**Using Geospatial Technology to Establish Marsh Bird Monitoring Sites for a Pilot Study in Maine in Accordance with the North American Marsh Bird Monitoring Protocol**

by

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A Thesis Presented to the
Faculty of the USC Graduate School
University of Southern California
In Partial Fulfillment of the
Requirements for the Degree
Master of Science
(Geographic Information Science and Technology)

August 2017

I dedicate this document to my husband Seamus Walsh and to my parents Calvin and Wilma Prescott for their constant support, patience and understanding.

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# Acknowledgements

I am grateful to my thesis advisor, Dr. John P. Wilson for his unwavering support and understanding and for the direction I needed. I am grateful to my committee members, Dr. Su Jin Lee and Dr. Travis Longcore for their suggestions and advice and I am grateful to my other faculty who gave me assistance when I needed it. I would like to thank Danielle D'Auria for her continuous support and suggestions. I am grateful for the data provided to me by the Maine Department of Inland Fisheries and Wildlife and the Maine Office of GIS.

## List of Abbreviations

| | |
|---|---|
| BBS | Breeding bird survey |
| DEP | Department of Environmental Protection |
| GIS | Geographic information system |
| GMMP | Global Mapper Mobile Package files |
| MDIFW | Maine Department of Inland Fisheries and Wildlife |
| MEGIS | Maine Office of GIS |
| NAD | North American Datum |
| NAIP | National Agriculture Imagery Program |
| NAMBMP | North American Marsh Bird Monitoring Program |
| NDVI | Normalized Difference Vegetation Index |
| NED | National Elevation Dataset |
| NHD | National Hydrography Dataset |
| NHDP | National Hydrography Dataset Plus |
| NLCD | National Land Cover Database |
| NWI | National Wetland Inventory |
| PSU | Primary sampling unit |
| SSU | Secondary sampling unit |
| US | United States |
| USFWS | US Fish and Wildlife Service |
| VFRBD | Virtual field reference database |

## Abstract

Interest in marsh birds has increased in recent years due to their role as indicator species of wetland health, which is exacerbated by their declining numbers. Marsh birds are secretive, hiding in thick marsh vegetation and infrequently emitting sound, making it hard to locate their habitat and determine their distribution and numbers. Previous studies to monitor marsh birds have been conducted to determine effective conservation and management methods. The North American Marsh Bird Monitoring Program (NAMBMP) estimates changes in breeding marsh bird abundance at different temporal and spatial scales across the country. Consistent with this approach, a pilot program, including a survey sampling scheme, database, and mobile application was developed using biological and environmental data specific to the state of Maine. This was achieved using the Esri Catalog of GIS Applications and the Blue Marble Geographics GIS Application: Global Mapper and projection management tool: the Geographic Calculator. Biogeographical data were captured, stored, and analyzed. A two-stage cluster sampling approach was used to identify potential breeding habitat for secretive marsh birds from which sites to survey were identified. These data were converted via taxonomies and unit conversions to correlate to the regional and national scale standards of the NAMBMP. Twenty of the survey sites were selected and field surveys were conducted to verify the accuracy of the points. In 2018, the Maine Department of Inland Fisheries and Wildlife (MDIFW) will use the resulting database and mobile application to complete the Maine section of the NAMBMP.

# Chapter 1 Introduction

## 1.1 Secretive Marsh Birds

There has been increased interest in secretive marsh birds in recent years due to their reflection of the health of wetlands that are in decline (Conway and Gibbs 2001). Marsh birds are secretive, hiding in thick marsh vegetation (Figure 1) and only making sounds when necessary. They live in areas that are not easily accessible to humans. This makes them very hard to locate and once located, to identify the species of marsh bird.

Figure 1 An example of a secretive marsh bird that is easily hidden in thick vegetation habitats: the American coot

Little is known about the population status of several secretive marsh bird species (Lor and Malecki 2002), because of the inconsistency of survey methodology that is being used

throughout the country and the lack of coverage of wetland habitat (Eddleman et al. 1988; Shriver et al 2004; Conway 2008). In 1998, the North American Marsh Bird Monitoring Program (NAMBMP) was created. The program estimates change in breeding marsh bird abundance at different temporal and spatial scales across the country (Ribic et al. 1999). It was set up to study the use of call-broadcast surveys of secretive marsh birds. In this study, a pilot program, based on the NAMBMP, including a survey sampling scheme and database, and mobile application has been developed using biological and environmental data specific to the state of Maine that will be implemented by the Maine Department of Inland Fisheries and Wildlife (MDIFW) in 2018.

Spatial and geographical data were captured, stored, and analyzed using specific Geographic Information Systems (GIS); ArcGIS 10.3 and Global Mapper v18; LiDAR data were obtained from The National Agricultural Imagery Program (NAIP). These tools and data were used to determine sampling sites in wetland complexes for Maine marsh bird species (Table 1) using spatially derived habitat metrics (Johnson et al. 2009). Layers created in ArcGIS and Global Mapper were used to locate and map potential breeding habitat for secretive marsh birds in Maine using a two-stage cluster sampling approach for identifying survey sites (Johnson et al. 2009). MDIFW will likely recruit seasonal workers and volunteers to routinely monitor the identified habitat for the presence of the marsh birds listed in Table 1 using the sampling scheme that is developed in this study. The ability to access the sampling sites by vehicle, boat or by foot was a determining factor in choosing the locations to monitor. Unlike many survey protocols that are randomly or evenly distributed; marsh bird monitoring required wetland identification, so that survey sites chosen were guaranteed to be in marsh bird habitat (Bart 2006).

Using remote imagery, GIS, and state and landowner information (Figure 2), habitat suitability analysis was used to identify and prioritize survey sites that had the potential to

include high value habitats supporting rare and focal marsh nesting birds. The species are considered "focal" based on the U.S. Fish and Wildlife Service's (USFWS) definition as a

Table 1 Maine species of marsh birds

| **Common Name** | **Scientific Name** |
|---|---|
| American bittern | *Botaurus lentiginosus* |
| Least bittern | *Ixobrychus exilis* |
| Great blue heron | *Ardea herodias* |
| Cattle egret | *Bubulcus ibis* |
| Green heron | *Butorides virescens* |
| Black-crowned night-heron | *Nycticorax nycticorax* |
| Yellow-crowned night heron | *Nyctanassa violacea* |
| Glossy ibis | *Plegadis falcinellus* |
| American black duck | *Anas rubripes* |
| Osprey | *Pandion haliaetus* |
| Common gallinule | *Gallinula galeata* |
| Black-bellied plover | *Pluvialis squatarola* |
| Semipalmated plover | *Charadrius semipalmatus* |
| American oystercatcher | *Haematopus palliatus* |
| Greater yellowlegs | *Tringa melanoleuca* |
| Lesser yellowlegs | *Tringa flavipes* |
| Willet | *Catoptrophorus semipalmatus* |
| Spotted sandpiper | *Actitis macularia* |
| Semipalmated sandpiper | *Calidris pusilla* |
| Least sandpiper | *Calridris minutilla* |
| Belted kingfisher | *Ceryle alcyon* |
| Marsh wren | *Cisthorus palustris* |
| Sedge wren | *Cistothorus platensis* |
| Nelsons sharp-tailed sparrow | *Ammodramus nelsoni subvirgatus* |
| Saltmarsh sharp-tailed sparrow | *Ammodramus caudacutus caudacut* |
| Seaside sparrow | *Ammodramus maritima* |
| Swamp sparrow | *Melospiza georgiana* |
| Red-winged blackbird | *Adelaius phoeniceus* |
| American coot | *Fulica Americana* |
| Yellow rail | *Coturnicops noveboracensis* |
| Sora | *Porzana carolina* |
| Virginia rail | *Rallus limicola* |
| Pied-billed | *Podilymbus podiceps* |
| GrebeWilson's Snipe | *Gallinago delicata* |
| Black Tern | *Chlidonias niger* |

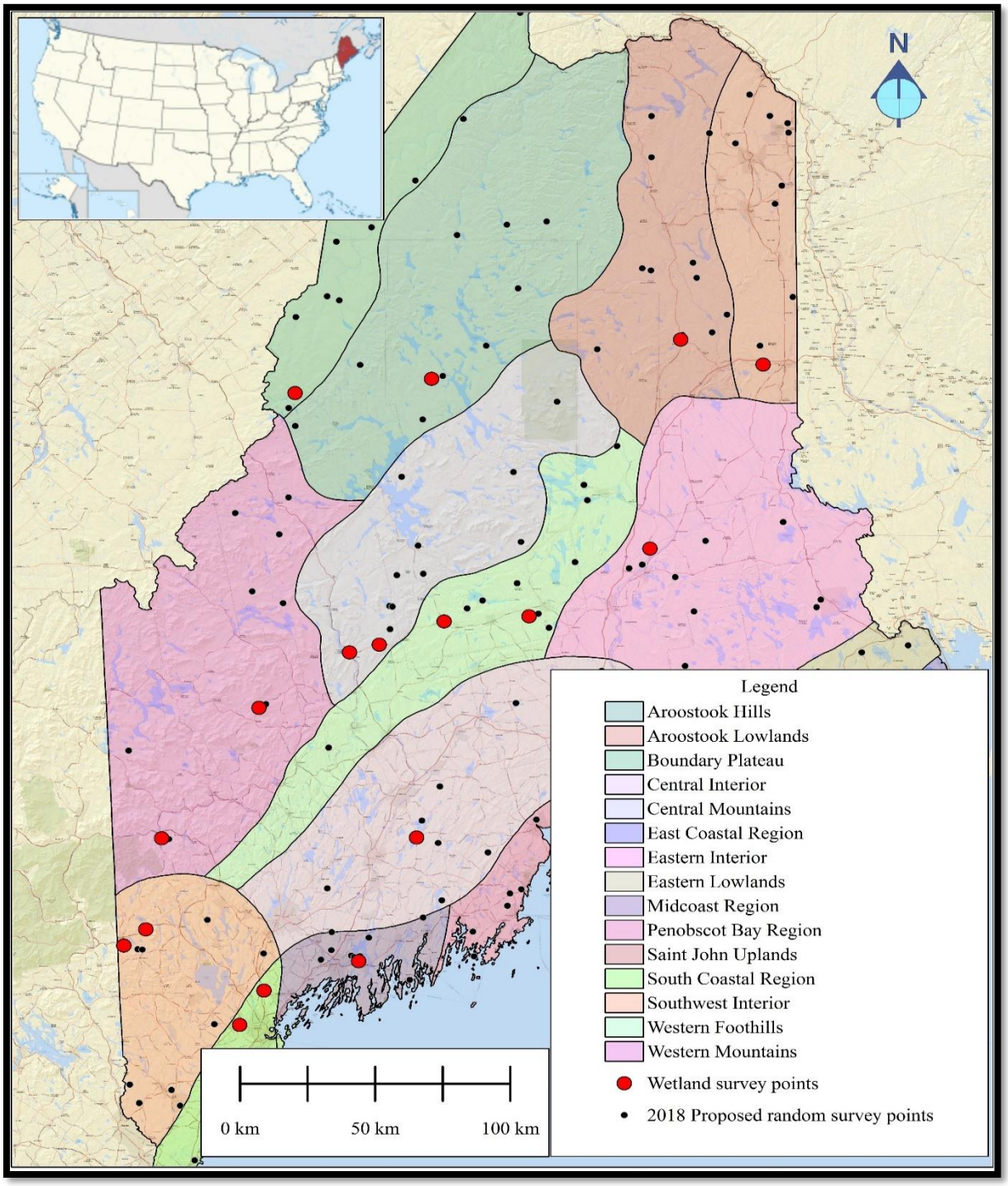


Figure 2 Map of Maine showing 15 bioregions used as Primary Sampling Units (PSUs) and the random survey points for 2018

specific group of species, protected by the Migratory Bird Treaty Act that have special management challenges due to many distinct factors. These factors include “at least one of the following five characteristics: (1) high conservation need; (2) representative of a broader group of species sharing the same or similar conservation needs; (3) high level of current program effort; (4) potential to stimulate partnerships; and (5) high likelihood that factors affecting status can realistically be addressed” (USFWS 2005; 2008). To make sure the results of this project can be rolled up to the regional and national scales, a random sampling was performed.

Starting in 2018, permanent and seasonal workers and volunteers for MDIFW will collect data on secretive marsh birds at sites identified by the created sampling protocol, maps and database resulting from this study. By conducting these surveys at the sites determined in this study, a better understanding of marsh bird species distribution, abundance and habitat selection will be discovered and it will be easier to determine where restoration efforts are needed. The information that is collected will be used to obtain a better understanding of the state of the emergent wetlands in Maine and of the marsh birds that are living there. By following the NAMBMP, the information will also transfer easily into the national database and contribute to results at the regional and national scales (Ribic et al. 1999). The working goals of this pilot study were to: (1) locate potential breeding habitats for secretive marsh birds in Maine using GIS and remote sensing; and (2) apply a two-stage cluster sampling approach to identify the survey sites for the pilot study that will be conducted in Maine using the NAMBMP as a template.

## 1.2 Motivation

A wetland is “land where an excess of water is the dominant factor determining the nature of soil development and the types of animals and plant communities living at the soil

surface. It spans a continuum of environments where terrestrial and aquatic systems integrate" (Cowardin et al. 1979). An emergent wetland falls under the category of Palustrine:

> All non-tidal wetlands that are substantially covered with emergent vegetation--trees, shrubs, moss, etc. Most bogs, swamps, floodplains and marshes fall in this system, which also includes small bodies of open water (< 20 acres), as well as playas, mudflats and saltpans that may be devoid of vegetation much of the time. Water chemistry is normally fresh but may range to brackish and saline in semiarid and arid climates (Cowardin et al. 1979, p. 10).

In North America, there has been a sharp decline in emergent wetland habitat (Cowardin et al. 1979; Dahl 2006).

Wetlands in Maine are one of the most productive avian habitats (Gibbs et al. 1991). These areas are declining at an alarming rate due to human activities including agriculture, silviculture and other forms of development (Gibbs et al. 1991). Secretive marsh birds, which are also in decline, are dependent on these areas due to their grass-like plants and tall grasses for nesting, breeding and feeding areas (Bystrak 1981; Eddleman et al. 1988). They live in areas with dense emergent vegetation and are not very vocal (Shriver et al. 2004); creating small clusters that cannot provide statistically significant results on marsh bird trends (Bart and Earnst 2002; Conway and Gibbs 2011). Despite their dwindling numbers, no specific monitoring protocol was set up for secretive marsh birds in emergent marshes until the NAMBMP (Conway and Gibbs 2011). The Breeding Bird Survey has data on some marsh bird species but not all species or the emergent marshes where they live are included (Bystrak 1981; Gibbs et al. 1991; North American Breeding Bird Survey 2011). Over the past 20 years, several states have worked to adopt the NAMBMP to learn more about the status of marsh birds. All species of bird that select marshes for habitat are considered marsh birds (Conway 2008), although the specific species that are of concern or protected may vary by state and/or region (Table 2).

Table 2 Species of marsh birds of primary concern in Maine

| **Common Name** | **Scientific Name** |
|---|---|
| King Rails | *Rallus elegans* |
| Clapper Rails | *Rallus longirostris* |
| Virginia Rails | *Rallus limicola* |
| Soras | *Porzana Carolina* |
| Black Rails | *Laterallus jamaicensis* |
| Yellow Rails | *Coturnicops noveboracensis* |
| American Bitterns | *Botaurus lentiginosus* |
| Least Bitterns | *Ixobrychus exilis* |
| Pied-billed Grebes | *Podilymbus podiceps* |
| Limpkins | *Aramus guarauna* |
| American Coots | *Fulica Americana* |
| Purple Gallinules | *Porphyrula martinica* |
| Common Moorhens | *Gallinula chloropus* |

The trends in marsh bird numbers need to be studied for many reasons. Marsh birds are considered indicator species of the health and integrity of emergent wetlands and when they return to an abandoned area it can be considered a restoration success (Conway 2008). Marsh birds are valued by both bird watchers and hunters and bring income into states (Shriver et al. 2004; Steidl, Conway, and Litt 2013). Several marsh bird species are either listed as threatened or endangered in Maine (Table 2) (Shriver et al. 2004). This is partially due to the polluting of wetlands and the invasion of non-native plant species into emergent wetlands (Klaas, Ohlendorf, and Cromartie 1980; Eddleman et al. 1988; Gibbs, Melvin, and Reid 1992; Conway and Gibbs 2001). The probability of marsh birds to choose a specific wetland based on its habitat characteristic has rarely been studied (Conway and Gibbs 2005; Conway and Nadeau 2006) and what is known about the relationships linking specific bird species to specific habitats has been summarized (Table 3) (Shriver et al. 2004). The key environmental features of wetlands that make them optimal habitat for marsh birds need to be identified and protected from the effects of

human disturbance and climate change (Gibbs et al. 1991). Once high value marsh bird habitat has been identified, it can be monitored and protected.

Table 3 Birds that use areas of salt marshes based on characteristics in the Gulf of Maine

| | |
|---|---|
| **Nest in high marsh and feed in high and low marsh**<br>saltmarsh sharp-tailed sparrow<br>nelson's sharp-tailed sparrow<br>willet<br>American black duck | **Nest on beaches, feed in salt marshes, beaches, mudflats**<br>least tern<br>piping plover |
| **Nest in maritime shrub transition zone, feed in marsh**<br>common yellowthroat<br>yellow warbler<br>eastern kingbird<br>gray catbird<br>common grackle | **Feed in salt marshes during migration**<br>semipalmated sandpiper<br>least sandpiper<br>short-billed dowitcher<br>greater yellowlegs<br>lesser yellowlegs<br>eastern meadowlark<br>northern harrier |
| **Nest in cattail or Phragmites**<br>swamp sparrow<br>marsh wren<br>Virginia rail<br>red-winged blackbird | **Winter in salt marshes**<br>snow bunting<br>snowy owl |
| **Nest on offshore islands, feed in salt marsh**<br>great egret<br>snowy egret<br>glossy ibis<br>great blue heron<br>common tern | **Use tidal creeks, bays and mudflats**<br>red-breasted merganser<br>osprey<br>great blue heron<br>common loon<br>semipalmated plover<br>gulls |
| | **Nest in cavities or nest boxes, feed in salt marsh**<br>tree swallow |

## 1.3 Thesis Organization

The remainder of this thesis consists of four chapters. The next chapter reviews the NAMBMP, the state of marsh bird habitat in Maine and how data are being managed in Maine to

correlate with the NAMBMP. Chapter 3 presents an overview of the methodology behind the creation of the GIS applications created for the MDIFW to support a pilot program in Maine for implementing the NAMBMP. It includes how sites for the program were selected and reviews the data sources that were necessary to complete the project. Chapter 4 presents the resulting database, and mobile application showing the survey sites chosen based on optimum habitat locations and ground truthing results of randomly selected survey sites. Chapter 5 reviews the significance of the results and suggests options for future research.

# Chapter 2 Background and Literature Review

Surveying wetland species, such as secretive marsh birds, can help managers to determine the quality of Maine's ecosystems, preserve its biodiversity and maintain its recreational value. For this to be successfully completed, there must be a cohesive methodology that can be understood by both professionals and volunteers. The following chapter reviews the origins of the database and protocol created for the Maine secretive marsh bird survey that will be conducted in 2018.

## 2.1 Secretive Marsh Birds

The focus of this thesis is a group of water bird species that select thick, emergent wetland habitat for their breeding area; this group includes bitterns, rails, gallinules, grebe and snipe (Ribic et al. 1999). They live in habitat that is hard to access and hardly every emit any calls so they are considered secretive in nature (Eddleman et al. 1988; Ribic et al. 1999; Conway and Gibbs 2005). Their choice of wetland for habitat has put their numbers in peril (Eddleman et al. 1988; Ribic et al. 1999; Velos et al. 2013) due to threats created by development, industrial and agricultural pollution, invasive species and human recreational and sport activities (Gibbs et al. 1992; Lor and Malecki 2002; Dahl 2006). Many species of marsh bird are declining and some have been listed as endangered, threatened or of special concern in many states including Maine (Hierl et al. 2007). Traditional survey methods for avian species are not effective for marsh birds due to their secretive behavior (Johnson et al. 2009). New more efficient protocols need to be developed. Conservation efforts are being researched to determine effective conservation and habitat management protocols (Johnson et al. 2009).

## 2.2 North American Marsh Bird Monitoring Survey

The North American Marsh Bird Monitoring Program began in 1999 as an outcome of the marsh bird workshop hosted at the Patuxent Wildlife Research Center in 1998 (Ribic et al. 1999). The outcome of this workshop was a marsh bird monitoring protocol for targeted species of marsh bird including those found in Maine (Table 1). The program began due to the lack of knowledge about the state of secretive marsh birds created by inconsistent survey methods used across the country and the small amount of significant data that was accumulated from broad scale monitoring efforts including the Breeding Bird Survey (BBS). The Patuxent group decided on a long-term monitoring approach that covered management and research issues (Ribic et al. 1999) that included fieldwork and database design. This program estimates changes in breeding marsh bird abundance at different spatiotemporal scales across the country (Ribic et al. 1999; Conway and Nadeau 2006; Conway 2008). Marsh bird vocalizations are broadcast to improve detection (Conway and Gibbs 2005; Conway and Nadeau 2006). The national program requires that marsh habitats are predetermined so that habitat which is suitable for marsh birds are the only areas selectable when random points are generated (Conway and Timmermans 2005). The Maine pilot program is based on the five objectives of the NAMBMP (Conway 2008):

1. Document presence and distribution of marsh birds in a specific area.
2. Compare the density of secretive marsh birds in wetland areas.
3. Discover trends in populations of marsh birds at the regional or local level.
4. Set up management plans and evaluate efforts.
5. Document the habitat types currently in use by marsh birds and conditions that affect abundance of marsh birds.

Using these objectives, the Maine pilot program data will transfer seamlessly into the national database and become part of the national effort to monitor secretive marsh birds. The result of the North American Marsh Bird Monitoring Program will be the cumulation of accurate estimates of regional, national and continental population trends (Conway 2008).

To date over 190 partners are involved in the program, including National Wildlife Refuges and other protected land areas, and state and federal agencies.

## 2.3 Mapping Suitable Habitat

Cowardin et al. (1979) describes a system by which wetland scientists created a universal system to characterize wetlands. It uses as a hierarchal approach (Appendix A) and is the standard used for this thesis project.

To determine areas of suitable habitat for secretive marsh bird species in Maine, a mapping database was constructed. The database for this research was created using GIS, remote sensing and spatial analysis techniques; these techniques have successfully been used in the past to create marsh bird monitoring databases (Zhang et al. 1997; Cedfelt, Watzin, and Richardson 2000; Lyon 2001; de Leeuw et al 2002; Host et al. 2005; Miller and Rogan 2007). All existing information was compiled and digitized into GIS data layers including historical aerial photographs, total area of existing wetland maps from the National Wetlands Inventory (NWI), the National Land Cover Database (NLCD), the National Hydrography Dataset (NHD), and other GIS data obtained from MDIFW. The USGS set up the NWI database using aerial photos that are classified into systems, subsystems, and classes based on the observed wetland characteristics at each site from the air and on-the-ground (USFWS 2011; NWI 2015). These NWI wetland classes were chosen based on preferred habitat and breeding area of secretive marsh birds (Longcore and Ringelman 1980; Wilen and Bates 1995; USFWS 2006; Conway

2008). Aerial photos and LiDAR from Google Earth and NAIP and elevation data from NED were used to delineate watersheds and create elevation and flow models using Digital Elevation Models (DEMs) (Maidment, Morehouse, and Friese 2002). All data sets were designated as North American Datum (NAD) 1983, Zone 19. The produced geodatabase and mobile applications included wetland inventory, biological and monitoring data sets. The use of many different sources of data made it easier to select optimum survey points based on suitable habitat and accessibility.

The NAMBMP (Conway 2008) recommends focusing survey attention on marshes that could support a breeding pair. The points should not be chosen only in areas where marsh birds are known to exist and should not be based on presence or abundance as this could lead to a biased sampling design. All areas of emergent wetland and scrub-shrub wetlands should be considered (Longcore et al. 2006). Surveys were conducted in all types of emergent marshes including freshwater, brackish, and salt marshes that are >0.5 ha in total area. Survey points on ponds should be located where emergent and upland meet or where open water and emergent meet (Conway 2008). Some of the survey points will be easier to access by boat, some by vehicle and some by foot. Permanent and semi-permanent wetlands and seasonal wetlands are included. The survey sites will be visited at least three times during the year (Conway 2008). The dates chosen for surveying should consider seasonal changes in water level and vegetation that could make access to the sites difficult. The survey points were selected using a random sampling method so the points chosen would be both accurate statistically and accessible logistically and could be combined into the national database (Johnson et al. 2009). Marsh bird surveys will be conducted in May and June. In southern Maine, each route will be surveyed once in each survey window (May 1-14, May 15-31 and June 1-15). In northern Maine, the survey

dates will be (May 15-31, June 1-15, and June 15-30). The visits should be separated by 10 days (Conway 2008). The replication of the survey will ensure that marsh bird calls are broadcast during the different species peak-response periods (Lor 2002) and doing these three times determines species presence or absence within 90% certainty (Gibbs and Melvin 1993). Surveys should be conducted in the morning (30 minutes to or three hours after sunrise) or the evening (three hours to or 30 minutes after sunset) (Gibbs and Melvin 1993). SSU's on the same route should be visited on the same day and in the same order. If there is bad weather, the surveying will be cancelled and all SSUs will be done on another day (Conway 2011).

## 2.4 Ground Truthing

Ground truthing was conducted to verify that the database set up using GIS and remote sensing could accurately select sites for secretive marsh bird monitoring. To verify the reliability of the NWI GIS datasets, a Garmin GPS was used to visit the coordinates and make site-specific observations, the coordinates are recorded and geo-referenced photography is taken (Figure 3). These photos are gathered into a virtual field reference database (VFRDB) (Wang and Christiano 2005). This VFRDB becomes a benchmark to record changes in the wetlands over time. The photos are reviewed and compared with the description of the existing classification for each wetland to check the accuracy of the existing classification. Verification of every random point chosen for this project was not practical so a set of 20 randomly chosen points were checked and verified for accuracy (Lyon 2001; Skidmore et al. 1997). Ground surveys will reveal the state of the emergent wetlands in Maine and the marsh birds that are living there. Very few studies have been conducted on the probability of marsh birds to choose a specific wetland based on the habitat characteristics (Shriver et al. 2004). If these characteristics are compiled in an accessible geodatabase, it will be easier to determine where restoration efforts are needed and provide

information to support the management of wetlands in Maine. Volunteers will follow the safest and easiest routes to the survey areas by following maps created in ArcGIS and Global Mapper.

Figure 3 Beta survey site in Moscow, Maine

## 2.5 Data Management and Mobile Applications

The data that were created in this thesis allows managers and volunteers to create, sort and edit survey points. To do this in the field, there must be adequate Internet service and software that can be accessed and edited in a web browser on either a tablet, laptop or cellphone with Internet access. The database was created using GIS, remote sensing and spatial analysis techniques; these techniques have successfully been used in the past to create marsh bird monitoring databases (Cedfelt, Watzin, and Richardson 2000). Most of the state of Maine does not have internet access or cell phone coverage available, so data must be collected using paper datasheets and entered into the database when Internet service is available.

# Chapter 3 Methodology

This chapter describes the methodology that was used to create the sampling plan for the MDIFW to support a pilot program in Maine for implementing the NAMBMP. The description of the methodology is broken up into two parts. The first part focuses on how sites for the program were selected, and the second reviews the data sources and how they were used to complete the project.

## 3.1 Sampling Design

The sampling area chosen was breeding habitat of marsh birds identified using Global Mapper and ArcGIS. The NWI (NWI 2015; USFWS 2011) was used to select wetland areas in Maine for survey sites and NAIP was used for preliminary ground truthing and 20 randomly selected survey points were visited in person to verify the accuracy of wetland identification and access. The survey points were selected using a random sampling method so the points chosen would be both accurate statistically and accessible logistically, such that they could be added into the national database (Johnson et al. 2009).

Cluster sampling was chosen as the sampling method for this research. Cluster sampling occurs when a group of locations are selected first and then sample points are determined in each location. A two-stage cluster sample was used to select the sampling sites (Figure 4). Separate selection criteria were utilized for each size of sampling unit. The primary sampling units (PSUs) consisted of specific eco-regions in Maine (Figure 2), found in the BIOPHY shapefile on the Maine Office of GIS (MEGIS). Fifteen regions are delineated based on biophysical data. Within these PSUs, secondary sampling units (SSUs) were chosen at random from specified wetland types obtained from the NWI which was also obtained from the MEGIS website. For secretive

marsh bird habitats, the wetland systems chosen were Palustrine, Lacustrine and Estuarine. In the Palustrine system, classes of SS (scrub-shrub) and FO (forested) and EM (emergent) were chosen. In Lacustrine, the subsystem of Littoral (2) and class of EM (emergent) was chosen. In Estuarine, the subsystem of Littoral (2) and class of EM (Emergent) was chosen. These NWI wetland classes were chosen based on preferred habitat and breeding area of secretive marsh birds (Conway 2008; Wilen and Bates 1995). Wetland size and classification was determined in Global Mapper using the information tool and the metadata for each layer and each individual wetland was assigned to one of five size classes (>0.5ha to ≤5 ha, >5 to 10 ha, >10 to 20 ha, >20 to 30 ha, and ≥ 30 ha). Survey site areas were chosen from the identified SSUs using stratified random sampling to ensure that there was equal representation of different sizes of wetlands and specific habitat area requirements were covered (Conway 2008).

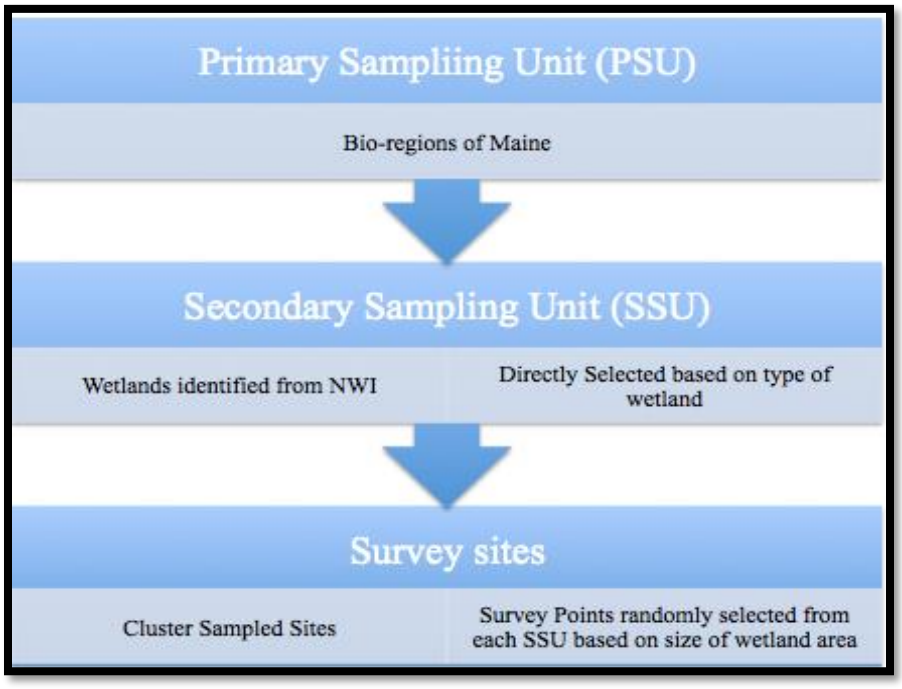


Figure 4 Flowchart showing two-stage design used to select survey sites

The Blue Marble Geographics line of products including Global Mapper, an open source

GIS application, was used to randomly select survey points in the state of Maine. The Maine NWI shapefile was downloaded from MEGIS into ArcGIS to separate out the correct wetland types of Palustrine, Lacustrine and Estuarine. It was then loaded into Global Mapper along with the BIO-PHY shapefile from MEGIS. In Global Mapper using the digitizer tool, the BIO-PHY regions layer was selected and using the right click function, the "SPLIT-Split into Separate Layers Based on Description/Attribute" option was used to select the attribute value of Name from the drop-down menu. This created a separate layer for each eco-region. Each layer was individually selected and then right clicking on the map to open the digitizer menu options, the Crop/Combine/Split Functions and Cut Selected Areas from all overlapping areas were selected to separate the identified wetlands based on eco-region. After the wetlands were separated by eco-region, they were again selected with the digitizer tool and Create Randomly Distributed Points within the Selected Areas Feature(s) was chosen. Survey points were selected from areas where the marshland met open water or upland to provide easier access to sites, shorter travel time between survey points and minimum disturbance to vegetation (Conway and Timmermans 2005). The minimum distance between points was set at 400 m to minimize the chances of double counting the same birds (Conway 2008). The number of points per wetland was based on the size of the wetland. This ensured that the area was surveyed evenly. Wetlands that are < 10 ha in size received one point, >10 and ≤ 20 ha received two, > 20 and ≤ 30 ha received three points, > 30 and ≤ 40 ha received four points and >40 and ≤ 50 received five randomly selected points. Large areas of open water (i.e. > 50 ha) were excluded because they are not used by the species that are being sampled (Conway 2008). All wetland locations found in each PSU were included in the set from which the random points were selected. If there were < 10 locations, they will all be sampled (Johnson et al. 2009). If > 10 wetland locations occurred in a PSU, 10

were randomly selected from those listed as accessible. A secondary list of sites in each chosen PSU was created if initially chosen locations are found to be inaccessible by car, kayak or foot, land ownership changed from public to private making it inaccessible or the habitat became unsuitable to be surveyed. After the map showing the sample sites was created, it was saved as a Global Mapper workspace.

The Global Mapper workspace was reloaded into Global Mapper and the naip_2013.kml was loaded to view aerial photography of the sites. This was used for preliminary ground truthing to see if the areas were wetland areas. Based on this information some sample points were removed and new random points were generated. Specific sample points were chosen and ground truthing was performed at those locations by travelling to the locations and physically verifying the existence of the specific wetland type at the location.

Ground truthing was conducted to verify that the database set up using GIS and remote sensing could accurately select sites for secretive marsh bird monitoring. A Garmin GPS was used to navigate to the exact sampling locations to ground check (ground truth) locations and verify accuracy (Ribic 2006) where site surveys would be conducted. Geo-referenced photography was taken with a Samsung Note 3 and an IPhone 6s plus (Figure 5). These photos were gathered into a VFRDB (Wang and Christiano 2005).

This VFRDB will be used to record changes in the wetlands over time as more surveys are completed. The photographs were reviewed and compared with the description of the existing classification for each wetland based on NWI to check the accuracy of the existing classification. Verification of every random point chosen for the project was not practical so a set of 20 randomly chosen points were verified for accuracy (Lyon 2001; Skidmore et al. 1997). This georeferenced photography was added to the Global Mapper workspace (Figure 6).

Figure 5 Geo-referenced photo taken in Gorham, ME for ground truthing

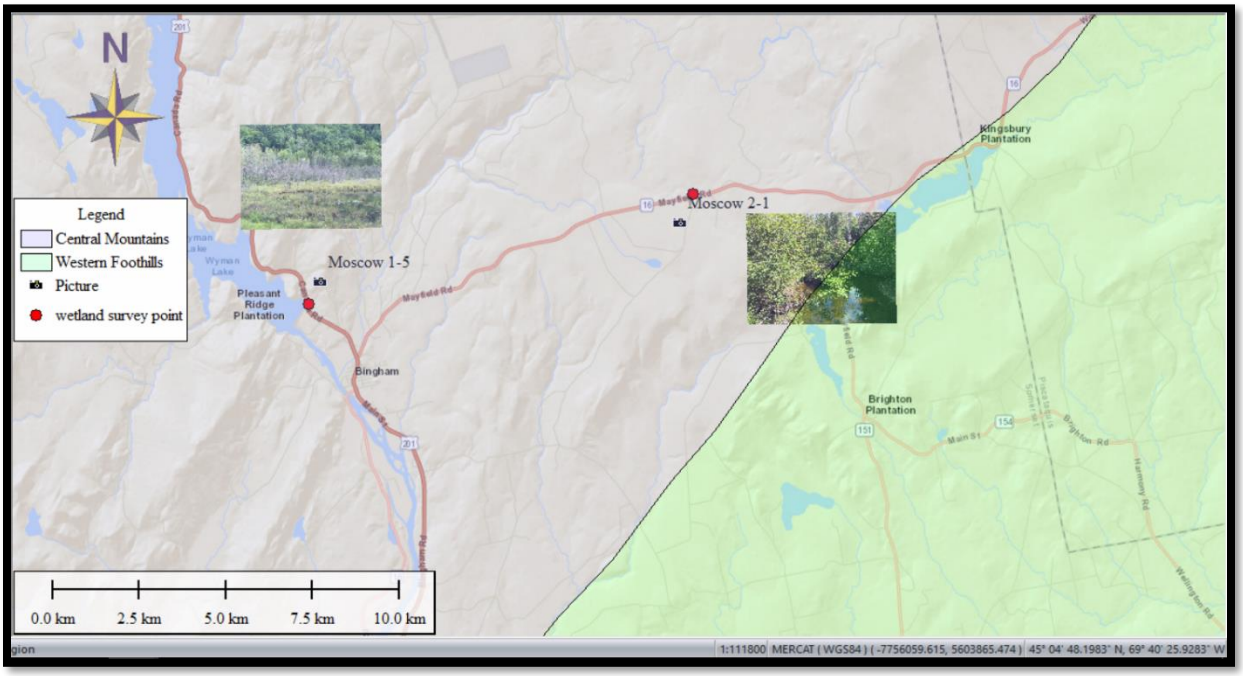


Figure 6 Global Mapper workspace with geo-referenced photography included

## 3.2 Mobile applications

A mobile application of the database is available on Global Mapper Mobile. This product is free with a Global Mapper license but you must have an IOS device and Internet access to use it. It allows for mobile GIS data viewing and provides field collection applications. The files created are Global Mapper Mobile Package (GMMP) files that can be sent back into Global Mapper and added to the existing database. Global Mapper Mobile can display the same vector, raster and elevation data that is supported in Global Mapper. It offers the same digitizing and drawing tools and allows the assignment of attribute data.

Using the Global Mapper mobile application, volunteers in the field can add attributes, take geo-referenced pictures, add additional information to existing survey points, and to navigate to the survey points. Any photos taken from the application will retain the tagged location in the GMMP file, including any associated photos, when transferred back to the desktop version of Global Mapper. The application also supports several collection options, including setting a point at a specific survey location and filling out a pre-configured attribute form with pick lists, required fields, and other attribute elements. A template layer also can be created to define the field data collection requirements and then be transferred to the device within the GMMP file.

The database raster and vector files were converted to GMMP files and then transferred to the IPhone 6s plus via iTunes. This can also be done through email. The GMMP file compresses all the layers into a single file that is seen in the menu in Global Mapper Mobile (Figure 7). When the field work is completed the datafiles can be uploaded into Global Mapper for further analysis and then exported into any of the supported formats.

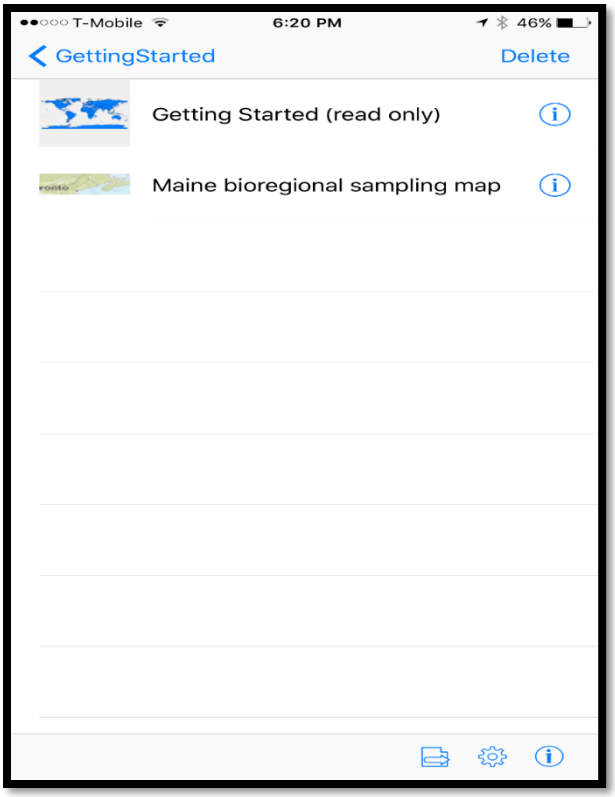


Figure 7 Menu that appears in Global Mapper Mobile

Global Mapper Mobile will allow the user to search for a specific location or wetland. They also have a choice of basemap to follow to use as directions to a specific site. Once at the site that has been chosen for them to survey, they can add in comments on the wetland attribute table or add additional fields for any marsh birds they identify. They can also see comments on any other birds that have been identified at that location and when they were made and by whom. Currently only Ios mobile devices can access the application and volunteers will have access to the maps wherever they have phone service if they have a Global Mapper account and the Global Mapper Mobile application downloaded onto their cell phone. The database was created using GIS, remote sensing and spatial analysis techniques that have successfully been used in the past to create marsh bird monitoring databases (Cedfelt, Watzin, and Richardson 2000). All existing information was compiled and digitized into GIS data layers including historical aerial

photographs, total area of existing wetland maps from the NWI, and the NAIP. All data sets were designated as North American Datum (NAD) 1983, Zone 19.

It is not recommended that volunteers use the mobile map while conducting their surveys. The light pollution and noise that would be created using the cell phone could bias the survey and potentially alarm or disrupt the marsh birds at the site. Any work done in the application should be filled in afterward and away from the survey site. In Maine, most of the locations will not have cell phone service available.

## 3.3 Data Sources

Data sheets were created to record data and can be used in the future by MDIFW to create models that provide the probability of marsh birds occupying a specific area based on habitat variables (MacKenzie et al. 2002, 2003). These models, in turn, can be used to detect occupancy in the future. The use of ArcGIS, Global Mapper, and the Geographic Calculator in creating the pilot program's sampling plan and database will be instrumental in assuring that the Maine data can flow seamlessly into the national program starting in 2018. The database created will provide a centralized location where data layers can be viewed and updated, maps can be created, and links can be obtained to additional resources relating to marsh bird monitoring. The data that was used for this research was obtained from the MDIFW, ArcGIS Online, and MEGIS (Table 4). These data were acquired from credible sources and the accuracy of the data was sufficient to set up the sampling plan and database for the pilot study. Sample sites derived from the data were ground-truthed to make sure the chosen sites are appropriate for the long-term project that will be conducted by MDIFW.

Table 4 Data sources used to delineate areas of suitable habitat for secretive marsh birds

| Data | Content | Source | Format | Date Created |
|---|---|---|---|---|
| Conus Wetlands (NWI) codes | National Wetland Identification codes. | http://www.maine.gov/megis/catalog/ | Shape File Aerial Photos | 9/11/11 |
| World Imagery | World map and transportation information | http://www.maine.gov/megis/ | Layer file | 1/16/12 |
| Maine Geodatabase (MEGIS) | State and county boundaries plus major roads and highways of Maine. | http://www.maine.gov/megis/catalog/ | Geodata base | 11/4/14 |
| Northeast Terrestrial Habitat Classification System | Mapping of ecosystems and habitats in the New England area. | http://nationalmap.gov/landcover.html | Raster dataset | 11/16/14 |
| National Agricultural Imagery Program (NAIP) 2013 Imagery | Natural and manmade land cover in the US | http://www.maine.gov/megis/catalog/ | Four band digital ortho imagery | 2011 |

# Chapter 4 Results

This chapter reports the results of using biological and environmental data specific to the state of Maine to create a pilot program, including a survey sampling scheme and database, and mobile application to survey marsh bird habitat. The MDIFW will implement the program that has been developed from this thesis in 2018.

## 4.1 Survey sampling scheme and database

Spatial and geographical data gathered from online state and federal sources as well as from the field successfully determined sampling sites in wetland complexes to survey for secretive marsh bird species using spatially derived habitat metrics (Johnson et al. 2009). Layers created in Global Mapper 18 (Figure 8) were successfully used to create maps for locating and mapping potential breeding habitat for secretive marsh birds in Maine using a two-stage cluster sampling approach to identify the survey sites (Johnson et al. 2009).

The database stores sampling sites that volunteers will be able to access by vehicle, boat or by foot (Figure 9). Using ArcGIS, it was possible to separate the optimum wetland habitats, Palustrine, Lacustrine and Estuarine, for secretive marsh birds from the total file of wetlands in Maine that was supplied by NWI on MEGIS. Creating a CSV file of the selected wetland sites in ArcGIS allowed the information to be sorted and then the correct wetlands to be added into Global Mapper for further analysis. Clipping the wetland files to the BIO-PHY layer in Global Mapper allowed the wetlands to be further sorted by area. The digitizer function in Global Mapper allowed for the selection of random survey sites, chosen at the correct minimum distance between points of 400 m. Each bio-region had > 10 appropriate wetlands so 10 were randomly selected for surveying and 10 more were randomly chosen as backup locations. The wetland

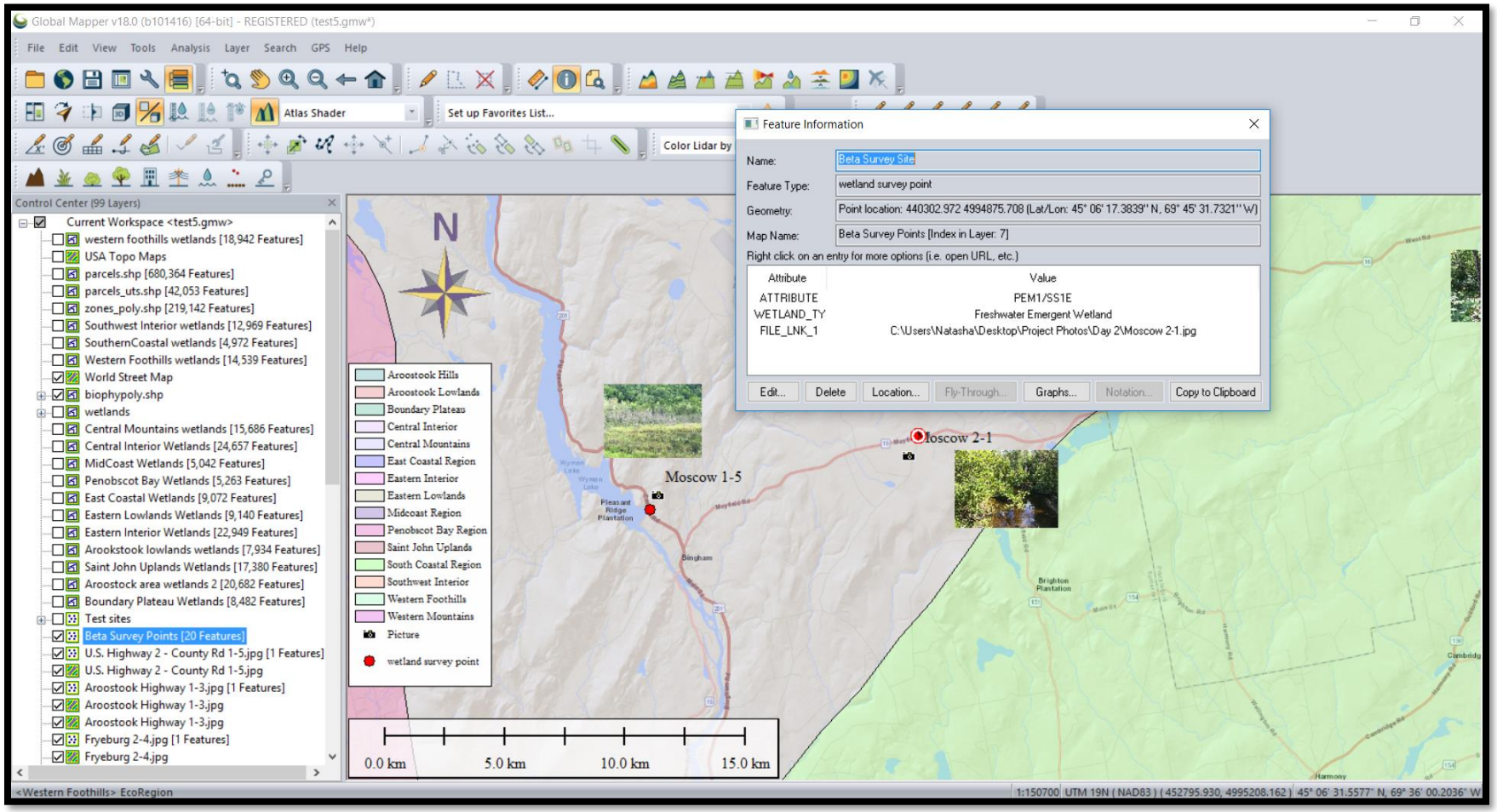


Figure 8 Map display created in Global Mapper 18 with random sites generated using two-stage clustering

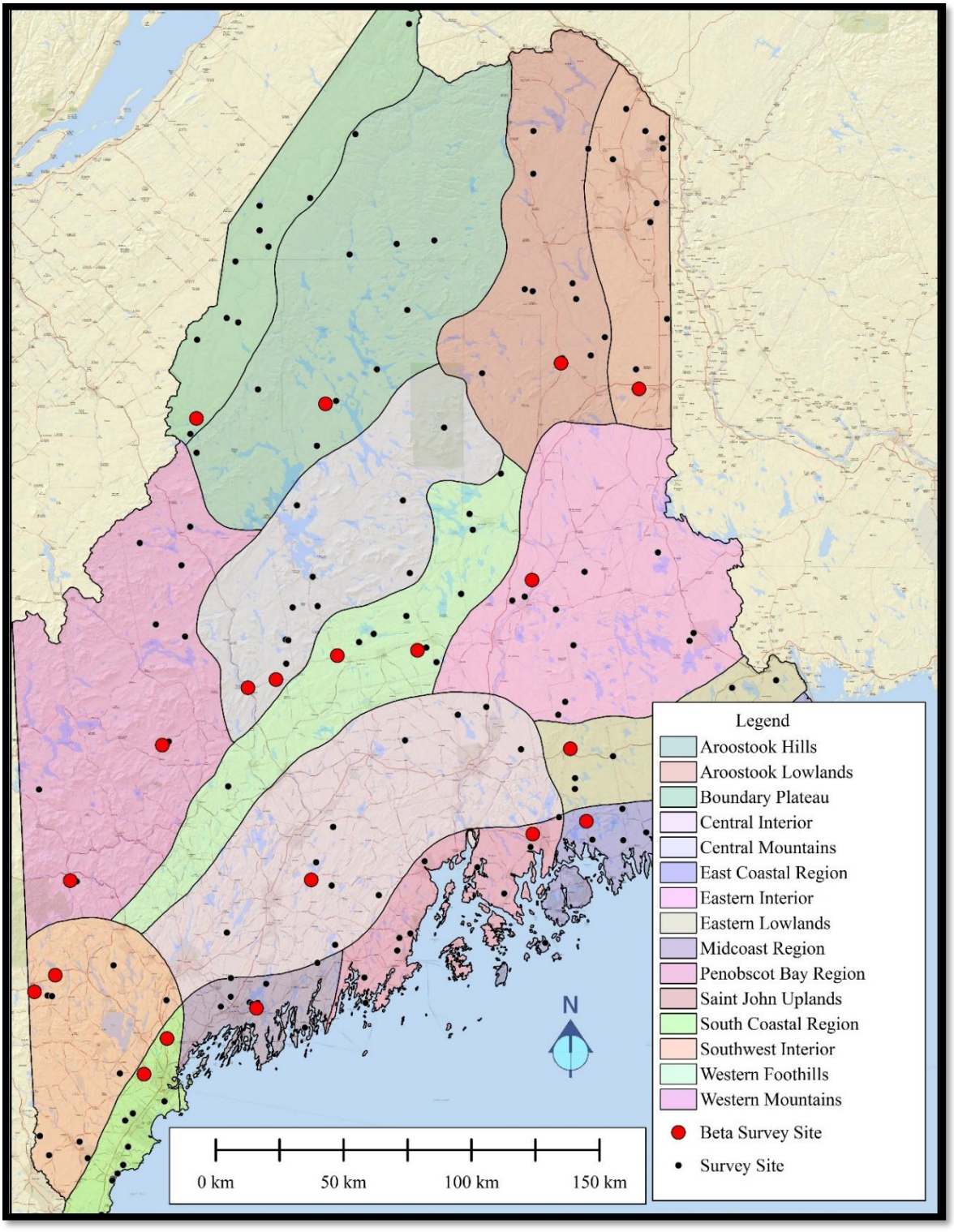


Figure 9 Map created in Global Mapper showing randomly selected survey sites and the 20 sites selected for ground truthing

locations that were randomly chosen were all < 10 ha in size so each wetland was assigned a single survey point. Using the Geographic Calculator, the data files created in Global Mapper were converted from the correct projection and datum for Maine, to the correct projection and datum for the information to be rolled into the national database.

Based on the beta testing completed in the summer of 2016, a bird biologist will be able to open the database and choose survey sites for volunteers to visit, add additional information to already existing sites and send information electronically to volunteers through the mobile application. Bird biologists will also be able to pull data for analysis and for demonstrations to receive additional funding for marsh bird research. Volunteers will use the database and mobile application to access their assigned survey locations. They can use the maps created to access data on their assigned locations and see what equipment they will need to bring with them to successfully conduct surveys. The volunteers will be able to add any new data that they acquire into the mobile application in the field if they have Internet access or into the database when they return home. Bird biologists may also use the database and mobile application to create data sheets that the volunteers can manually fill out if they are not tech savvy and then return the forms so the data can be added into the database.

Shapefiles, raster files and aerial imagery provided the necessary information to create a database that could accurately predict optimum habitat sites for secretive marsh birds. NWI files were accurate enough to show where wetlands were historically known to be located (Figure 10), and ground truthing and NAIP imagery were used to verify that the sample sites chosen were wetland types used by secretive marsh birds. By draping imagery over elevation and land cover data it was possible to determine the best way to access the randomly chosen sampling sites (Figure 11).

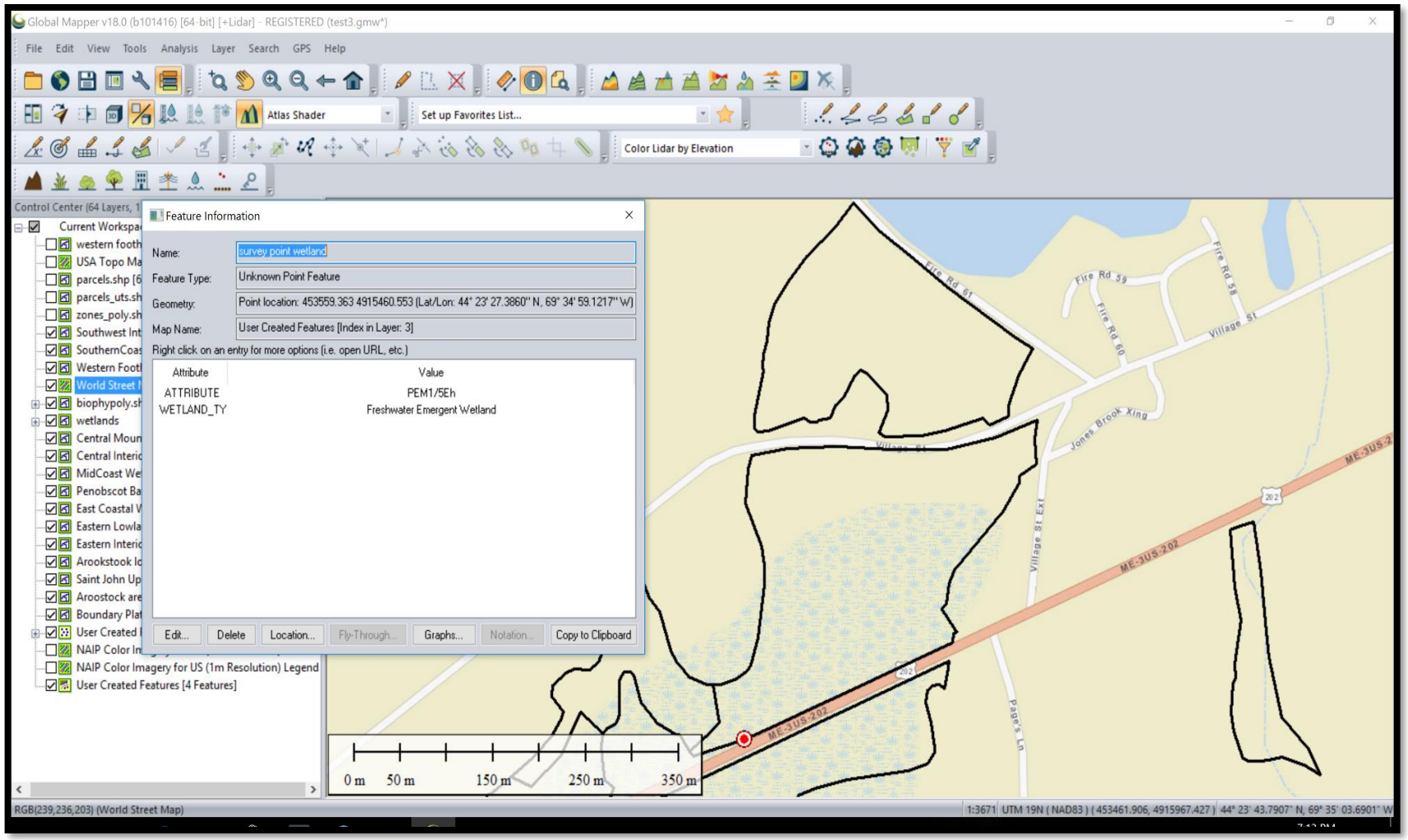


Figure 10 Map display created in Global Mapper showing NWI and World Street Map views of selected wetland location

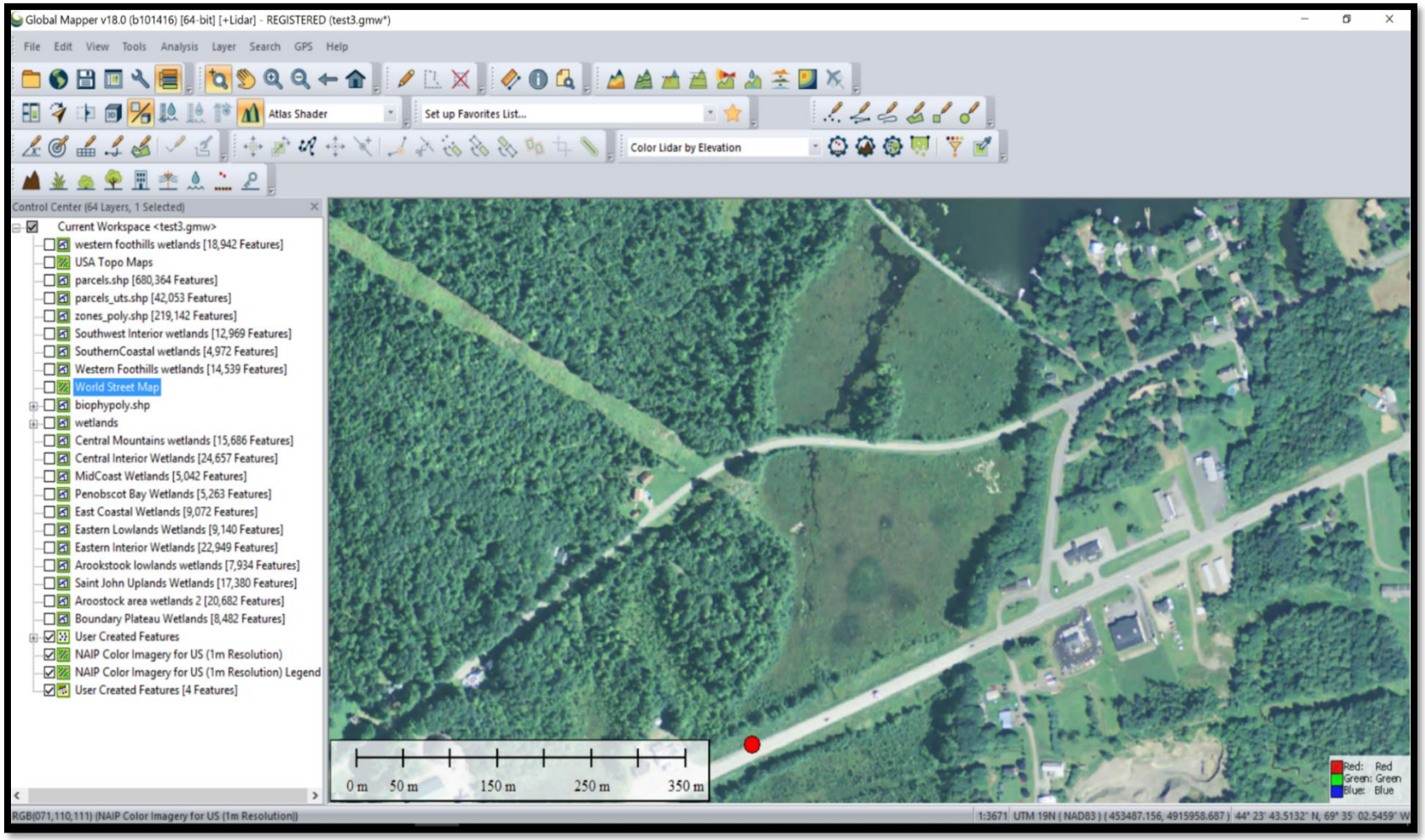


Figure 11 Map display created in Global Mapper showing NAIP color imagery of a selected wetland location (1 m resolution)

## 4.2 Beta test and ground truthing

Twenty of the randomly selected sites created in Global Mapper were visited to verify the accuracy of the existence of wetland at the coordinates chosen and accuracy of the NWI wetland category currently defining the site. In addition, whether or not the location was public land, the distance from a major road and whether or not additional equipment was required to access the site were recorded and verified ( Table 5). All the points selected were chosen with the following criteria: (1) verified wetland, (2) verified accessible by car, and (3) the site was ≤ 50 m from a serviceable road. Both private and public land was chosen as acceptable sites and a mixture of the two were included in the beta test. Twelve locations were listed as private and eight were listed as on public land. Many of the points were within 50 m of a road but many of the roads were Maine wood roads. These roads were gravel and dirt and not kept up to the standard of a normal road. Many of them were barely passable and one location was not accessible because the road had washed out (Figure 12). Other locations that had wood roads were overgrown and not accessible without a four-wheel drive vehicle (Figure 13 and Figure 14). At these locations, more walking was required. The wetland descriptions given by the NWI for the beta test sites were accurate for the sites that could be accessed. For the location in Fryeburg, the NWI classification was listed as PSS1E-Palustrine Scrub-Shrub Broad Leaved Deciduous-Seasonally Flooded/Saturated. The plant life at the site agreed with this description (Figure 15). The coordinates were at the upland edge of the wetland but the vegetation in the wetland agrees with the NWI and the ground was spongy and saturated.

Table 5 Summary of ground truthing results for 20 sample sites

| Coordinates | Ecozone | Town | Wetland-see Appendix A | Verified /Photos Taken | Public Land (Y/N) | Distance from Road (M) | Equipment (required or optional) | Access by Car | Cell Phone Coverage |
|---|---|---|---|---|---|---|---|---|---|
| 43° 59' 15.8250" N, 70° 58' 04.5865" W | Southwest Interior | Fryeburg | PSS1E | Yes | Y | 35 | Car, Kayak (optional), knee boots | No | Yes |
| 44° 02' 52.7944" N, 70° 51' 50.4659" W | Southwest Interior | Fryeburg | PEM1E | Yes | y | 0 | Car, Kayak (optional), knee boots | Yes | Yes |
| 43° 49' 06.9353" N, 70° 18' 17.1663" W | South Coastal Region | Cumberland | PSS1/EM1E | Yes-no Photo | N | 0 | Car | Yes | Yes |
| 43° 41' 21.4766" N, 70° 25' 10.9340" W | South Coastal Region | Gorham | PSS1/EM1E | Yes | N | 0 | Car | Yes | Yes |
| 44° 23' 18.0975" N, 70° 47' 20.7358" W | Western Mountains | Bethel | PSS1E | Yes | Y | 1100 | Car, knee boots | No | No |
| 44° 52' 19.7889" N, 70° 19' 41.3073" W | Western Mountains | Phillips | PEM1E | Yes | Y | 40 | Car, knee boots | Yes | No |
| 45° 04' 34.0466" N, 69° 53' 59.7910" W | Central Mountains | Moscow | PEM1F | Yes | Y | 0 | Car, knee boots | Yes | No |
| 45° 06' 17.3839" N, 69° 45' 31.7321" W | Central Mountains | Moscow | PEM1/SS1E | Yes | Y | 0 | Car, knee boots | Yes | No |
| 45° 11' 23.6410" N, 69° 27' 06.6886" W | Western Foothills | Abbott | PSS1E | Yes | N | 10 | Car, knee boots | Yes | No |
| 45° 12' 30.7199" N, 69° 03' 01.6837" W | Western Foothills | Milo | PSS1E | No pictures | N | 15 | No access-Road Blocked Private Property | No | No |
| 46° 01' 21.8446" N, 70° 09' 27.1669" W | Boundary Plateau | Golden Road | PSS1E | No Access | Y | 0 | Car, $15.00 fee Road washed out | No | No |
| 46° 04' 26.0608" N, 69° 30' 40.3569" W | Aroostook Hills | Brandy Brook Rd | PSS1Eb | Yes | Y | 0 | Car, $15.00 fee | Yes | No |
| 46° 12' 56.3018" N, 68° 19' 57.4980" W | St. John Uplands | Aroostook HWY | PSS3BA | Yes | N | 0 | Car | Yes | No |
| 46° 07' 31.9737" N, 67° 56' 34.0216" W | Aroostook Lowlands | US HWY 2 | PSS1E | Yes | N | 0 | Car | Yes | No |
| 45° 27' 24.1531" N, 68° 28' 42.4845" W | Eastern Interior | RTE 116 | PEM1E | Yes | N | 0 | Car | Yes | No |
| 44° 51' 33.0719" N, 68° 17' 11.4386" W | Eastern Lowlands | Aurora | PSS7Ba | Yes | N | 0 | Car, knee Boots | Yes | No |
| 44° 36' 02.7737" N, 68° 12' 20.2280" W | East Coastal Region | Franklin | PEM1E | Yes | N | 0 | Car | Yes | No |
| 44° 33' 17.3922" N, 68° 28' 28.9919" W | Penobscot Bay Region | Ellsworth | PEM1/FO5 Eb | Yes | N | 0 | Private Propery-Posted No Access | No | Yes |
| 44° 23' 27.3860" N, 69° 34' 59.1217" W | Central Interior | China | PEM1/5Eh | Yes | N | 0 | Car | Yes | Yes |
| 43° 55' 42.8228" N, 69° 51' 24.4156" W | MidCoast Region | Brunswick | PEM1C | Yes | N | 0 | Car | Yes | Yes |

Figure 12 Photograph showing washed out road that prevented access to one survey site

Figure 13 Photograph showing Fryeburg, ME wood road used to access another survey site

Figure 14 Photograph showing road to survey site in Bethel, ME that was not accessible without a four-wheel drive vehicle

Figure 15 Photograph showing the vegetation at the Fryeburg, ME survey site

Another beta test location located in Aroostook County, ME has the NWI classification of PSS3BA-Palustrine Scrub-Shrub Broadleaved Evergreen Seasonally Saturated and Temporary Flooding. A photograph of the survey site revealed that this was correct (Figure 16). This location was correctly classified but whether it could be a survey site for secretive marsh birds would have to be researched further by the bird biologist because the habitat was wet but with little to no emergent vegetation and therefore it may not satisfy the criteria necessary for this class.

Figure 16 Aroostook Highway survey site

Twenty locations were randomly selected for the beta test from the survey sites chosen in the Global Mapper database. The coordinates that were given in Global Mapper were used to create accurate driving instructions in Google Maps to get to the site locations. Five of the 20

locations were not accessible by car: two of these were posted as private property, one was due to a washed-out road and two others were impassible wood roads. The NWI classification for each of the twenty locations was accurate. Only 7 of the locations has cell phone service so datasheets would need to be brought to all survey sites done in Maine.

## 4.3 Mobile Application

Files that were created in Global Mapper were transferred to GMMP files and then transferred to and from Global Mapper Mobile effectively using the File Sharing function in iTunes. At beta survey sites in southern Maine where there was cell phone reception, the Global Mapper Mobile application was accessed (Figure 17) and attribute information was added to one of the survey sites in the field (Figure 18). This task was completed in the vehicle, away from the actual survey site. After returning from the field, the modified files were uploaded back into Global Mapper for further analysis.

The stated objectives were met, as GIS and remote sensing techniques were verified as accurate in selecting potential breeding habitats for secretive marsh birds in Maine and converting the data to the national format needed for the NAMBMP. Groundtruthing will also be necessary to set up the pilot program in Maine.


Figure 17 Screenshot showing Global Mapper Mobile application on an IPhone

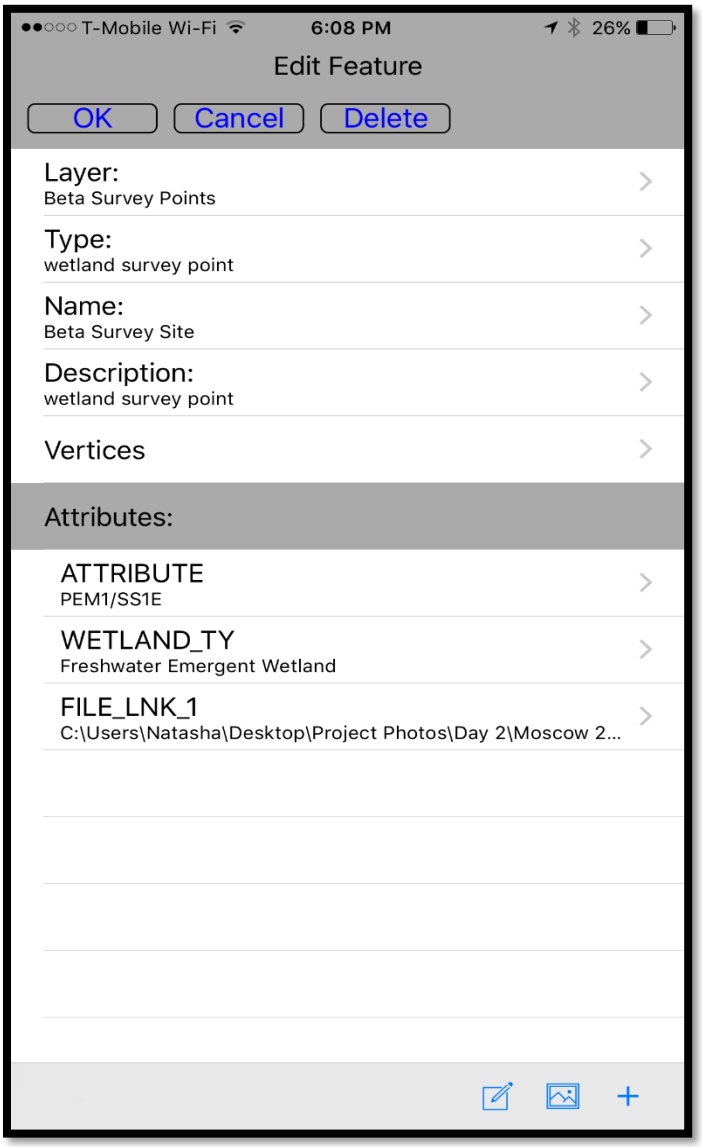


Figure 18 Page where attributes can be added or edited in Global Mapper mobile app

# Chapter 5 Discussion and Conclusions

Secretive marsh birds are an indicator species of the health of Maine's wetlands. It is important that a protocol is in place to monitor how these species are doing. It is also important that this information can be added to that from other states to form a national picture of wetland health. The North American Marsh Bird Monitoring Protocol (NAMBMP) provides the methods needed to successfully monitor these species. GIS and remote sensing offer an efficient means to gather all the collected data from this protocol in one place for consolidation, analysis, and interpretation.

## 5.1 Development of Maine Marsh Bird Protocol

For the state of Maine to begin working towards their part of the national survey, a database had to be created to store the information that would be accumulated and create the maps needed to find appropriate survey locations. ArcGIS and Global Mapper were selected and used to capture, store, and analyze data.

The Esri Catalog of GIS Applications was initially used to separate out the correct wetland types for optimum marsh bird habitat from the complete list of wetlands found in the Maine NWI shapefile from MEGIS. In ArcGIS, a CSV file was created that held this information and could be shared with other platforms.

The Blue Marble Geographics platform was selected to do most of the analysis and provide a mobile application. This is a local company in the state of Maine that was found to be less expensive and provided products that were easy to use with access to a large variety of spatial datasets and projection management using the Geographic Calculator library. It has a very

large library of data analysis and processing tools. It also offers the ability to share a single license between many users which will be useful when the actual survey is done.

NAIP was used to provide aerial imagery of the selected sites for initial verification that they were the proper habitat and NWI was selected to define the wetlands themselves. Using these tools a database was created that will be used in 2018.

Once the database was complete and survey sites had been selected, the locations were verified with ground truthing to test the accuracy of the NWI. Based on these results, it was discovered that out of the 20 sites where groundtruthing was performed, 5 percent were misclassified and some were not accessible (Figure 19). Due to variables, such as these, additional backup survey locations will be added in each randomly selected wetland to guarantee a minimum number of sites will be surveyed.

Figure 19 Photograph showing road issues that could make a site inaccessible

Some of the roads that were listed as accessible by car were not. This is something that must be considered when selecting locations in rural areas of Maine. Some of the roads in northern Maine are wood roads where you cannot drive faster than 20 mph and what looks like it would take 30 minutes on a map, could take hours. With the specific time requirements for this surveying, it will be very important for volunteers to plan their travel time accordingly and leave room for error. Some of the locations also required a fee to access and passing through a check point that may not always be manned. With no cell service, it will be very important for accurate contact information and emergency numbers to be gathered from volunteers before they begin their surveying, as well as their itineraries and planned routes of travel.

The state of Maine has over five million acres of freshwater wetlands and another 157,500 acres of tidal wetlands, this adds up to over 25 percent of Maine's land area (Maine DEP 1996). Due to this state-of-affairs, much of the state must be included in the sampling universe and assigned to bio-regions to make it more manageable. The bio-regions were further broken down to include appropriate wetland areas which volunteers could access the said areas to conduct the surveys. By using the two-stage cluster sampling technique the results were statistically and logistically efficient and the points were random but balanced across the entire state. These sites are also easily rolled into the national dataset found at the Patuxent Wildlife Research Center at https://cals.arizona.edu/research/azfwru/NationalMarshBird/.

The bio-regions and other shapefiles necessary to set up the database were readily available on the MEGIS website at no cost. Once these locations were selected and verified with NAIP remotely sensed information, they were further verified in the field to make sure the locations selected from the database were accessible to volunteers and contained the wetland type defined by NWI. To make the ground truthing statistically significant, 20 of 160 sites

chosen were visited physically and only five of the 20 were not accessible. The results gained from the ground truthing displayed that the database set up in ArcGIS and Global Mapper using the recommendations of the NAMBMP could successfully choose optimal locations for the Maine surveys that will be launched in 2018.

The mobile application that was created in Global Mapper Mobile is an excellent tool if you have Internet access and cell phone service. It should not be used directly at survey locations as the sounds and light pollution from the phone may bias the survey results and disrupt the marsh birds at the location. In the state of Maine, it should be noted that there is no cell phone service in much of the state and paper forms must be created and brought to the survey sites.

## 5.2 Future Work

Before the actual survey in 2018 there are a few items that should be addressed. It is important for MDIFW to decide if they want to use one or the other or both ArcGIS or Blue Marble Geographics platforms. Choosing one platform would streamline the various work tasks associated with the databases and mobile applications that accompany the chosen technology platform. They will also need to purchase whichever software suite they choose and set up accounts and passwords to allow the volunteers the access what they will need.

Data sheets that correspond with the attribute tables should also be created in case there is a problem in the field and the volunteers cannot access the mobile data or if they are in an area where there is no Internet service. Volunteers should be chosen based on their geographic locations and instructional sessions provided or webinars created to explain how to use the mobile applications and to conduct the surveys themselves.

## 5.3 Conclusion

Programs that monitor indicator species are very important for discovering conservation needs, population trends, where wildlife management interventions may be needed and the effects of human interference. There is also a more urgent need now for monitoring of wetlands due to the increasing effects of climate change and sea level rise. With the reduction in available funds for research on wildlife species and wetland health, it is also very important that these programs are carried out in the most efficient and cost-effective manner possible. The research done here has shown that this can be accomplished using geographic information systems and spatial data.

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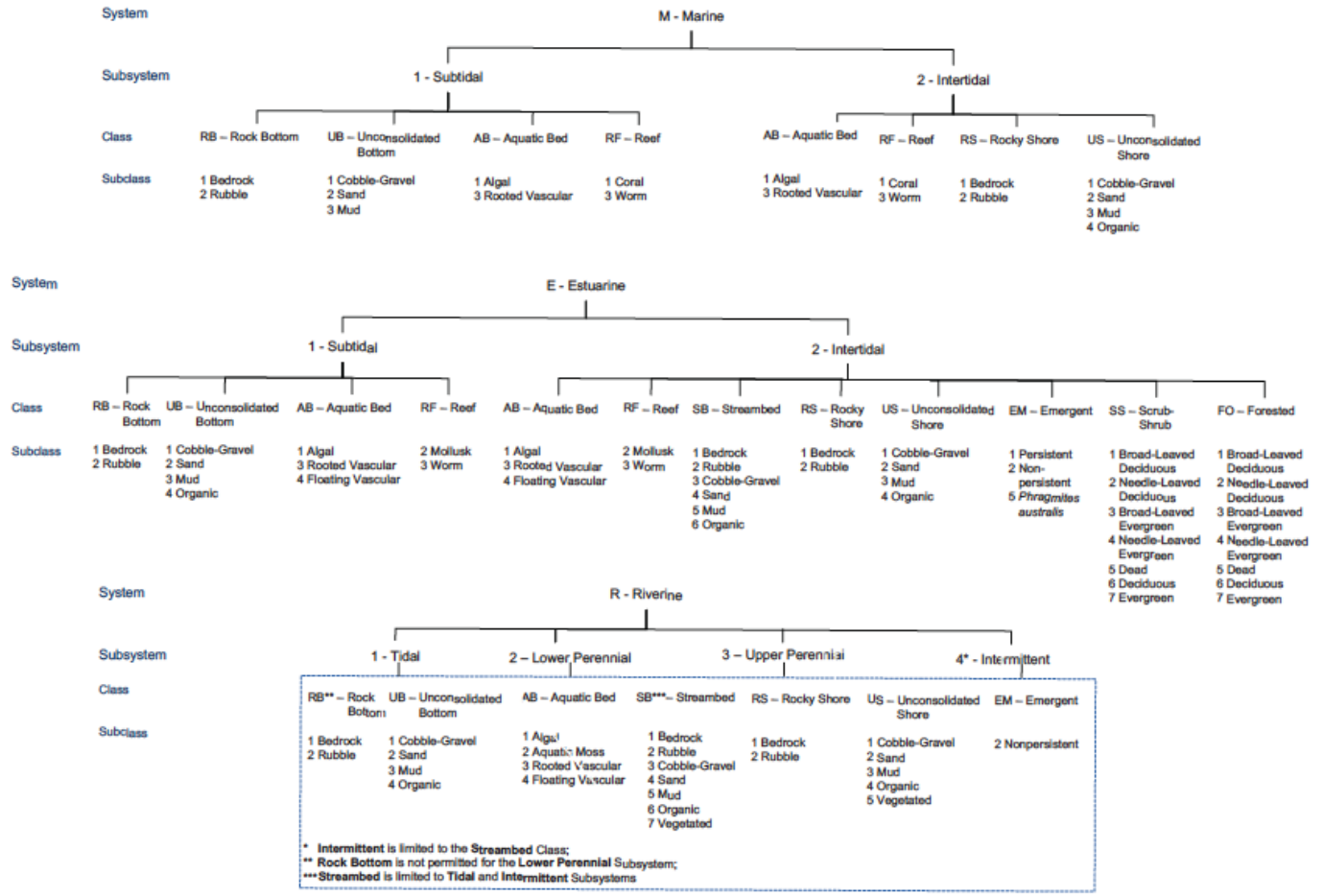
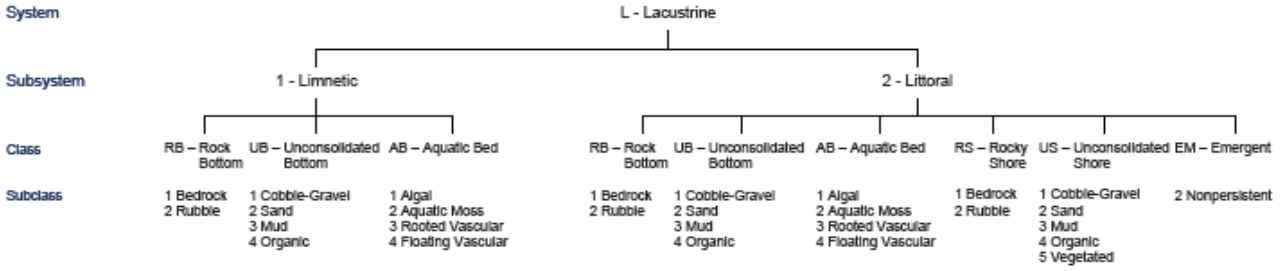
# Appendix A: NWI Wetlands and Deepwater Map Code Diagram

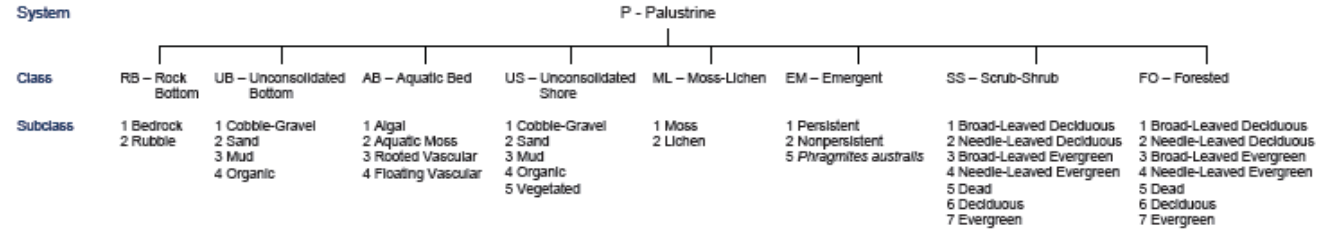





Classification of Wetlands and Deepwater Habitats of the United States, Cowardin *et al.* 1979

# NWI Wetlands and Deepwater Map Code Diagram (cont.)




## MODIFIERS

In order to more adequately describe the wetland and deepwater habitats, one or more of the water regime, water chemistry, soil, or special modifiers may be applied at the class or lower level in the hierarchy.

| Water Regime | | | Special Modifiers | Water Chemistry | | Soil |
|---|---|---|---|---|---|---|
| Nontidal | Saltwater Tidal | Freshwater Tidal | | Halinity/Salinity | pH Modifiers for Fresh Water | |
| A Temporarily Flooded | L Subtidal | S Temporarily Flooded- Fresh Tidal | b Beaver | 1 Hyperhaline / Hypersaline | a Acid | g Organic |
| B Seasonally Saturated | M Irregularly Exposed | Q Regularly Flooded-Fresh Tidal | d Partly Drained/Ditched | 2 Euhaline / Eusaline | t Circumneutral | n Mineral |
| C Seasonally Flooded | N Regularly Flooded | R Seasonally Flooded-Fresh Tidal | f Farmed | 3 Mixohaline / Mixosaline (Brackish) | i Alkaline | |
| D Continuously Saturated | P Irregularly Flooded | T Semipermanently Flooded-Fresh Tidal | m Managed | 4 Polyhaline | | |
| E Seasonally Flooded / Saturated | | V Permanently Flooded-Fresh Tidal | h Diked/Impounded | 5 Mesohaline | | |
| F Semipermanently Flooded | | | r Artificial Substrate | 6 Oligohaline | | |
| G Intermittently Exposed | | | s Spoil | 0 Fresh | | |
| H Permanently Flooded | | | x Excavated | | | |
| J Intermittently Flooded | | | | | | |
| K Artificially Flooded | | | | | | |



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August, 2015