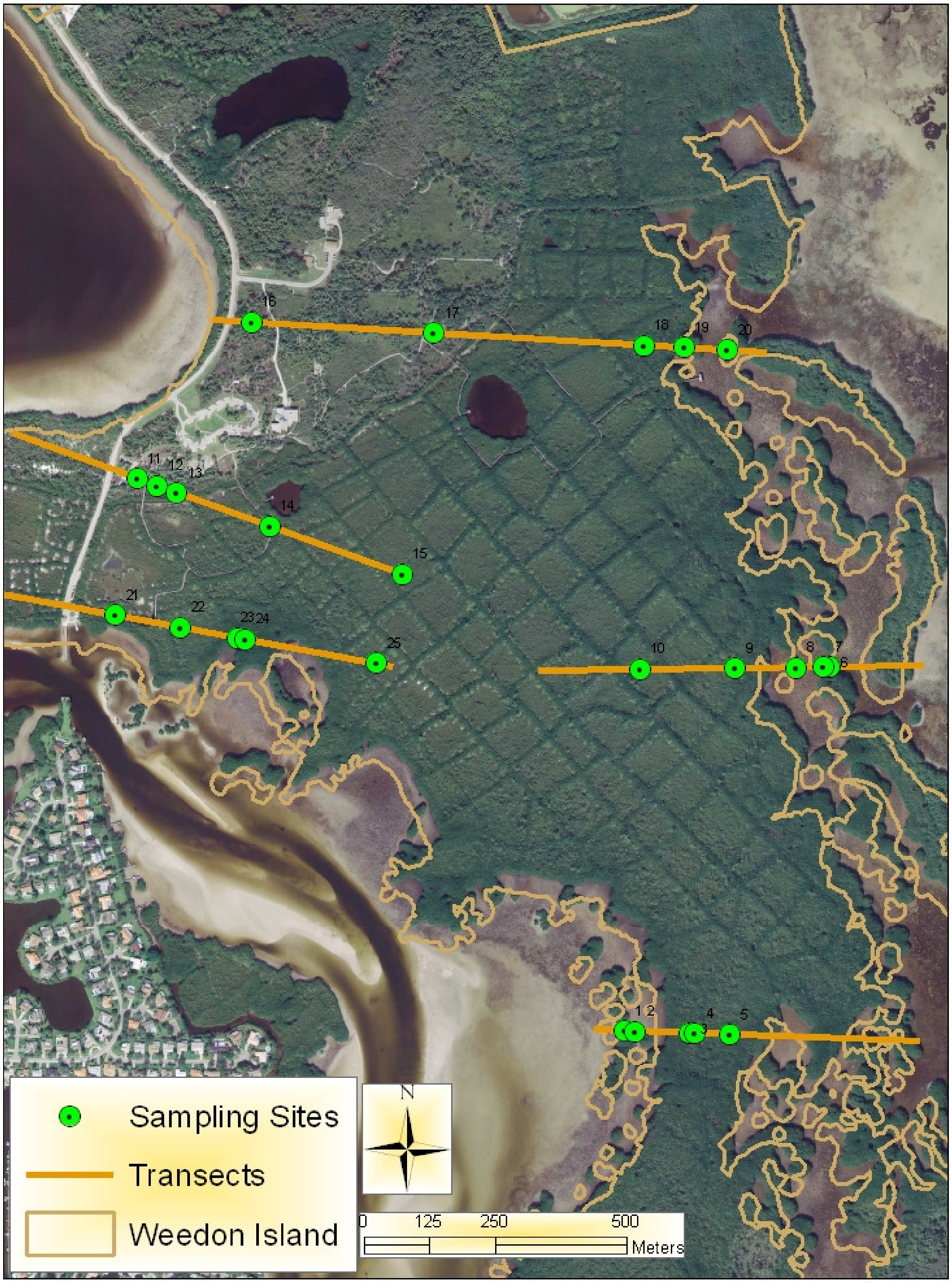


Figure 9. Transects and sampling sites in Weedon Island

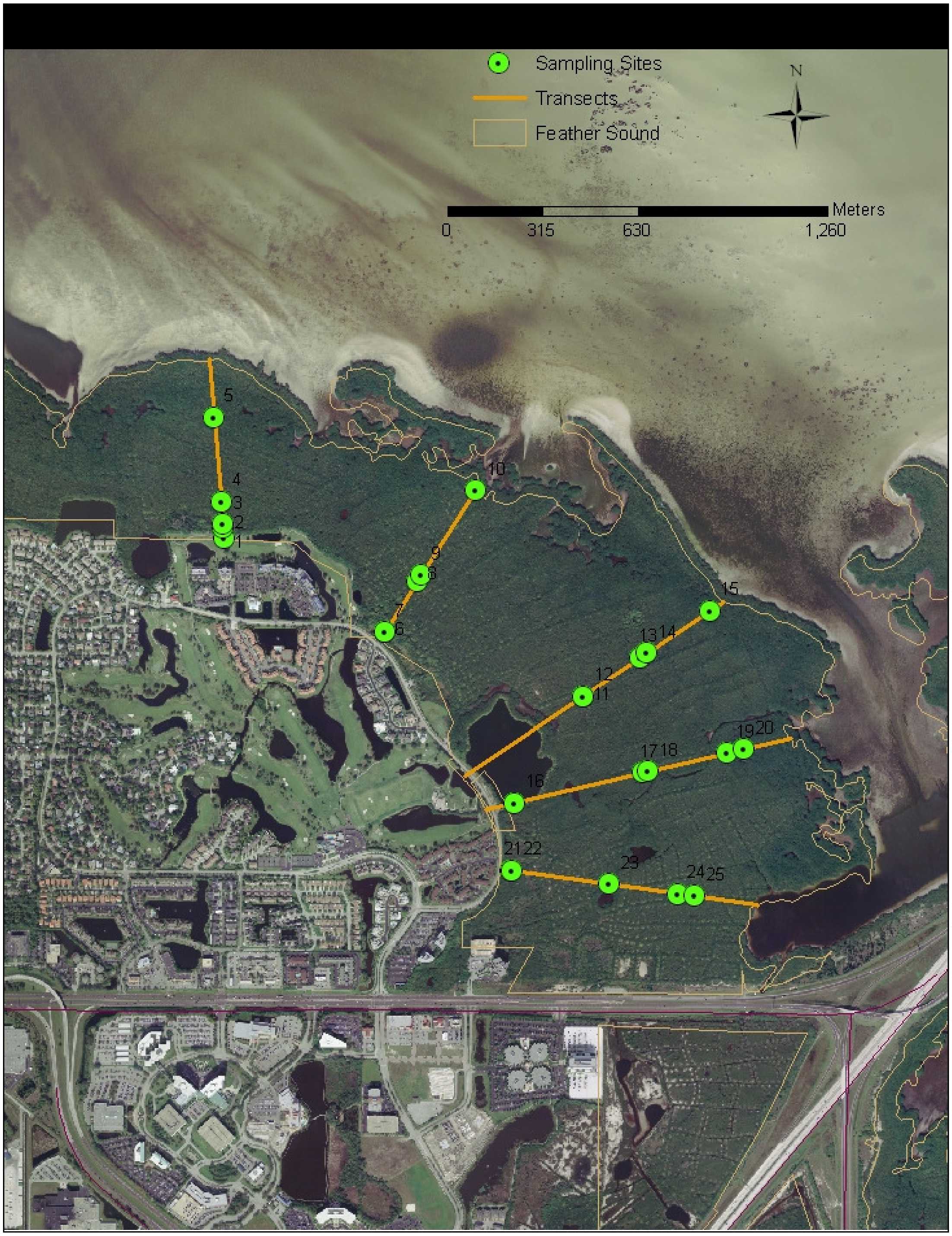


Figure 10. Transects and sampling sites in Feather Sound

Field Sampling

Stutula et al. (2006) and Wakely and Smith (2001) suggest field testing and the assessment methods by collecting samples across a reference network. At each of the sites plotted in the study locations the following sampling was conducted:

Water - In locations where there was greater than one foot of water present 300ml to 500ml of water was collected using direct sampling for chlorophyll and turbidity analysis. Dissolved oxygen and temperature were measured *in situ* using a dissolved oxygen probe. Salinity was measured during sampling using a refractometer.

Soil – 400g to 500g of soil was collected using a corer for organic content and composition analysis.

Biota – Animal utilization was determined by counting the number of crab holes in a 0.5m quadrant. The number of species was also noted at locations where more than one species were visible. Vegetation abundance and diversity were measured using the point centered quarter method (Mueller-Dombois and Ellenberg, 1974). The presence of invasive species was also noted.

Additional observations – Where possible GPS coordinates were recorded. However, in many places the thick mangrove canopy prevented transition of the signal. A general description of the site was recorded as well as the presence of garbage. The hydrologic conditions were also noted as well as tides and weather observation, from local weather sources, for the sampling period.

Laboratory Analysis

Soil organic content was determined using the loss on ignition method outlined by Nelson and Sommers (1998). Particle size analysis was conducted using sieve analysis from Day (2001). Chlorophyll analysis was conducted using the spectrophotometric method outlined by Parsons et al. (1984). Turbidity was measured using the absorptometric method, the result being turbidity in Formazin Tubidity Units.

Data Analysis

To determine the effectiveness of the proposed metrics, the MQI was calibrated as suggested by Stutula et al. (2006) and Wakely and Smith (2001). This was accomplished by statistical analysis of the data acquired from the field sampling and laboratory analysis. Known measures of condition as well as indicators that correlate known measures of condition were selected as metrics. Summary statistics were plotted for all indicators to look for trends that would indicate a correlation between the indicator and condition. Plant density is a known measure of wetland condition (Whigham, 1999). The indicators were plotted thus against density and the strength of the correlation was used to determine whether the indicator should be used as a metric.

The scoring for each metric in the index was compiled by plotting the cumulative frequency of the values obtained for each metric. The boundary points were determined by dividing the curve into 5 equal parts at 20 percent intervals (figure 11).

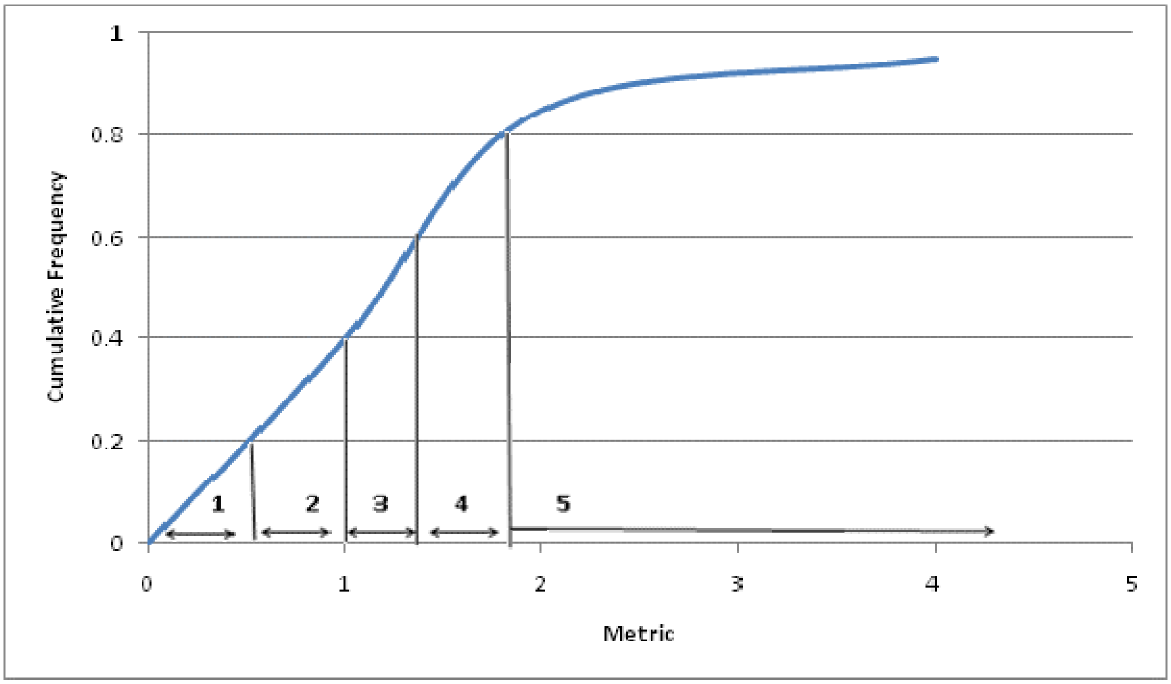


Figure 11. Cumulative Frequency curve used for scoring index.

Results and Discussion

Of the proposed 75 sampling sites, 65 were sampled. Sites were not sampled because they were either inaccessible or did not contain mangrove species within 20m of the site.

Crab holes

The number of crab holes/m^2 varied across the three sampling locations (figure 12). A large amount and a wide assortment of wildlife using a habitat is a strong indicator of a healthy well functioning habitat (Shafer et al., 2007). Crab holes are considered an indicator of condition because they crab holes increase the quality of the habitat and the plant species (Hogarth, 2007). A decrease in the number of crab holes results in poor habitat quality. The average mangrove has 40-50 crab holes per square meters. Several species of crabs can be found in Florida's mangroves. The crabs burrow into the soil and their holes can be seen from the surface. The number of holes in a given area is indicative of the number of crabs in the habitat. One limitation of this method is that there may be holes that are no longer occupied by crabs or one crab may utilize more than one hole. Despite these limitations the number of crab holes can still be used as an indicator because of the impact of the crab hole on habitat quality. There is an increase in the median number of crab holes as quality increases (Figure 12). Feather Sound has the fewest crab holes and Cockroach Bay has the most with Weedon Island between these two end members (figure 12).

The cumulative frequency curve of the crab holes from all three locations shows some distinct changes in slope (figure 13). These were points where the slope changes were used to determine the intervals for the index scores (Table 6). A score of 1 is assigned to the number of crab holes indicating the most pristine conditions and a score of 5 to the lowest quality mangroves.

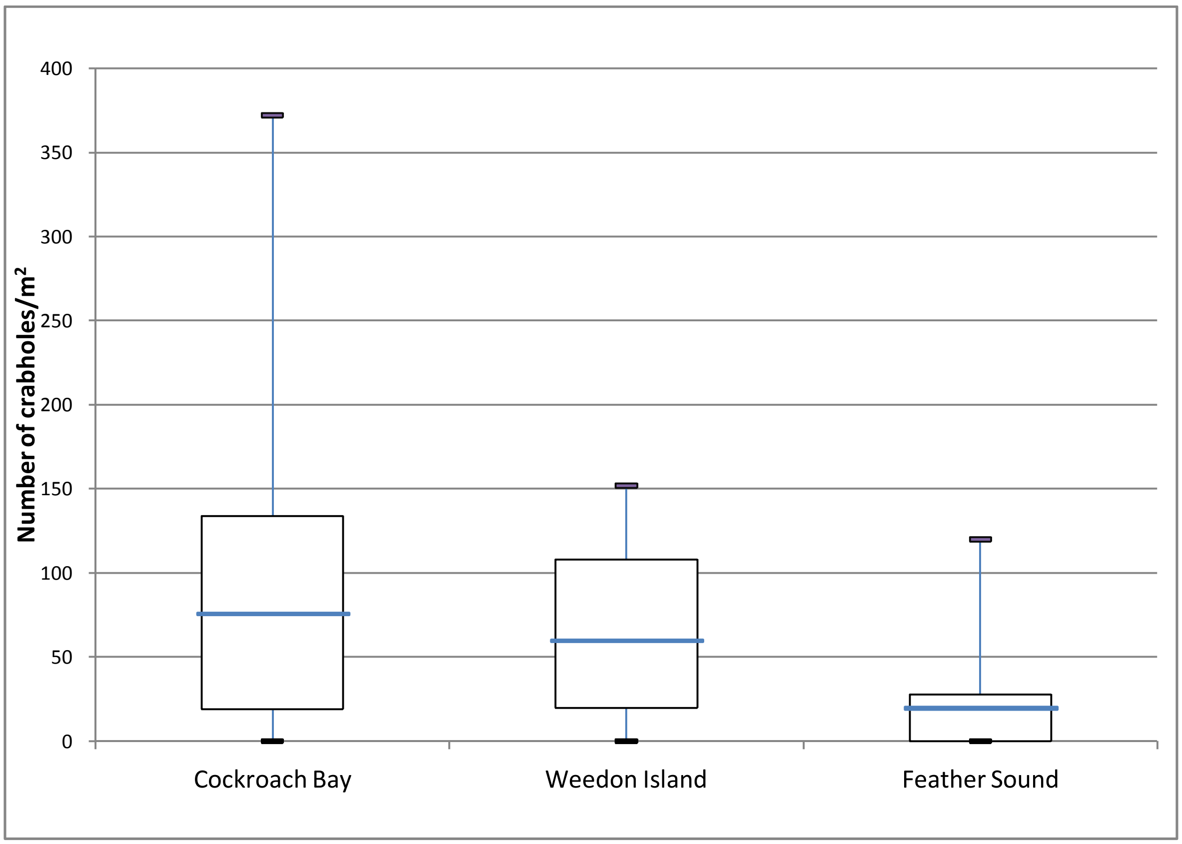


Figure 12. Summary statistics of crab holes at each study location. The box and whisker plot shows the minimum, 1st quartile, median, 3rd quartile and maximum values. The differences in range and trend of decreasing value with increased human impact is evident.

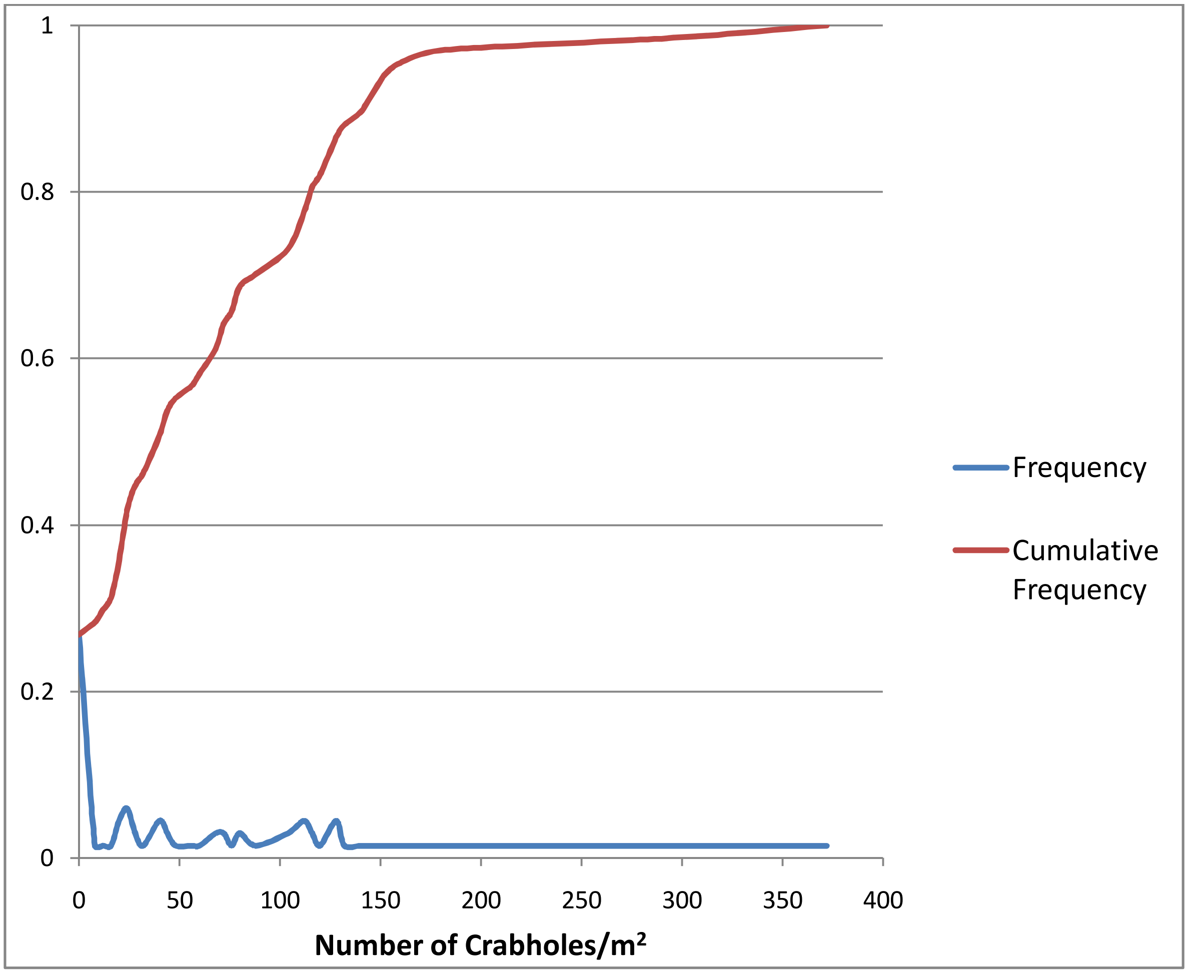


Figure 13. Cumulative Frequency distribution of crab holes at all locations combined. Arrows show points used to determine intervals for scoring of the metric.

Table 6. Scoring of the Crab hole Metric

Score	Crab holes/m^2
1	121 or more
2	61- 120
3	21-60
4	1-20
5	0

Vegetation

Vegetative composition is important in defining a wetland because vegetation affects its hydrology (Brinson 1993). Mangroves forests are defined by their vegetative assemblage. In some wetlands an increase in the number of plant species is indicative of ecosystem health. This is not the case with mangroves as their distribution of species is determined by salinity, competition and other physical factors (Hogarth, 2007). These factors include hydrogeology and elevation. A large stand containing a single mangrove species is not necessarily less healthy than a similar forest with several species. Figure 14 shows the number of species at the sampling locations. There is a trend in the number of species as mangrove quality changes. Comparison with density shows no correlation (r^2= 0.009, p=0.230). In mangrove forests, number of species does not reflect condition.

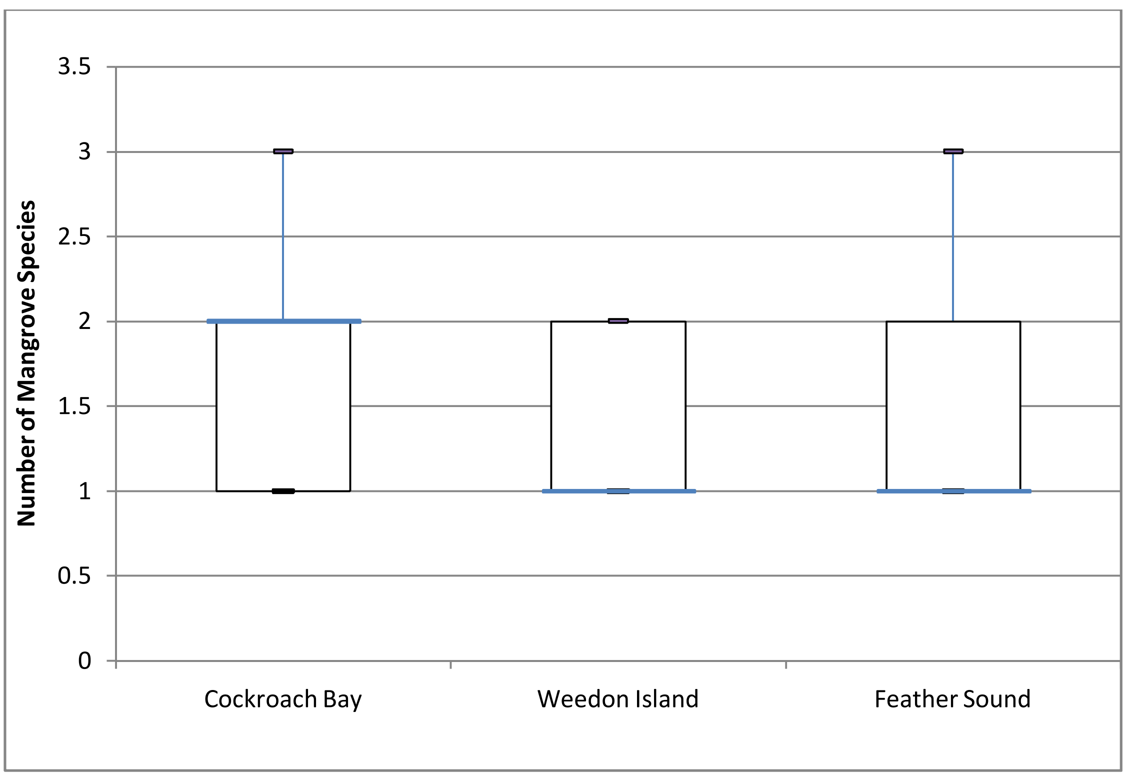


Figure 14. Summary statistics for the number of mangrove species at each sampling site.

Absolute density is the number of mangroves in a given area. In this study it is measured in trees per $100m^2$. It is determined from the data obtained from the point-center-quarter method using the following formula:

$$\text{Absolute Density} = \frac{\text{Area}}{(\text{mean distance})2};$$

where mean distance is the mean point to nearest tree distance for all quarters. Absolute density is an established measure of condition (Whigham, 1999). As conditions of an ecosystem improve, it is expected that a greater number of trees will thrive in a given area. The data from this study shows that absolute density increases with condition. Cockroach Bay has the highest absolute density, followed by Weedon Island in Feather Sound with the least (figure 15).

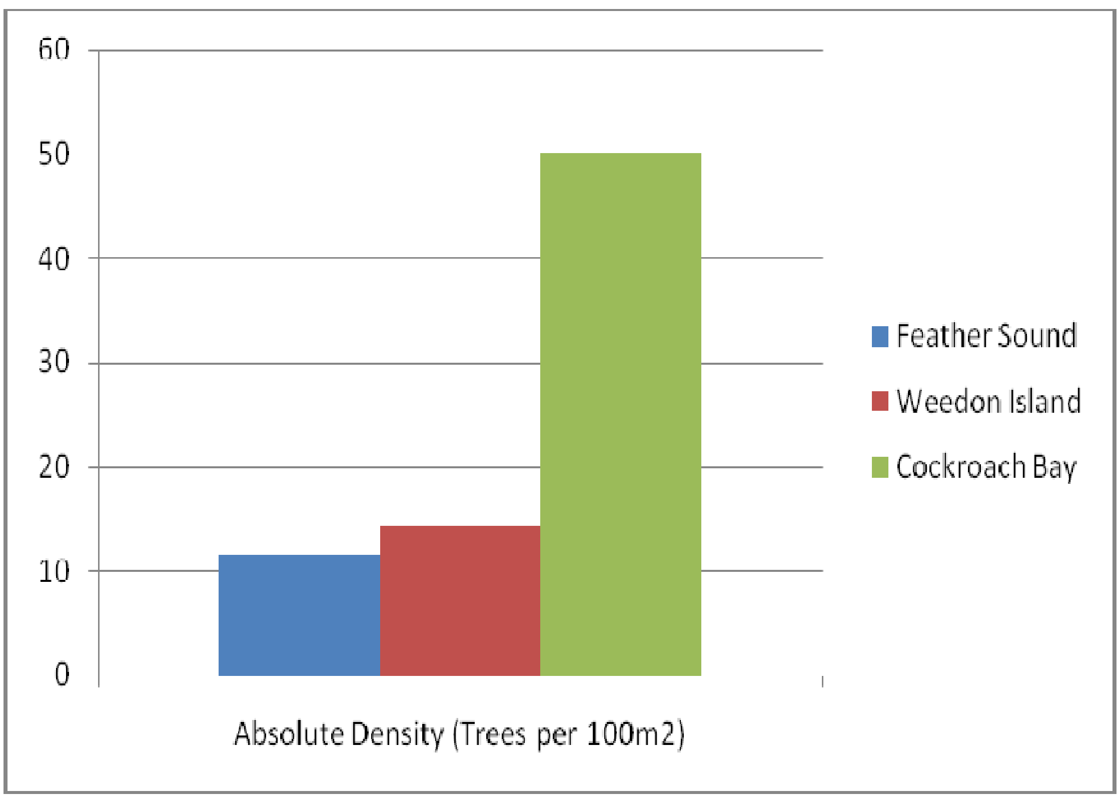


Figure 15. Absolute density of mangrove species at Feather Sound, Weedon Island and Cockroach Bay.

Tree basal area is another physical measurement that can be used to characterize and compare trees (Brack, 1999). There is a decrease in the median basal area as condition decreases (figure 16). This trend also occurs with the minimum and maximum basal area. An inspection of basal area of the individual mangrove species indicates that there is no apparent pattern (figure 17). However, the overall trend of decrease in basal area with condition is confirmed by the strong negative correlation with density (r^2=0.089, p<0.001) (figure 18). Basal area (or stand basal area) refers to the total cross-sectional area of the trees in a stand, at breast height (University, 2006). It can be calculated by combining the average tree basal area with absolute density. Basal area increases with condition. Cockroach Bay has the highest basal area, followed by Weedon

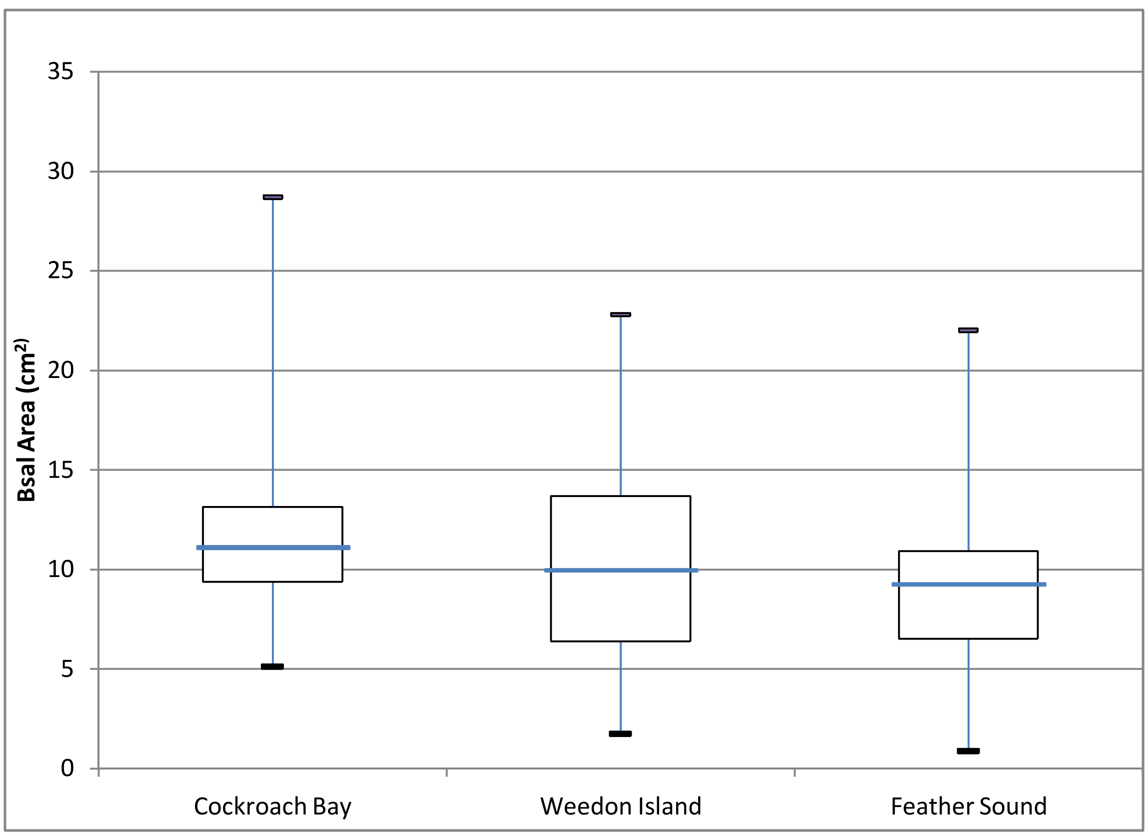


Figure 16. Summary statistics for tree basal area at each sampling location.

Island and then Feather Sound (figure 19). Therefore, stand basal area is appropriate as a metric for the MQI. The inflexion points of the cumulative frequency curve of basal area for the combined study locations were used to determine the intervals for the index scores (figure 20). A score of 1 is assigned to the average basal area indicating the most pristine conditions and a score of 5 to the lowest quality mangroves (Table 7).

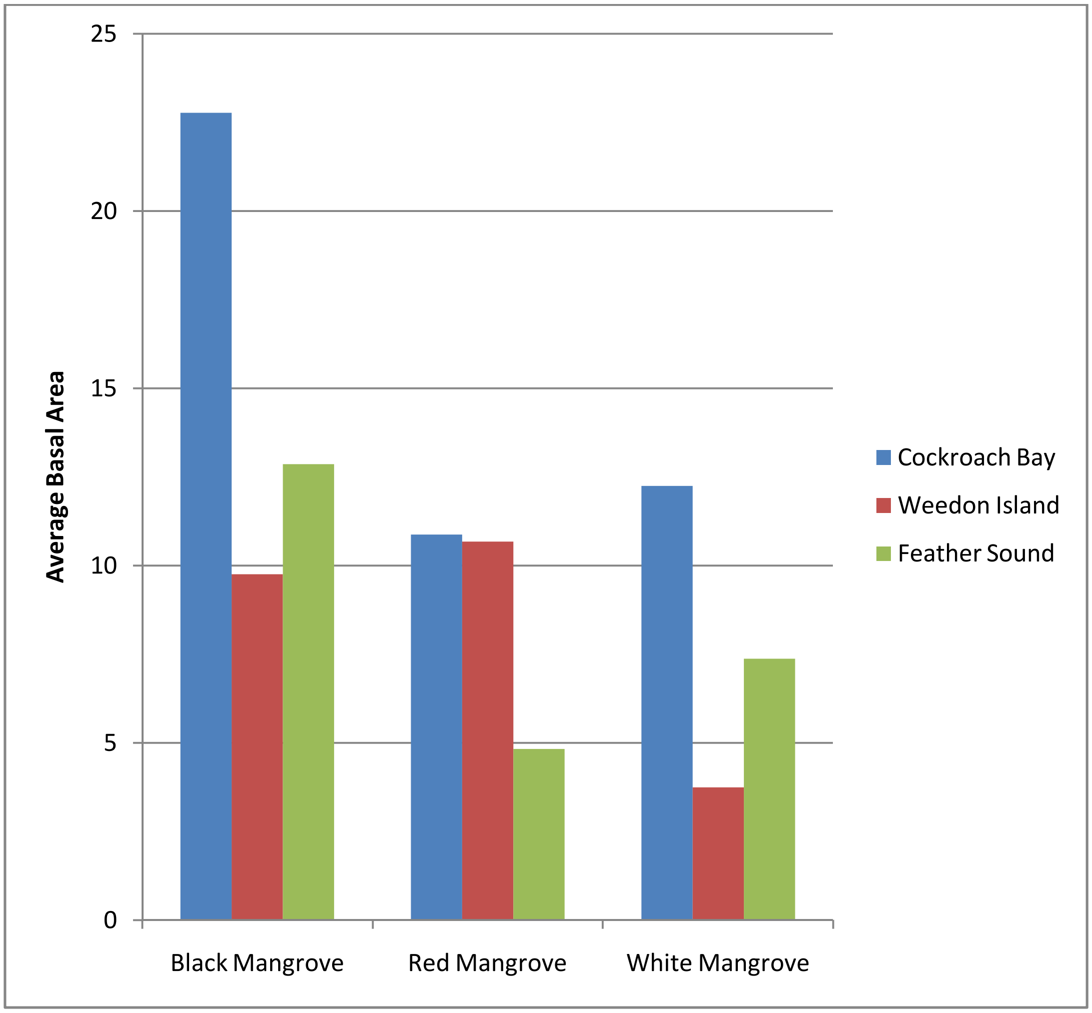


Figure 17. Comparison of basal area of individual mangrove species at the study locations.

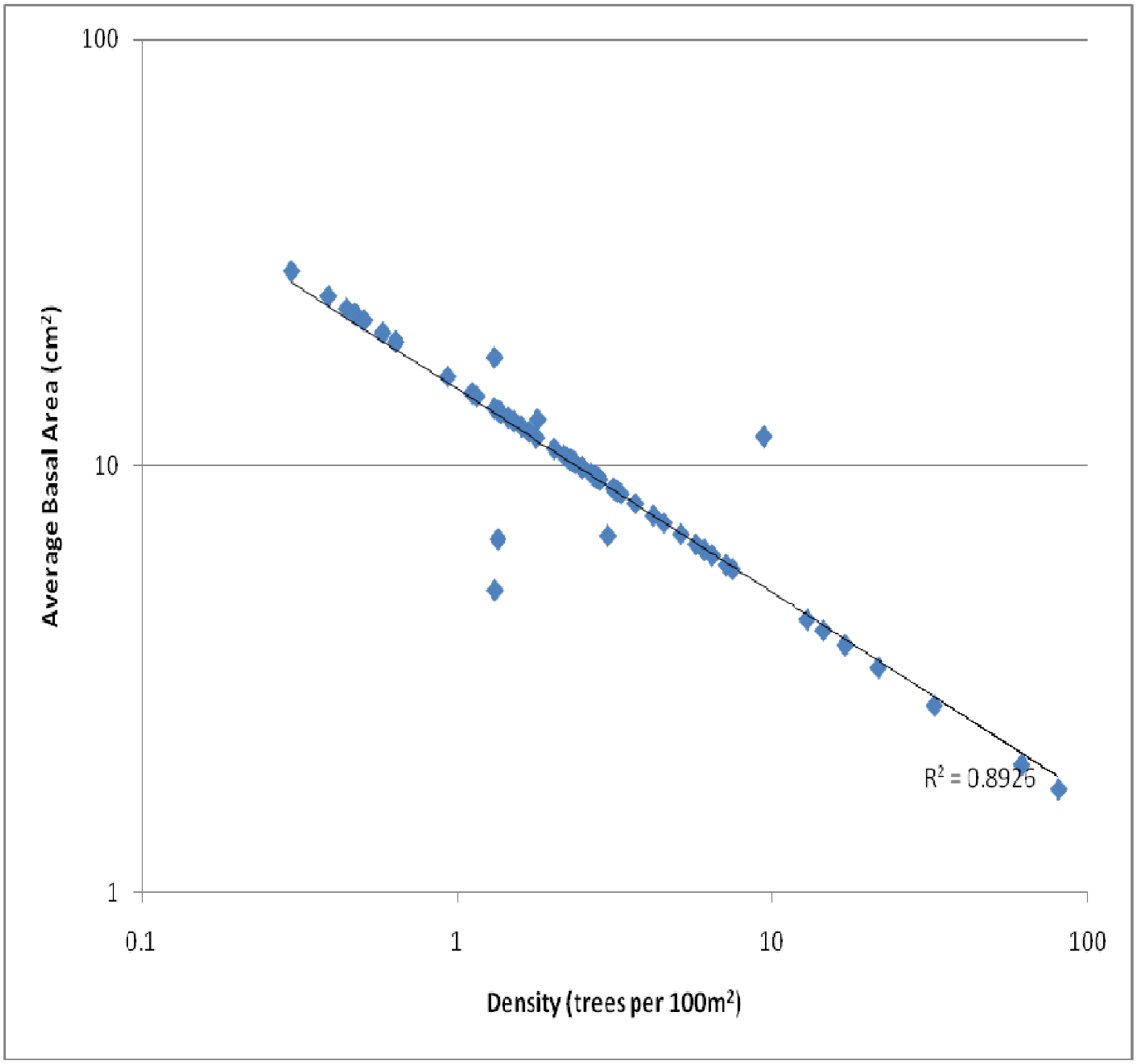


Figure 18. Plot of density against basal area on a logarithmic scale.

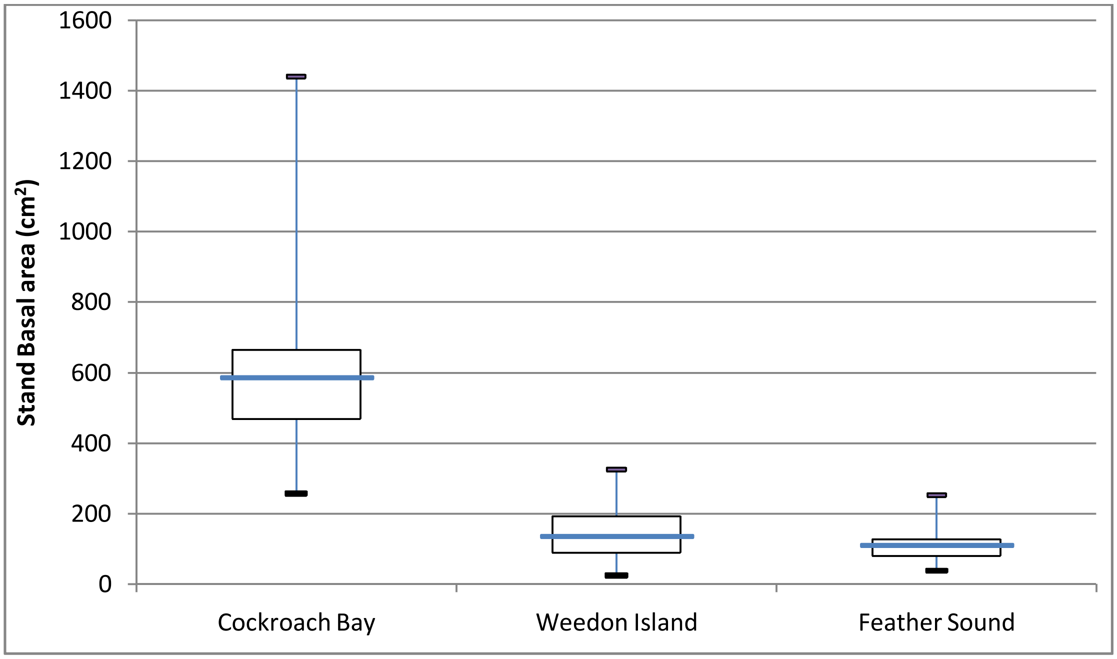


Figure 19. Summary statistics for stand basal area

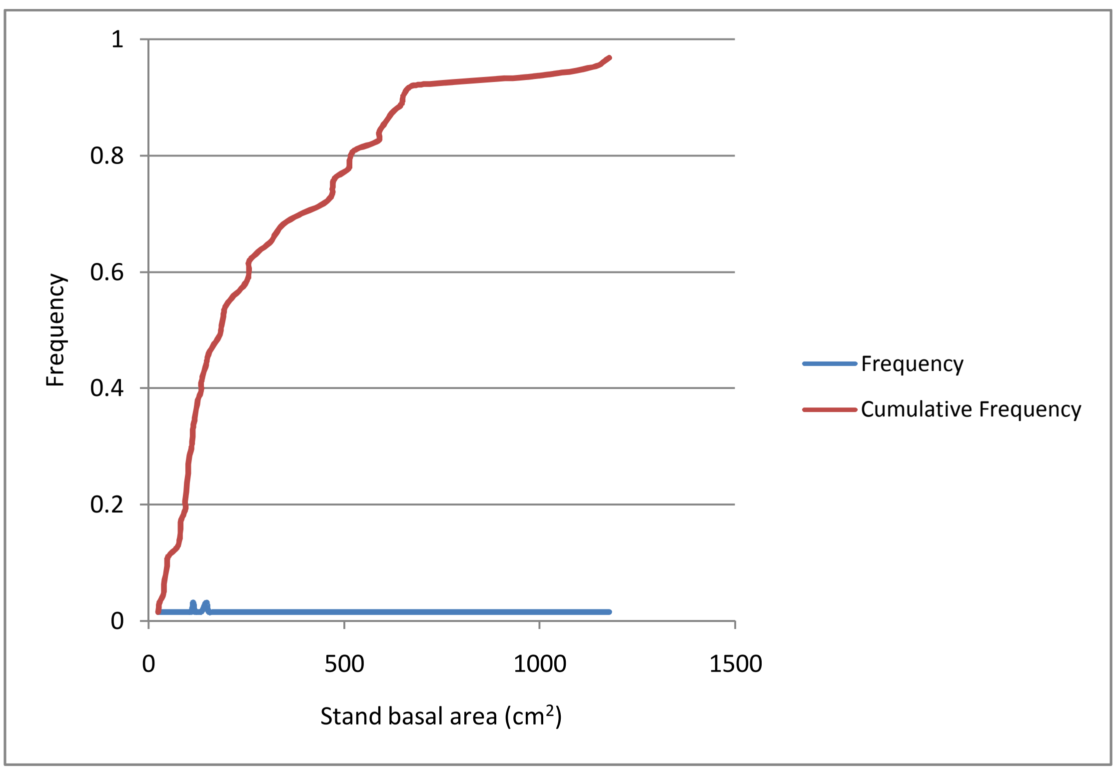


Figure 20. Cumulative frequency distribution of stand basal area

Table 7. Score of basal area metric.

Score	Basal Area (cm^2)
1	514 or more
2	254-514
3	135-253
4	94-134
5	0-93

Water

Hydrology plays a very important roles in wetland function. Water is also sensitive to outside forcing factors such as changes in vegetative community, hydrogeology, and upland land use. Due to its sensitivity, it is essential for comparison of water samples that all samples are taken from comparable locations. For example, water taken from the bay can only be compared to water taken from the bay at another location and not to water taken from a ditch, canal or another location within the mangrove. For this study, chlorophyll and turbidity were investigated as metrics that indicate the condition of mangroves.

Water does not appear to be the best indicator for this index. This is because water with a depth of greater than one foot is not always present in Florida's mangroves. This varies from one season to the next. It is also affected by tidal inundation and rainfall. Less than 30% of the sites sampled had enough water for sampling. No sampling locations at Feather Sound contained enough water for sampling.

Chlorophyll a is a possible metric because it indicates the amount of phytoplankton in the water and often increases as water quality declines (Brando et al., 2009). The results of chlorophyll analysis show an apparent decline with poor condition (figure 21). Cockroach Bay also has a much greater range of chlorophyll that Weedon

Island. Further analysis shows exponential relationships between chlorophyll and density (r^2=0.466, p=0.009) (figure 22). Other relationships reveal less correlation. A 2nd order polynomial has an r^2 value of 0.236 and a p value of 0.070, 3rd order has an r^2 value of 0.359 and a p of 0.004. These values confirm that the strongest correlation is an exponential one. This negative correlation occurs because the density of vegetative community affects the amount of light reaching the water beneath. Less dense overhead vegetation results in more light penetration to the water, thereby increasing primary productivity and chlorophyll concentration. Given the small number of samples, this correlation requires further investigation. As a result, chlorophyll cannot be used as a metric.

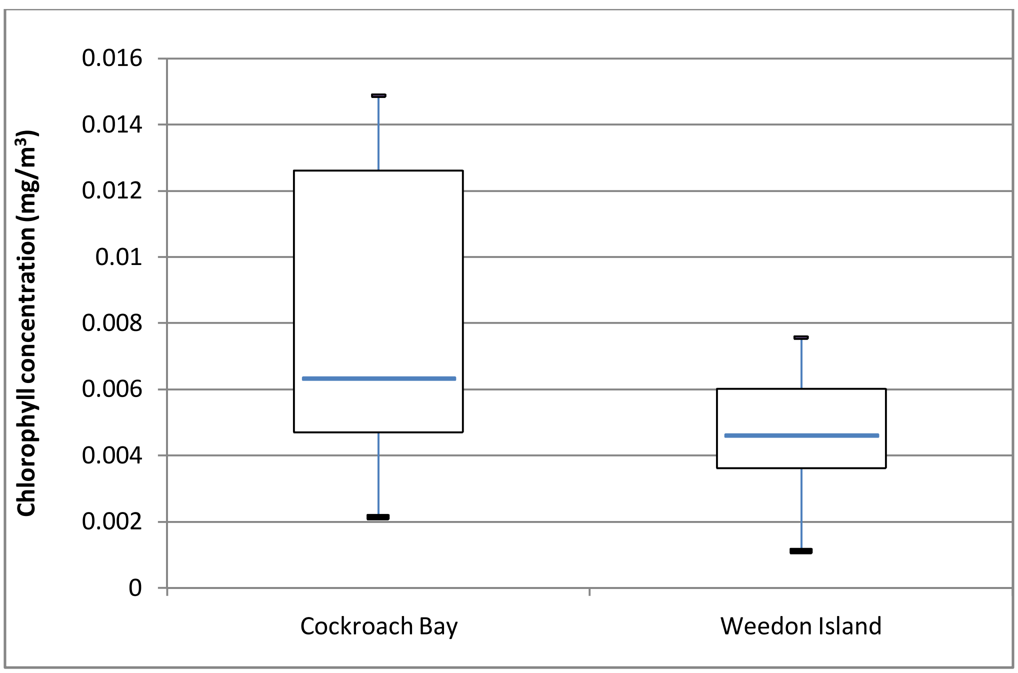


Figure 21. Summary statistics for chlorophyll at sampling locations where water was collected.

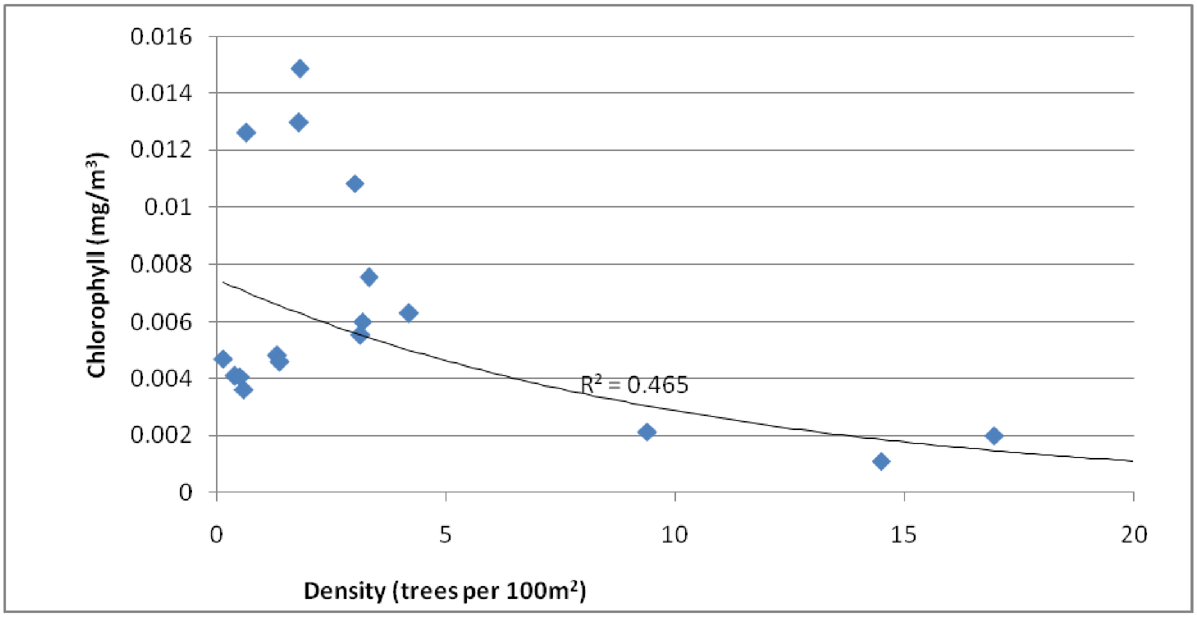


Figure 22. Plot of chlorophyll against density, showing a moderate exponential correlation.

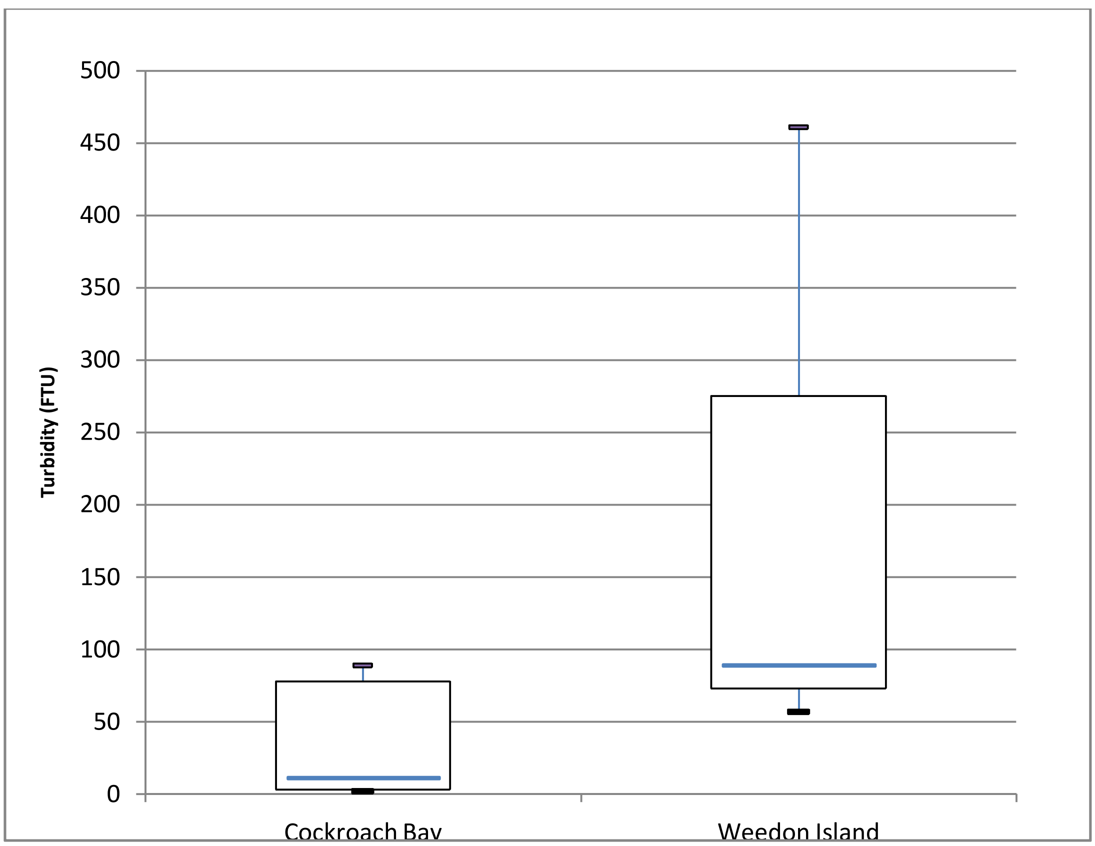


Figure 23. Summary statistics for turbidity at sampling locations where water was collected.

The results of the turbidity testing show a difference between Cockroach Bay and Weedon Island (figure 23). However, the small number of samples and the lack of samples from Feather Sound indicate that these results require further investigation. Furthermore, this comparison includes samples for both bayside and internal water. The expected result is that as density increases, turbidity will decrease because there will be less light for microscopic primary producers and the greater density of trees will lead to more removal of sediment from the water column. The results show that there is very little correlation between density and turbidity (r^2=0.206, p=0.069) (figure 24). A possible explanation could be that there are other factors affecting turbidity such as

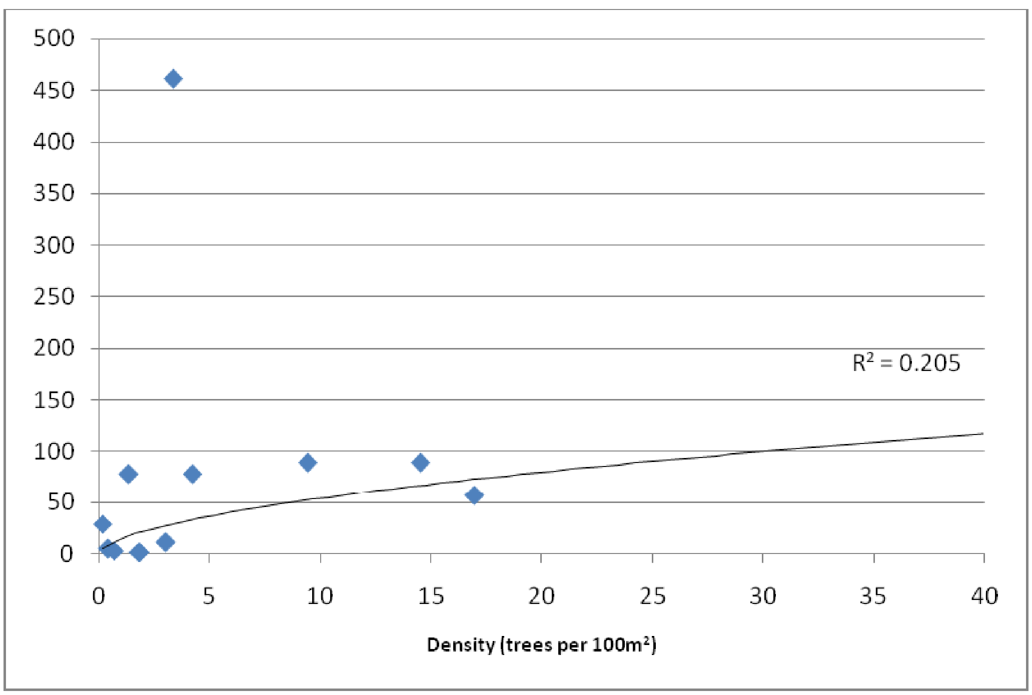


Figure 24. Plot of turbidity against density.

rainfall, tree litter and water input. This was confirmed by investigating the relationship between turbidity and chlorophyll (figure 25). There is an inverse relationship between chlorophyll a concentration and turbidity. This shows that turbidity is not cause by phytoplankton but rather as a result of sedimentation. This, in addition to the fact that turbidity increases from Cockroach Bay to Weedon Island, leads to the conclusion that turbidity increases from as the condition of the mangrove forests declines. This is as expected because wetlands that are heavily impacted be human activities often show increased sedimentation (Whigham, 1999). As a result turbidity is recommended as a metric for the MQI. The scoring for the turbidity metric was determined using the inflexion points on the cumulative frequency curve (figure 26, Table 8).

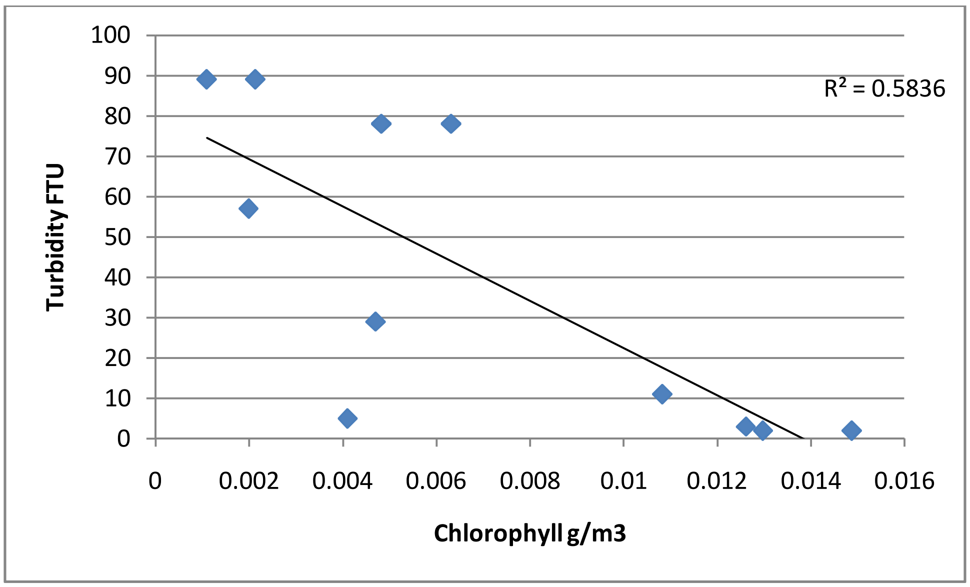


Figure 25. The inverse relationship between chlorophyll and turbidity showing that turbidity is as a result of sedimentation rather than microscopic fauna.

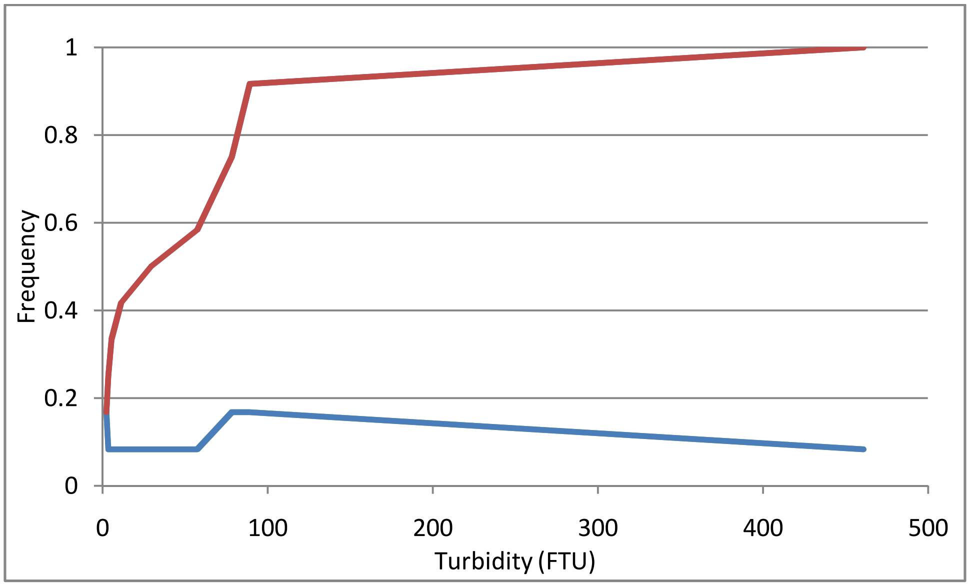


Figure 26. Cumulative frequency curve of turbidity.

Table 8. Score of turbidity metric.

Score	Turbidity (FTU)
1	0-2
2	3-10
3	11-57
4	58-79
5	80 or more

Soil

The physical integrity of soil varies with conditions within a wetland (Whigham, 1999; Campbell et. al., 2002). Soil organic content is critical for the health of plant communities; therefore, it was expected that there would be a positive correlation between density and soil condition (Whigham, 1999). As soil organic content increases so does plant density. Weedon Island has a larger range and general higher organic content than the other locations (figure 27). This implies that there is no correlation between condition and organic content, and is further confirmed by the comparison to plant density (figure 28) with no correlation between the density and organic content (r^2=0.017, p=0.152). This may be because organic content is affected by other factors such as litter fall and rates of utilization by organisms.

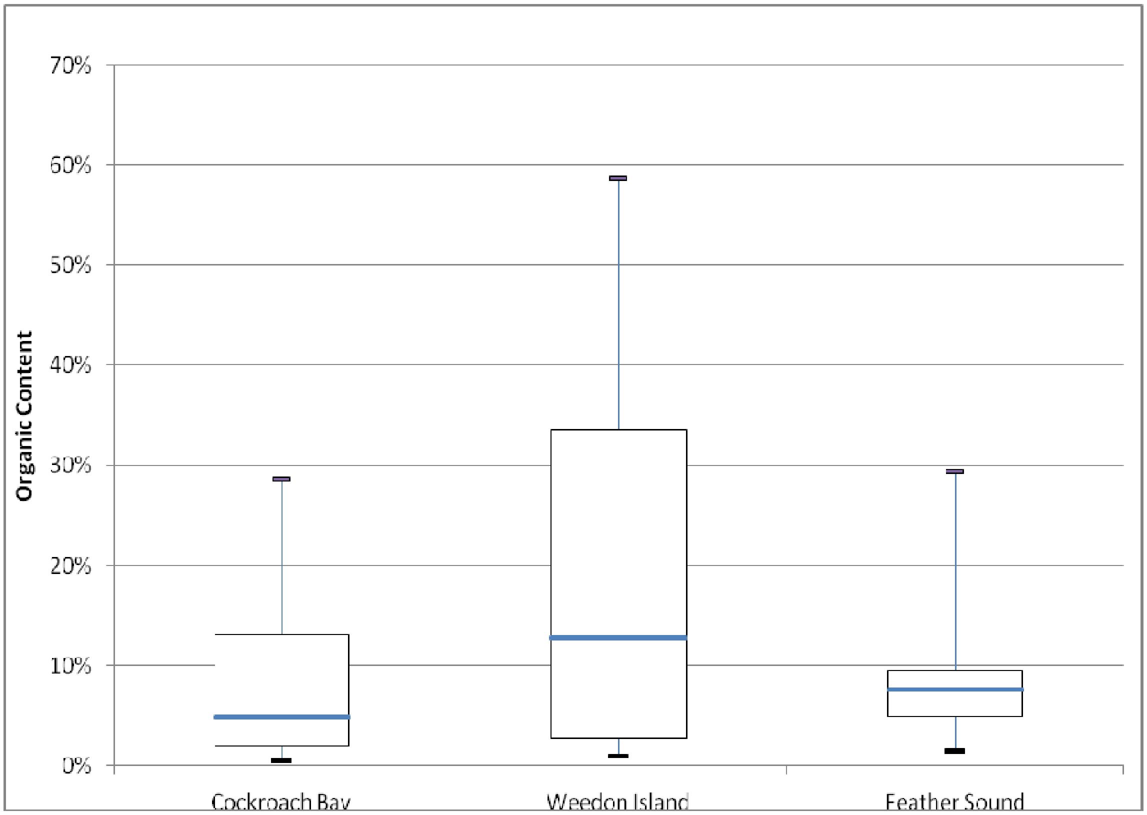


Figure 27. Summary statistics for soil organic content at study locations.

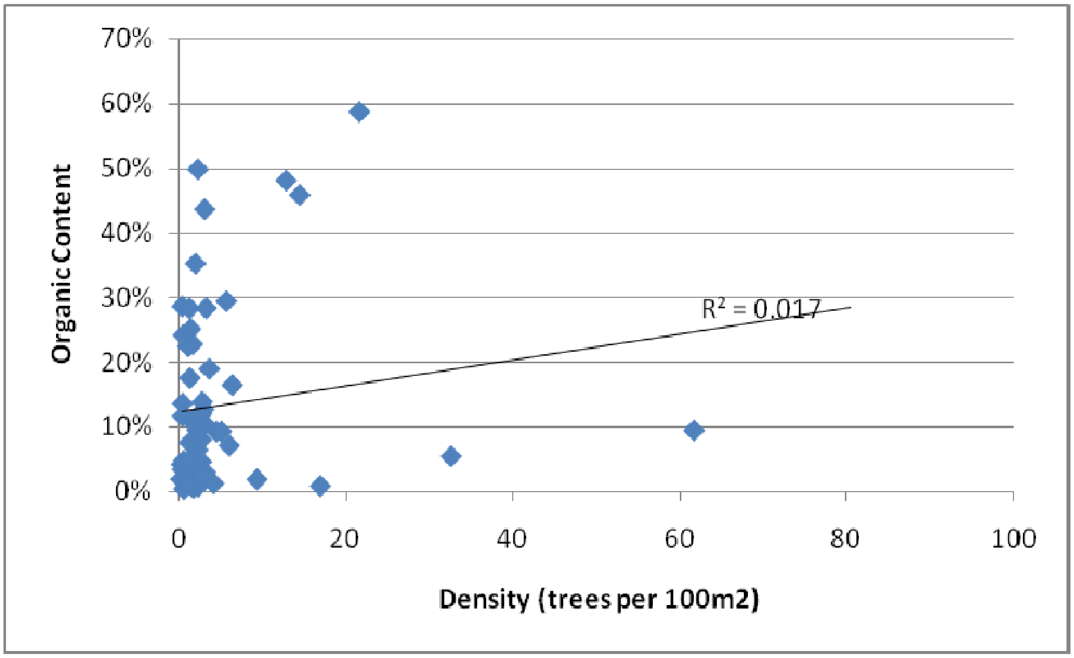


Figure 28. Plot of soil organic content against density.

The physical characteristics of soil are also described using the coefficient of uniformity and the coefficient of curvature (Day, 2001). The coefficient of uniformity, also referred to as the Hazen coefficient, describes the particle size range in a soil. All three sites have a large particle size range suggesting that there is no relationship between coefficient of uniformity and condition (figure 29). This is confirmed by the fact that there is no correlation with plant density (r^2=0.015, p=0.017) (figure 30). The coefficient of uniformity can be used to place the soil under consideration into one of three categories: very uniform, well uniform and not uniform. Weedon Island and Cockroach Bay have a much larger percentage of very uniform soil than Feather Sound (Table 9).

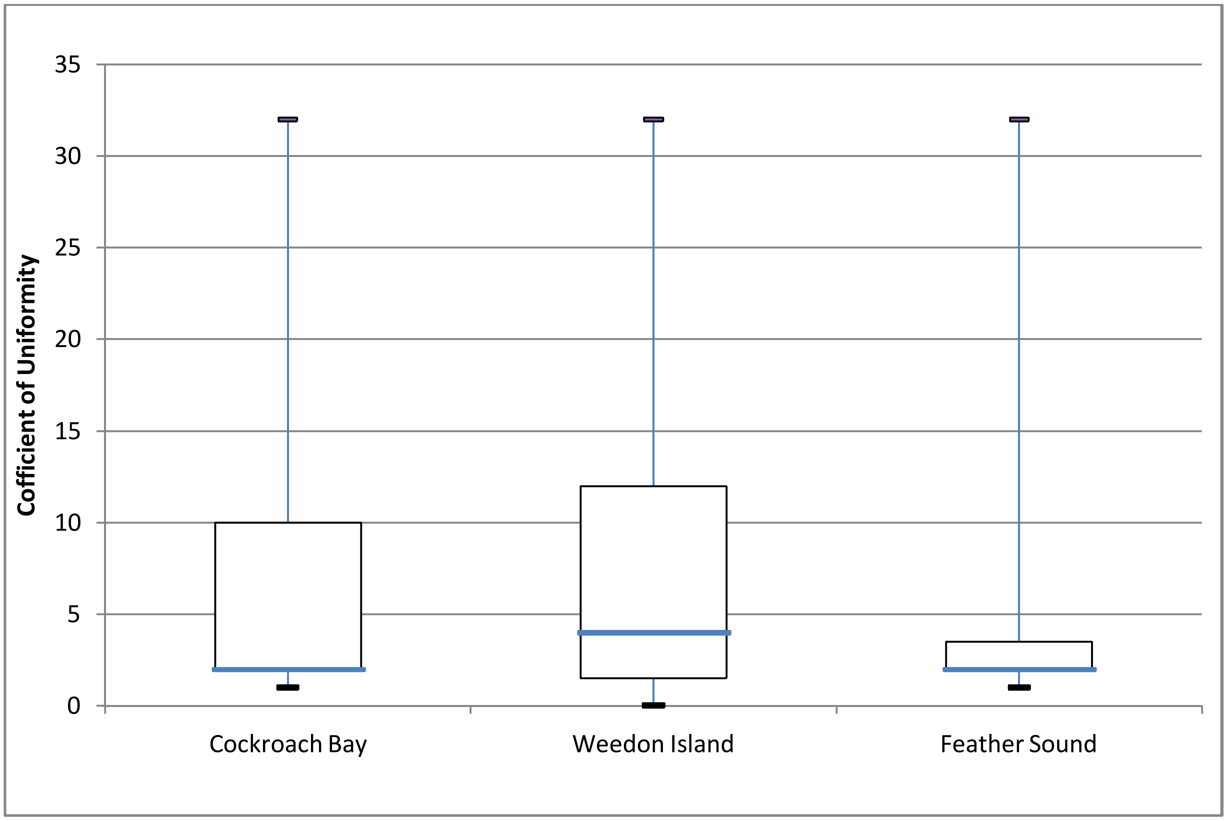


Figure 29. Summary statistics for coefficient of uniformity at study locations.

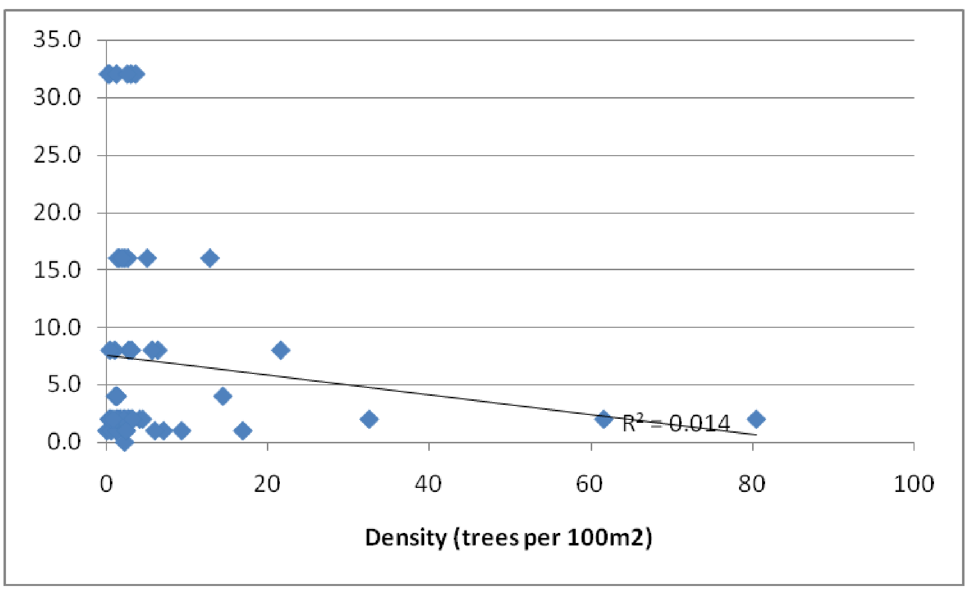


Figure 30. Plot of coefficient of uniformity against density.

Table 9. Soil uniformity at each sampling location. The percent of sampling falling into each category is displayed.

Soil Uniformity	Cockroach Bay	Weedon Island	Feather sound
Very uniform	34.8%	39.1%	16.7%
Well uniform	0.0%	0.0%	0.0%
Not uniform	65.2%	60.9%	83.3%

The coefficient of curvature, referred to as the coefficient of gradation, describes the physical integrity of soils. It describes the distribution of particle sizes within a soil. This is important because particle size distribution affects compactness and permeability. The three sampling locations have the same median coefficient of curvature but varying ranges (figure 31). The majority of samples from all three locations are not well graded (table 10). There is no apparent relationship between condition and coefficient of curvature, confirmed by the lack of correlation with density (r^2=0.003, p=0.335) (figure 32). As a result it cannot be used as a metric.

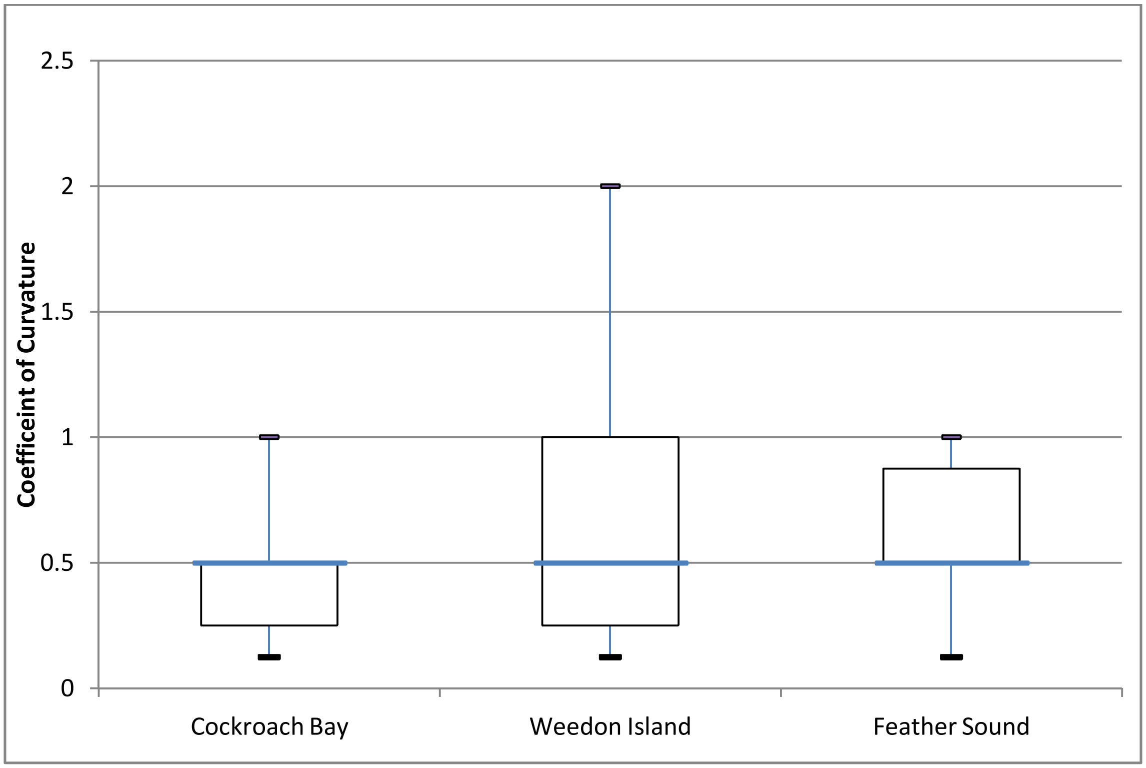


Figure 31. Summary statistics for coefficient of curvature at study locations.

Table 10. Soil Gradation, percent of samples that are well graded and those that are not.

	Cockroach Bay	Weedon Island	Feather Sound
not well graded	87.5%	72.7%	72.2%
well graded	12.5%	27.3%	27.8%

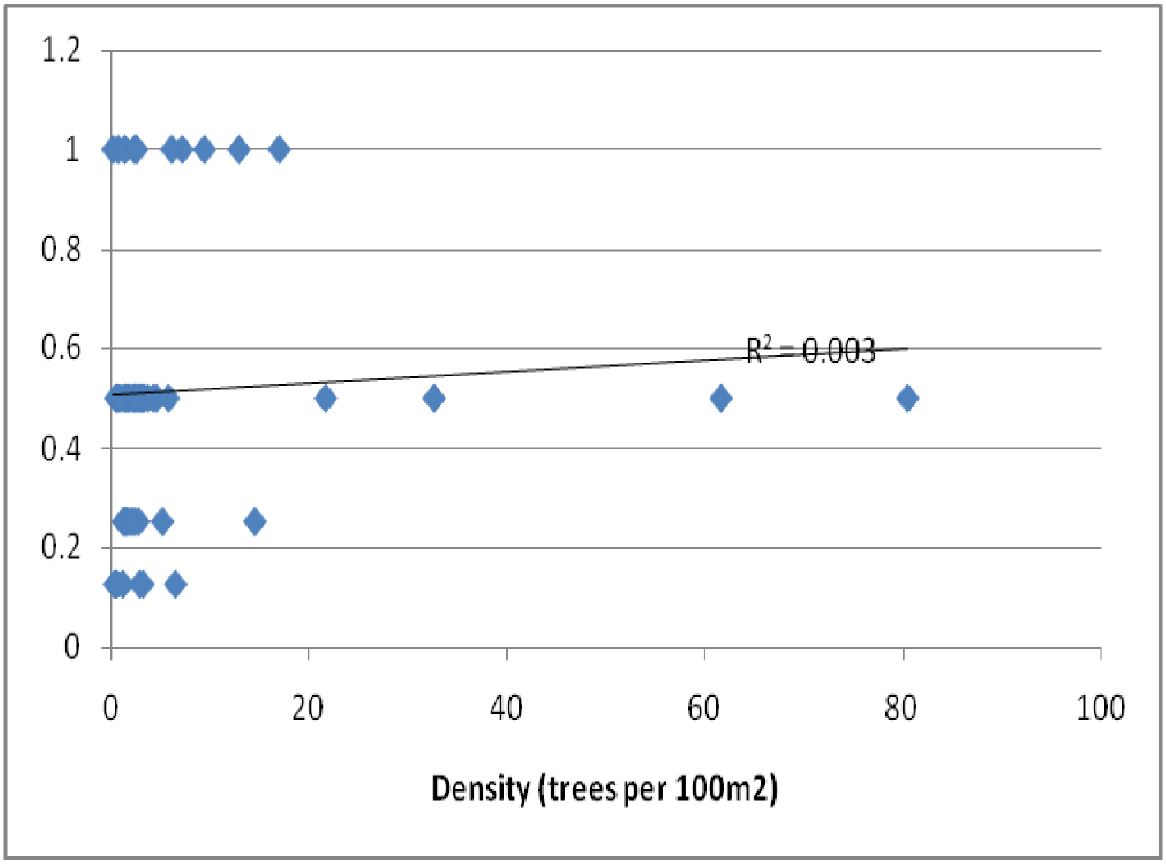


Figure 32. Plot of coefficient of curvature against density.

A comparison of created and natural wetlands showed that the soils differed by the percentage of sand sized particles (Campbell et al., 2002). A comparison of the median percent sand particles at the study locations revealed no clear patterns (figure 33). Furthermore, all location had a higher percentage of samples with more silt than sand (Table 11). Therefore, percent sand should not be used as metric. Although soil could not be used as a metric in the MQI, this may simply be a constraint of the geographic location. Should this MQI be applied to another location, soil may then be pursued as a possible metric. It may well be that the physical properties of soil vary based on condition in other places even though this is not the case in Tampa Bay.

Table 11. Percentage of samples with a higher amount of sand or silt size particles.

	Cockroach Bay	Weedon Island	Feather Sound
more silt	91.7%	63.6%	90.0%
more sand	8.3%	36.4%	10.0%

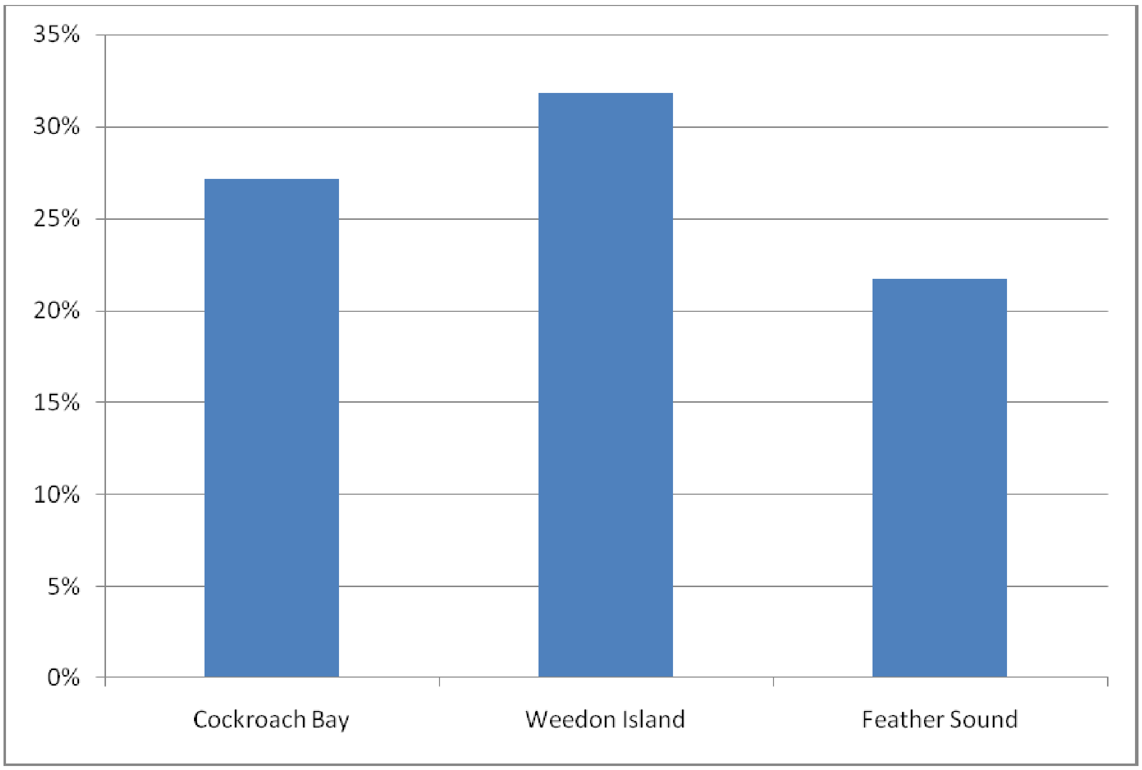


Figure 33. Median percent sand in soils samples at the study locations.

Hydrologic Conditions

The hydrologic condition of a wetland is crucial to its overall function. Hydrology of a wetland is affected by several factors including neighboring land use and modification to the wetland (Seilheimer and Chow-Fraser, 2006). Using the Florida Land Use and Cover Classification System, the land uses in Florida were divided into five categories based on the level of impact on the neighboring mangrove (DOT, 1999). The general description of each category is given in Table 12 and the detailed land uses outlined in appendix A. This category characterizes the overall landscape surrounding the mangrove by using GIS to calculate the score per unit area. The steps used in this process are outlined in Appendix B. This takes into account the amount of area under each type of land use. Applying this concept to the study area Cockroach Bay has the lowest value, then Weedon Island, followed by Feather Sound (Table 13). This GIS method is especially useful for tracking the condition of a mangrove over time.

Table 12. Neighboring land use

Score	General Description
1	Natural Environments: Land that is undeveloped and in its natural form
2	Low impact uses: Uses that have a onetime impact and minimal continued impact
3	Moderate impact Agricultural
4	Moderate Impact non-agricultural
5	High Impact use

Table 13. Score per unit area for the three study locations.

Location	Neighboring land use
Cockroach Bay	1.16
Weedon Island	1.32
Feather Sound	1.53

Modifications to a mangrove can significantly alter hydrologic flow. Based on the modifications observed during field visits and recorded in field notes, five categories were recommended for the modification category (Table 14). The examples given are not exhaustive and other modifications may be placed in a category based on the description.

Table 14. Modifications

Score	Description	Examples
1	Pristine	No modifications
2	Minor Modifications - minor modification to a small portion of the mangrove that does not add any impermeable surface, or change the general quantity or quality of water flowing into the mangrove	Boardwalk, unpaved roads and paths, trimming
3	Some Modification - minor modification to a small portion of the mangrove that adds impermeable surface	Paved roads and paths
4	Moderate Modification - major changes and changes that alter water input into the mangrove	Deforestation, dumping of waste water, major roads
5	Major Modification - changes that significantly alter hydrology	Infilling, dredging, ditching, impounding

One of the common modifications in Florida's mangroves is mosquito ditches. In an effort to control the mosquito population the mangrove forests were ditched mechanically and the excavated material was deposited as spoil piles in the forest (Lewis et al., 1985). These ditches were characterized in this study by calculating the ditching density. Using GIS and assuming a width of 2m the total area covered by ditches was calculated. This was then divided by the total area of the mangrove forest to obtain square meters of ditches per square kilometer of mangrove forest (Table 15). The scoring for this metric is shown in Table 16.

Table 15. Ditch density for the study areas.

Location	Ditch Density (m^2/km^2)
Cockroach Bay	2192.35
Weedon Island	11108.84
Feather Sound	19877.95

Table 16. Scoring for Ditch Density Metric

Score	Ditch Density (m^2/km^2)
1	0 - 4000
2	4001- 8000
3	8001- 12000
4	12001- 16000
5	16001 and over

The Mangrove Quality Index

The mangrove quality index (MQI) is calculated by summing the scores from each category (Table 17). This score is then divided by the total possible score to obtain a ratio between 0 and 1. Dividing by the total possible score allows the user to compare scores when some categories are absent or cannot be sampled. This index was created specifically for mangroves in peninsular Florida. Sampling should occur in summer or fall at least three days after a heavy rainfall event. After a heavy rainfall event there is a large input of fresh water into the mangroves and this could potentially skew the results. This protocol was used in the development of the MQI. As a result the MQI is not representative of conditions immediately after heavy rain. Further the MQI should not be used when a mangrove forest has changed drastically as a result of natural stressors such as hurricanes as this will most likely represent extremes and be unable to capture the effect of anthropogenic stressors.

The scores can be recorded in the MQI worksheet (Table 17). The number of crab holes is determined by counting the number of crab holes in a 1 square meter quadrant or using a 0.5 square meter quadrant and multiplying by four. At least 30 samples representative of the mangrove forest should be taken to give a good representation of the forest. This was determined by examining the number of sampling points required to reduce the fluctuation in the average score (Figure 34). The density and basal area are determined using point center quarter method. At least 20 sampling points should be used as required for the accuracy of the method (Mueller-Dombois and Ellenberg, 1974). Turbidity should be used with caution as it requires further testing. Water should be sampled in areas where there is greater than 1 foot of water using direct sampling methods.

Table 17. Mangrove Quality Index worksheet

Category	**Metric**	**1**	**2**	**3**	**4**	**5**	**Score**
Biota	Crab holes	121 or more	61- 120	21-60	1-20	0	
	Basal Area	515 or more	254-514	135-253	94-135	0-134	
Water	Turbidity	0-2	3-10	11-57	58-79	80 or more	
Hydrologic	Neighboring land use	Natural	Low impact	Moderate Impact Ag	Moderate Non-Ag	High Impact	
	Modifications	Pristine	Minor	Some	Moderate	Major	
	Ditch Density (m2/km2)	0 – 4000	4001-8000	8001-12000	12001-16000	16001 and over	
						Total	

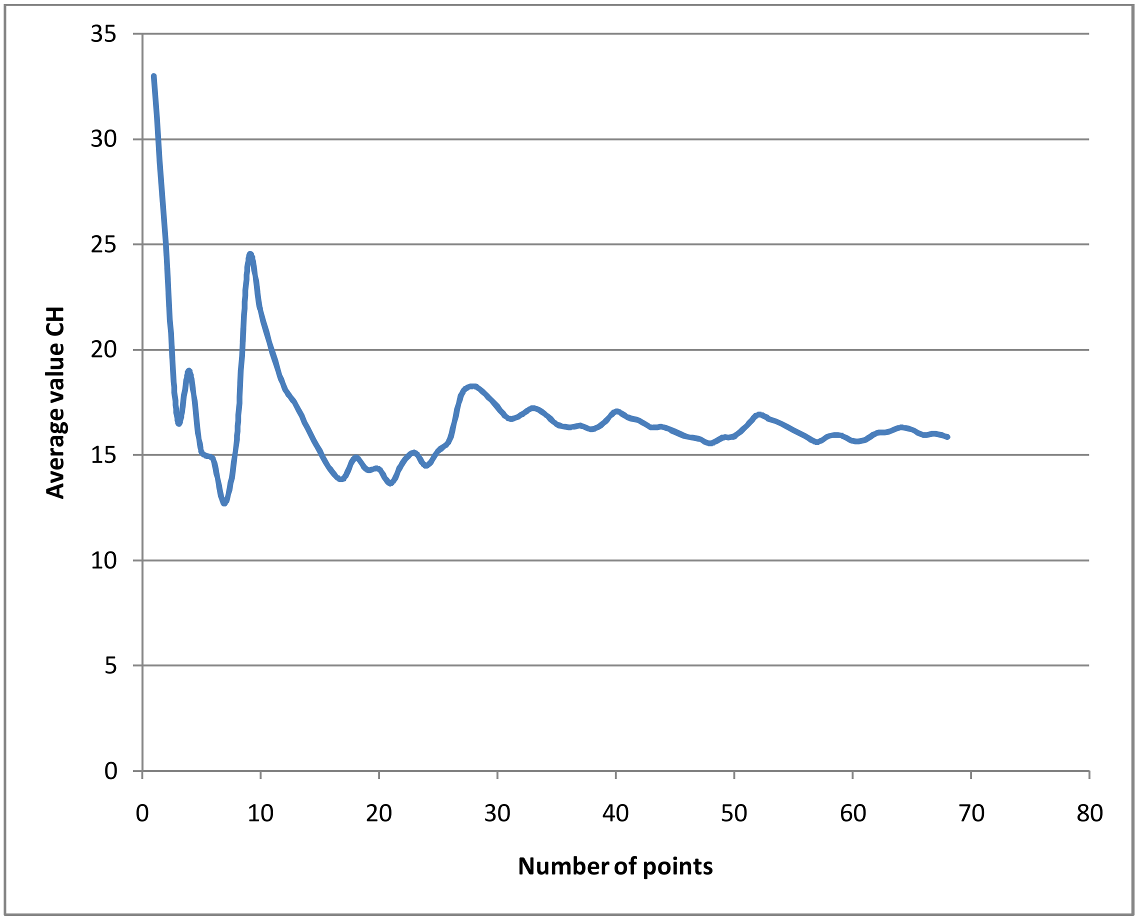


Figure 34. Graph of Average crab holes in relation to number of sampling points used to determine ideal number of sampling points

Neighboring land use and modifications can be determined using GIS to analyze the land uses within 100m of the mangrove forest. GIS can also be used to visually represent the neighboring land uses as shown in Appendix C. This index may be adapted to mangroves in other areas by selecting reference wetlands of varying condition and determining the range of value for each metric in this area. This is done to determine the range of values typical for that area. The total score will range from 0 to 1 with 1 being the most pristine mangroves and 1 the most impacted. Using the data from this study, table 18 demonstrates how the MQI score is calculated.

Table 18. Demonstration of application of MQI for Tampa Bay Locations

Category	Metric	1	2	3	4	5	CB	WI	FS
Biota	Crab holes	121 or more	61-120	21-60	1-20	0	2	3	5
	Basal Area	515 or more	254-514	135-253	94-135	0-134	1	4	5
Water	Turbidity	0-2	3-10	11-57	58-79	80 or more	2	5	NA
Hydrologic	Neighboring land use	Natural	Low impact	Moderate Impact Ag	Moderate Non-Ag	High Impact	1	1	1
	Modifications	Pristine	Minor	Some	Moderate	Major	3	5	5
	Ditch Density (m2/km2)	0 – 4000	4001-8000	8001-12000	12001-16000	16001 and over	1	3	5
						Total	10	21	21
						Score	0.33	0.70	0.84

After recording the scores for mangroves forests, a manager has a variety of options of how to use this information. For example, with the scores in Table 18 the manager can clearly see that Cockroach Bay is of higher quality and the two other locations. The manager can then look at individual categories to determine why there are differences in the quality. The differences in the number of crab holes may be because of soil characteristics or food availability. Feather Sound may have fewer crab holes because there is not as much food for the crabs or because the soil is not ideal for burrowing. The differences in basal area may be because of slightly different structures of the forests resulting from differences in topography and water input. Turbidity may be different because of water input from upland water sources and tides or human activities. The manager may then decide to use more resources for Feather Sound because it is the most impacted. Conversely the manager may decide to focus on Weedon Island because it may require fewer resources to improve the condition.

The MQI may also be used as part of the decision making process for new projects. For example, there may be a proposal for a boat basin or an aquaculture pond in the vicinity of a mangrove forest. The manager can then determine whether these activities will increase the turbidity in the mangrove forests and change the score accordingly in the neighboring land use category. As a result the project may or may not be allowed. On the other hand, the project may be allowed but with restrictions to ensure that it does not negatively impact said mangrove forest. This is a very useful application of the MQI.

The manager can also use the MQI to track the condition of a mangrove forest over time. The manager may simply wish to know whether there is degradation or improvement of the habitat over time. The MQI may be applied once a year to determine the quality or less often. The results of this assessment can then be used to determine what activities are allowed in the mangrove forests and whether there needs to be a reallocation of resources to aid in improvements to the swamp condition. It can also be used to determine whether management resources need to be allocated toward the management of the mangrove.

The MQI is a valuable tool because it is simple and easy to use. It does not require a lot of statistical analysis, or great expertise in mangroves and ecology or a large time commitment. With the exception of chlorophyll it does not require expensive equipment or materials. Most of the required sampling can be done by simple observation or direct sampling. Chlorophyll measurement is different because it requires the use of a spectrophotometer and other expensive materials. The field sampling may easily be done by a small group of two or more persons in a short amount of time. Furthermore, it gives the manager one final number that can be used to compare and track mangrove quality.

Despite its usefulness, there are limitations to this index. Due to the simplicity of the MQI it is not comprehensive in its use of metrics. There may be other factors that affect mangrove quality that are not included in the MQI. These include nutrient input, sediment delivery, soil salinity and the presence of out flow (Whigham, 1999). Nutrient input may affect eutrophication of the water and consequently the amount of oxygen available to aquatic species. The rate and quality of sediment delivery affects the quality of the soil in the mangroves, its nutrient and oxygen content. Outflow and inflow affects the ability of the habitat to support mangroves and associated estuarine species. Other possible metrics include macrobenthic invertebrates, ditch density, non-mangrove tree species, nutrient content of soil, prevalence of invasive species, soil salinity as well as oxygen content of soil and water. These could be added to the index to strengthen its accuracy and validity.

Furthermore the MQI does not account for the changes that occur in a forest as a result of extreme weather events. These extreme events include periods of low temperatures, known as freezes, hurricanes, floods and other natural disasters. It is further limited in geographic scope because it can only be applied without further calibration to Peninsular Florida. This is because assessment methods are most accurate when used in the area they were developed for and account for regional variability in wetlands. In order to apply this index to mangroves in another geographical region it needs to be recalibrated by applying it to a network of reference mangrove forests.

Although the MQI has limitations it is still a valuable tool because it fills the gap left by other assessment methods. Currently there are no assessment methods specifically for mangrove forests of peninsular Florida. The available wetland assessment methods are inappropriate for Florida's mangroves because they do not account for characteristics unique to the mangrove ecosystem. These include factors such the presence of plant and animal species unique to the mangroves. Mangrove forests are different from freshwater wetlands mainly because of the eurohaline conditions and the resulting habitat associated with it. They can further be distinguished from other estuarine habitats by the presence of tree species compared to the grass species of saltwater marshes. As a result of these differences the assessment methods for these habitats cannot be simply applied to mangrove forests. In order for these methods to be applied to mangrove forests, they would have to be modified to reflect the ecological properties of mangrove forest and tested on mangrove forests to ensure they were applicable. The MQI meets all of these requirements because it was developed similar to previous assessment methods and based on the ecological characteristics of mangroves. Furthermore, it was developed based on field sampling of mangroves and is simple and easy to use.

Although the MQI meets the criteria established for its creation, it is simple easy to use and measures the impact of human activities on mangroves forests, it can be strengthened through verification. This is done to ensure that the MQI satisfactorily measures quality and can be done in a variety of ways. The easiest method is to apply the MQI to different areas of the three study locations. If the expected results of an increase in score from Cockroach Bay through Weedon Island to Feather Sound are obtained then the MQI is accurate and works as expected. It can also be strengthened by determining the scoring for the categories using computer generated cut points for the data. Also other possible metrics that were not investigated in this study can be investigated for inclusion in the index. For example remote sensing may be used to determine factors such as prevalence and penetration of invasive species as well as hydrologic factors such as drainage density.

The next steps in the development of this MQI ensure that the index measures desired end points through validation. This is done by applying the index to mangroves of varying condition and ensuring it accurately assesses quality. Then is should be ensured that the index can be applied by variety of people. This is done by having test subjects apply the index to the same location. If the testers get similar results then it can be applied by a variety of persons. The MQI has to meet the needs of managers. Whether it adequately meets the needs of managers is assessed by creating a channel to receive feedback from managers. This can be done in the form of interviews, questionnaires or focus groups conducted after mangers have had the opportunity to review the index. The final steps before the index is fully implemented are to perform training and outreach. In this stage the persons who will be applying this index are trained in its application. These may be managers or members of the community who help with monitoring and sample collection.

Conclusion

Historically mangroves have not been valued because their benefits were not fully understood. Mangroves forests are important because they perform many functions that are valuable to human beings. They provide a habitat for commercially and recreationally important fisheries, protest and stabiles shores as well as reduce nutrient load to the near shore coastal environment. Mangroves in Tampa Bay have been negatively impacted by human development in the region. They have been ditched to reduce mosquito breeding and negatively impacted by nearby dredging, housing developments and industrial activities. This has led to the loss and degradation of the habitat.

The impact of human activities on mangroves can be measured using physical and biological characteristics in the form on an environmental index. Physical and biological properties of the ecosystem reflect the overall condition of that ecosystem. Therefore, mangrove water, biota and hydrology are properties can be used to determine the condition of and the impact of human activities an ecosystem. These properties are affected by human activities. Their quality can be measured using metrics such as turbidity, basal area and neighboring land use.

The physical and biological properties of mangroves were used as metrics to create an environmental index to measure the quality of mangrove forests. The MQI created as a result of this study is comprised of three categories and six metrics. These metrics are scored along a scale based on field testing in a reference network. Each metric is scored on a scale of 1-5 with 1 indicating the most pristine conditions and 5 the most impacted. The scores are then added together and divided by the total possible score resulting in a number from 0 to 1 with 0 being the most pristine and 1 being the most impacted.

The MQI created in this study can be used to quantify the impact of human and monitor the quality of mangrove forests. It shows which areas are affected the most by human activities. As applied to the Tampa Bay region it showed that the vegetation, biota, water and hydrology have all been negatively impacted by anthropogenic stressors. Mangrove forests can be managed with an aim at improving quality based on the MQI. By decreasing the MQI score the quality of mangrove increases. It can also be used to determine the impact of potential development on the quality of ecosystem. Although it is not comprehensive, it provides two levels of assessment with the overall score and the individual metric scores. The MQI is valuable because it objectively quantifies mangrove quality in a simple, easy to use tool.

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Appendices

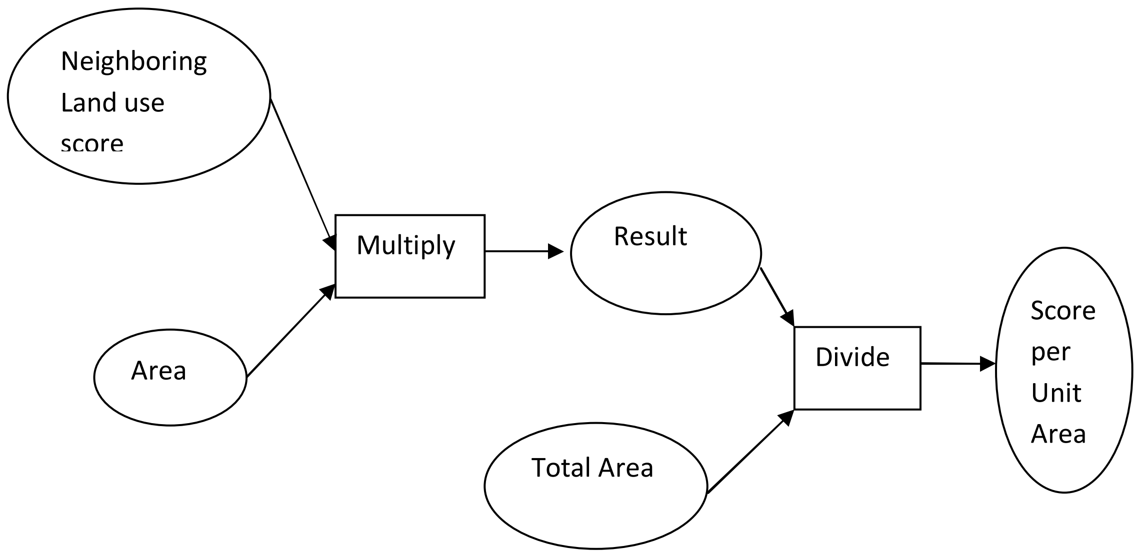
Appendix A: Neighboring Land Use Detail

Score	General Description	Land Use
1	Natural Environments: Land that is undeveloped and in its natural form	MANGROVE SWAMPS BAY SWAMPS BAYS AND ESTUARIES BEACHES OTHER THAN SWIMMING BEACHES CYPRESS EMERGENT AQUATIC VEGETATION FRESHWATER MARSHES HARDWOOD CONIFER MIXED INTERMITTENT PONDS LAKES OPEN LAND OTHER OPEN LANDS <RURAL> PINE FLATWOODS SALT FLATS SALTWATER MARSHES SAND OTHER THAN BEACHES SHORELINES SHRUB AND BRUSHLAND STREAM AND LAKE SWAMPS (BOTTOMLAND) STREAMS AND WATERWAYS UPLAND CONIFEROUS FOREST UPLAND HARDWOOD FORESTS - PART 1 VEGETATED NON-FORESTED WETLANDS WET PRAIRIES WETLAND FORESTED MIXED WETLAND HARDWOOD FORESTS
2	Low impact uses: Uses that have a one time impact and minimal continued impact	RESIDENTIAL LOW DENSITY < 2 DWELLING UNITS RECREATIONAL RESERVOIRS
3	Moderate impact Agricultural	CROPLAND AND PASTURELAND ROW CROPS NURSERIES AND VINEYARDS TREE CROPS MIXED RANGELAND DISTURBED LAND

Appendix A (Continued): Neighboring Land Use Detail

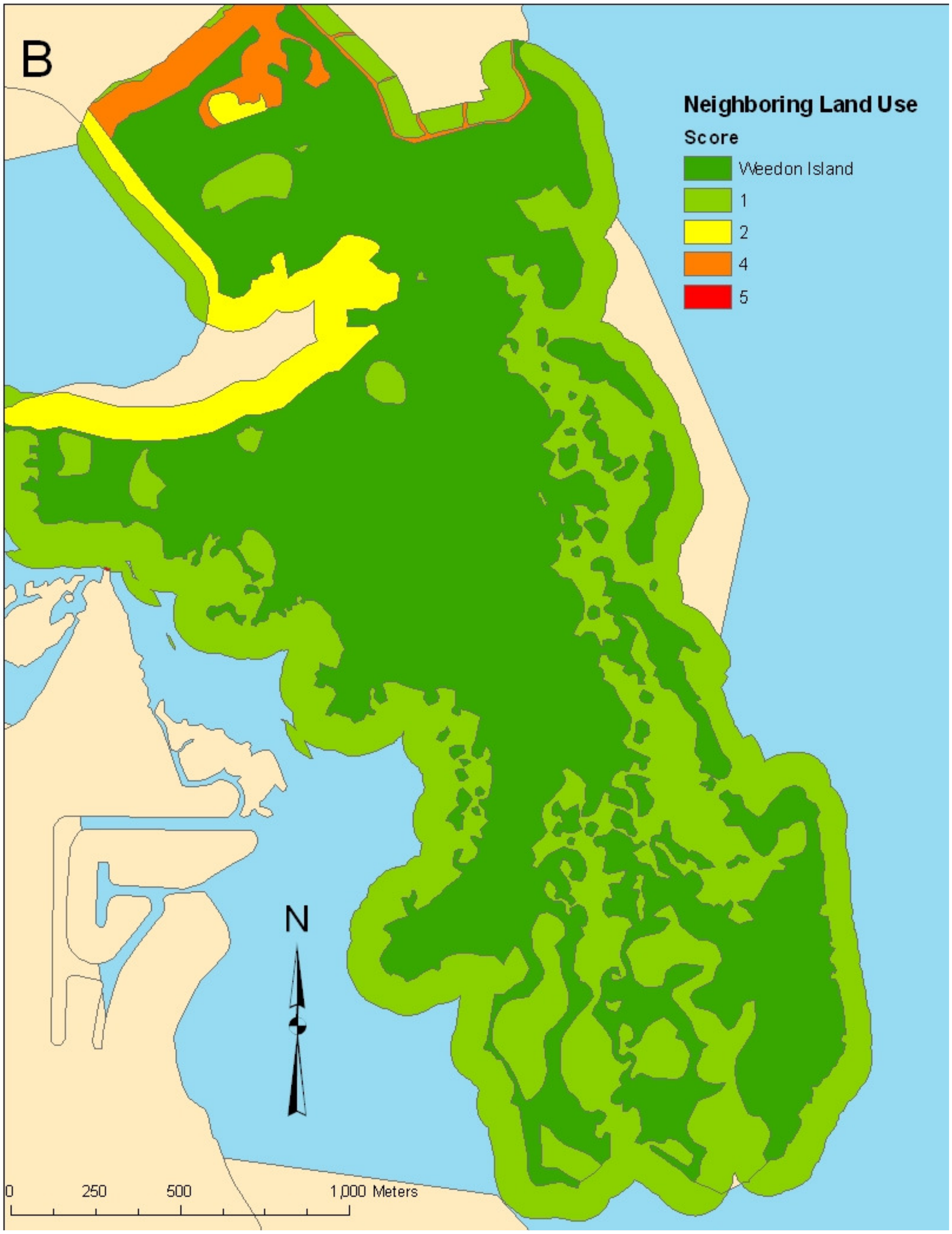
Score	General Description	Land Use
4	Moderate Impact non-agricultural	RESIDENTIAL MED DENSITY 2->5 DWELLING UNIT
		TRANSPORTATION
		EXTRACTIVE
		GOLF COURSES
		UTILITIES
5	High Impact use	COMMERCIAL AND SERVICES
		COMMUNICATIONS
		INDUSTRIAL
		INSTITUTIONAL
		RESIDENTIAL HIGH DENSITY

Appendix B: Model showing GIS Determination of Neighboring Land Use Score



Appendix C: GIS Visualization of Neighboring Land Use,
A: Cockroach Bay, B: Weedon Island, C: Feather Sound

Appendix C (Continued): GIS Visualization of Neighboring Land Use,
A: Cockroach Bay, B: Weedon Island, C: Feather Sound



Appendix C (Continued): GIS Visualization of Neighboring Land Use,
A: Cockroach Bay, B: Weedon Island, C: Feather Sound