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A Predictive Model for Occurrence of Invasive Glossy Buckthorn *(Frangula alnus)* on Mount Desert Island, Maine, USA

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ABSTRACT

Invasive species are a worldwide problem. Many research projects have been undertaken to prepare an effective management model for these species. In Acadia National Park, Maine, USA, botanists have recorded a large invasion of glossy buckthorn (*Frangula alnus*). The park manages this invasive plant in the Great Meadow Watershed (GMW), but it does not have appropriate information about other areas in the park where glossy buckthorn may occur. For my bachelor's thesis, I developed a GIS predictive model for occurrence of glossy buckthorn on Mount Desert Island (MDI) which originates from the predictive model I prepared for GMW. The predictive model for GMW is based on field GPS data collected by park biologists in 2009. The predictive model includes layers of important features of soils (drainage, permeability, depth, plant competition, and pH), land cover, and slope. Since the most important soil features for growth of glossy buckthorn are drainage and permeability, these are weighted twice in the model. Layers of land cover, slope, and the cumulative layer of all soils are weighted equally. The predictive model is based on a ranking system of these features. I assigned numbers from 1 to 5 to every single feature of each layer depending on the density of its occurrence within the GMW.

The final predictive model for glossy buckthorn on MDI should help park biologists manage glossy buckthorn throughout the island. To check the accuracy of the model, I generated 20 random points within the polygons with the highest probability of occurrence.

Key words: Glossy buckthorn, invasive plants, GIS modeling, predictive model, management of invasives

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ABSTRAKT

Invazní druhy jsou celosvětovým problémem. Pro přípravu efektivního managementu těchto druhů již bylo sestaveno mnoho výzkumných projektů. V Acadia National Park ve státě Maine v USA botanici zaznamenali rozsáhlou invazi krušiny olšové (*Frangula alnus*). Správa národního parku provádí management této invazní rostliny pouze v jedné části parku – na Great Meadow Watershed (GMW), ale nemá potřebné informace o ostatních územích v parku, kde by se krušina olšová mohla objevit. Ve své bakalářské práci jsem sestavila GIS prediktivní model výskytu krušiny olšové na Mount Desert Island (MDI), který vychází z prediktivního modelu připraveného pro GMW. Prediktivní model pro GMW je založen na terénních GPS datech sesbíraných biology z národního parku v roce 2009. Prediktivní model zahrnuje vrstvy důležitých půdních znaků (odvodňování, propustnost, hloubka, rostlinná kompetice a pH), land cover a sklon svahu. Protože nejdůležitějšími půdními znaky jsou odvodňování a propustnost, mají v modelu dvojnásobnou váhu. Vrstvy land cover, sklon svahu a kumulativní vrstva všech půdních znaků mají v modelu stejnou váhu. Prediktivní model je založen na kategorizačním systému těchto znaků. Jednotlivým znakům všech vrstev jsem přiřadila čísla od 1 do 5 v závislosti na hustotě jejich výskytu na GMW.

Konečný prediktivní model pro krušinu olšovou na MDI je směřován v první řadě biologům NP, aby mohli provést management krušiny olšové na ostrově. Pro zkontrolování přesnosti modelu jsem vygenerovala 20 náhodných bodů uvnitř polygonů s největší pravděpodobností výskytu.

Klíčová slova: krušina olšová, invazní rostliny, GIS modelování, prediktivní model, management invazních druhů

Affirmation

I declare that I wrote this Bachelor's thesis independently under supervision of RNDr. Miroslav Zeidler, PhD. and I used cited literature only.

In Olomouc, 2nd May, 2011 ....

Signature

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ANP	Acadia National Park
GIS	Geographic Information System
GMW	Great Meadow Watershed
GPS	Global Positioning System
MDI	Mount Desert Island

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1 INTRODUCTION

1.1 Invasive species

Invasions of nonnative species are a worldwide problem, because these invasions alter the composition of native communities, ecosystem processes, fire frequency, nutrient cycling, and water availability (Frappier et al., 2003). Because invasive plants compete with native plants for nutriments, water, sunlight and because they adversely impact soil moisture, soil pH, carbon and nitrogen cycles, and microbial activity, native plants often have difficulty becoming established (Nagel et al., 2008). Native plants can also hybridize with invasive species and consequently alter the gene pool (Richburg et al., 2001).

Invasive plant species progressively modify forests of the northeastern United States. Invasive shrubs and vines change understories, "particularly in young, over-browsed, or physically disturbed forests" (Dukes et al., 2009) and can eliminate tree regeneration. Many of the nonnative species have greater tolerance for different climates than do indigenous species (Dukes et al., 2009). They are also characterized by long-range dispersal (Dukes et al., 2009) and rapid growth, and they occupy new places in response to water, nutrients, and light resources (Nagel et al., 2008). Invasive species also "form dense monocultures that inhibit native regeneration and depress forest herb populations" (Webster et al., 2006). All of these traits enable invasive species to become established.

Chytrý and Pyšek (2009) demonstrate that the percentage of nonnative species in natural vegetation of the United States is much higher compared to the European vegetation which is manmade or strongly influenced by man. That reflects the difference in invasibility of US and Europe. Moser et al. (2007) name four important factors of invasibility: disturbance, competitive release, resource availability, and competitive pressure. Particularly vulnerable to invasion are lands that were cultivated, grazed, or used for timber production (Richburg et al., 2001). However, some species can also invade undisturbed ecosystems such as intact forest habitats and thus greatly reduce density and diversity (Sanford et al., 2003). In addition, soil features are important in identification vulnerability of plant community to invasion. The invasion increases with the accessibility of nitrogen. At the same time, finer textured soils (high percentage of clay) are more likely to be invaded than sandy soils with coase texture.

The higher invasibility of these soils may be caused by higher water-holding capacity (Johnson et al., 2006).

1.2 Glossy buckthorn

In New England and specifically on Mount Desert Island, one of the most aggressive invasive plant species is glossy buckthorn (*Frangula alnus* or *Rhamnus frangula*). Native to Eurasia and northern Africa, glossy buckthorn was imported into the United States in 1800s as a hedge species and soon spread into wildlife habitat. Glossy buckthorn is now naturalized in northeastern United States and southeastern Canada and is distributed from Nova Scotia south to Pennsylvania, west to Illinois with some spotty distribution in Minnesota and Wisconsin (Frappier et al., 2003).

In its native area, glossy buckthorn grows in forested edges and related ecotons, it is sensitive to grazing but very tolerant to trampling (Klotz et al., 2002). It inhabits 4 floristic zones: meridional, submeridional, southern temperate, northern temperate, and boreal (ib). Glossy buckthorn is a species of marine climates, however it does not grow in very extreme marine and very extreme continental climates (ib.). Hemeroby levels of glossy buckthorn are mesohemerobic and oligohemerobic. That means that it grows in weakly utilized woodlands, forests with well developed bush and forb layer, growing dunes, bogs and swamps as well as heathland, dry grasslands, slightly utilized pastures and meadows (ib.). It appears primarily in non-urban areas (ib.). It is a part of various plant communities: acidic deciduous bush communities; willow marsh shrublands; blackthorn and buckthorn shrubs; alder marsh woodlands; mesophilous, summer-green deciduous forests; birch-oak forests; snow-heather pine-forests; bog bilberry pine-forests (ib).

Although glossy buckthorn can invade various types of environments, in the USA, it is most common in wetland habitats, dry areas such as sand plains, prairies, forest edges, fencerows, and old fields (Possessky et al., 2000). It can also appear in upland woodlands (Frappier et al., 2004). Typical wetland habitats characteristic for glossy buckthorn include "open and treed fen, sedge marsh, swamps of [red maple], ash, cedar, alder, etc" (Catling and Porebski, 1994). Glossy buckthorn prefers locations close to water which are periodically but not fully flooded (Catling and Porebski, 1994; Frappier et al., 2003). Its distribution is not dependent on disturbances, and hence it poses a challenge to many high quality wetlands. In the understory of closed white pine (*Pinus strobus* L.) forests, glossy buckthorn reaches high cover, reduces gaps in forests, and favors shade-tolerant species in these gaps. It reduces establishment of new populations in the gaps (Fagan and Peart, 2004).

Glossy buckthorn is a strong aboveground competitor (Klotz et al., 2002) because it leafs out earlier and holds leaves longer than other deciduous plant species in the understory (Webster, 2006). It grows up to 3 m in the understory and 4 – 5 m in open areas (Fagan and Peart, 2004). Its fleshy black berries are consumed and dispersed by birds (Drezner and Weckerly, 2004). Important traits which help glossy buckthorn to repel generalist consumers are its secondary metabolites (emodin nad other anthraquinones) in fruit and foliage (Trial and Dimond, 1979 in Johnson et al., 2006). Because of an extensive shallow root system, it may also be a strong below-ground competitor (Fagan and Peart, 2004). With these properties, it shades and prevents the germination and growth of other species, and consequently lowers species diversity and abundance (Reiner and McLendon, 2002). An established canopy of glossy buckthorn can also change and replace native plant communities (Fagan and Peart, 2004) as well as "form a dense homogenous monoculture, outcompete native shrubs, and alter other ecosystem processes" (Nagel et al., 2008) because seeds are longer lasting and spread in fall.

Although glossy buckthorn can grow on a wide range of soil types (Fagan and Peart, 2004), it prefers nutrient rich soils (Cunard and Lee, 2009) and is abundant in moist-to-mesic organic soils of acid, neutral, or alkaline reaction (Catling and Porebski, 1994). They suggest that "it occurs also on sand, clay, limestone rock and pure peat."

The National Park Service is managing glossy buckthorn on MDI. This invasive plant grows on the northwest side of Bear Brook Pond, in the southeast portion of Great Meadow, the south end of the Tarn, and the intersection of Kebo Street and the Park Loop Road (Reiner and McLendon, 2002). Reiner and McLendon (2002) also suggest that glossy buckthorn is spreading rapidly in these areas. Staff from Acadia National Park collected data from places where glossy buckthorn has grown. However, there was no map or model to predict further dispersion of glossy buckthorn.

1.3 Geographic information system (GIS) modeling

Geographic information system (GIS) is broadly used in different disciplines to visualize data layers, clearly organize data, and simulate complex environmental interactions (Gillham et al., 2004). Thus, GIS can be very useful in predicting where invasive species might appear.

Researchers use different approaches to prepare predictive models and maps of invasive species. Higgins et al. (1996, 2000) prepared theoretical models based on environmental interactions and biological features. Although their models are substantively developed, they lack graphic visualization, which is useful for practical management. In addition to creating GIS models for invasive species, Gillham et al. (2004) included parameters for modeling the following geographic data layers: soil texture, soil pH, distance from direct water sources, distance from disturbances, annual precipitation, associated land cover, elevation, slope, and aspect. They classified each grid cell for all of the named layers, numbered either 0 or 1. They defined susceptibility parameters for five species and used them in classifying: Number 1 meant that the site was susceptible; 0 meant that it was not. Finally, when all grid cells were marked for each environmental parameter, total scores were calculated for each raster cell. Cells with a score of 9 are the most likely to have an area favorable to invasive species if this species is introduced into the area. This study clearly mapped areas susceptible to invasive species, which is useful for management.

Bushing et al. (1997) listed other GIS data layers used in their study of invasive plants. These layers include: terrestrial elevation, aspect, slope, geologic rock types, soils, and solar insolation. Peterson et al. (2003) prepared "an ecological niche model based on the ecological characteristics of known occurrences in the native distribution of a species to identify suitable areas for the species on a potentially invaded range." They used a number of layers to summarize elevation, slope, aspect, flow accumulation (= upstream area contributing to water flow), flow direction (= modeled direction of water flow), topographic index (= tendency to pool water), and aspects of climate (including different temperatures, precipitation, radiation etc.). They concluded that an ecological niche model can accurately predict the appearance of invasive species.

Elith et al. (2006) compared different predictive models for invasive species and found that the number of presence records for modeling does not have a noticeable influence on accuracy. Therefore, rarer species are modeled with greater accuracy. Using different techniques, we can generate various predictive maps.

An important technique for data organizing in common is ranks using. According to Mitchell (1999), "ranks put features in order, from high to low" and they are useful if "the quantity represents a combination of factors." For example, different feature attribute can be a basis for assigning ranks. In my work, I use this method in designing a predictive model for invasive glossy buckthorn.

1.4 Important features for preparing a predictive model

The primary literature focused on designing predictive models of invasive species discusses using different features. I selected those which are connected to glossy buckthorn and climate conditions on MDI: soils (Johnson et al., 2006; Franklin, 1998), land cover, and slope (Gillham et al., 2004; Peterson et al. 2003; Bushing et al., 1997).

The information included drainage (Franklin, 1998), permeability (Catling and Porebski, 1994; Frappier et al., 2003), depth, plant competition, and pH (Gillham et al., 2004; Johnson, 2006). Since soils have many different characteristic features, I chose those which McKeage recommended as the most important (pers com). Source data layers were in two different formats: a grid raster format and a vector format (Table 1).

2 AIMS

The primary aim of my bachelor’s thesis is to prepare a predictive model for occurrence of glossy buckthorn on MDI – a model that can be used to manage this invasive plant. The final raster map with scale from the lowest to the highest possibility could help botanists working with invasive plants by showing them where they may find glossy buckthorn and consequently manage it.

3 MATHERIAL AND METHODS

3.1 Study site

Mount Desert Island (280 km^2) is the largest island in the north-eastern coast of the USA,. The topography of northern part of the island is mostly mildly descending with many coves and mudflats whereas the southern part is characterized by set of 200 to 500 m high mountains with steeper topography. Precipitation on the area is 140 cm/year, which is more then on the rest of the island (Nielsen and Kahl, 2007). The majority of MDI is occupied by Acadia National Park (ANP). Because of its position within the transition zone of two types of forests: the northern boreal forest and the eastern deciduous forest there is a wide variety of tree species (National Park Service, 2011). Most of the area is covered by white spruce (*Picea glauca*), red spruce (*Picea rubens*), and balsam fir (*Abies balsamea*). Deciduous tree species are represented by paper birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*), big-tooth aspen (*Populus grandidentata*), red maple (*Acer rubrum*), and red oak (*Quercus rubra*) (Bank et al., 2006). In 1947, extensive fire destroyed a large part of the eastern side of MDI. The area has regenerated as a deciduous and mixed deciduous-coniferous forest (Nielsen and Kahl, 2007). Nowadays, there are spacious areas of 50-year-old woodlands (National Park Service, 2011).

Plant species common in woody areas of ANP include lily-of-the-valley (*Maianthemum canadense*), bunchberry (*Cornus canadensis*), goldthread (*Coptis groenlandica*), bluebead lily (*Clintonia borealis*), starflower (*Trientalis borealis),* asters *(Aster sp.)* and goldenrods *(Solidago sp.)* (National Park Service, 2011). The most widespread moss in ANP is sphagnum *(Sphagnum sp.)*. Ferns are represented by rock polypody (*Polypodium virginianum* and *P. appalachianum*), cinnamon fern (*Osmunda cinnamomea*), and interrupted fern (*Osmunda claytoniana*) (National Park Service, 2011).

Around 6 – 10% of the island is classified as wetland. There are different types of wetland: “marine aquatic beds, intertidal shellfish flat, salt marshes, freshwater marshes, forested wetlands, and peatlands” (National Park Service, 2011).

3.2 Data collection

During 2009, Aleta McKeage, a field biologist in Acadia National Park, collected GPS data on glossy buckthorn in the most invaded area, the GMW, Mount Desert Island. I used this data to prepare a predictive model of glossy buckthorn for the whole island. The first step in preparing a model for the entire island was to model a small area which could be extended into a larger area. As a base area, I used the Great Meadow Watershed (Figure 1) where glossy buckthorn was already mapped.

3.3 Software

I prepared the entire project in ArcGIS Desktop (ArcView) v9.3, ArcGIS Spatial Analyst Extension, v9.3 produced by Environmental Systems Research Institute, Redlands, CA.

3.4 Models

For preparing the predictive models, I used layers named in Table 1. The coordinate system I worked with was NAD_1983_UTM_Zone_19N.

Table 1. Information about used layers

Layer	Originator	Publication Date	Geospatial Data Form	Original map scale
Elevation/Digital Elevation Model source	USGS MEGIS	2000	vector digital data	1:24,000
MELCD Land cover	Sanborn	2004	grid raster	1:24,000
Soil Survey	USDA	1998	vector digital data	1:24,000
Watersheds	USGS MGS	1999	vector digital data	1:24,000
Acadia National Park Boundary	DCBPL	2009	vector digital data	1:24,000
Roads	MaineDOT	2009	vector digital data	1:24,000

USGS	U.S. Geological Survey
MEGIS	Maine Office of Geographic Information Systems
USDA	United States Department of Agriculture
MGS	Maine Geological Survey
DCBPL	Department of Conservation Bureau of Parks and Land

3.4.1 The predictive model for Great Meadow Watershed

Soils

In the attribute table of soils (Appendix 1), I merged all the fields of the same classes of soils. Then I recalculated the total area for each soil polygon within the GMW (Figure 1), as units I chose square meters. I subjoined numbers of GPS points for every polygon of the classes of soil (Table 2).

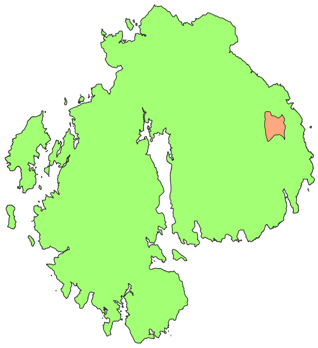

Figure 1. Location of GMW (red color) on MDI

Table 2. Names and abbreviations of soils in Great Meadow Watershed

Name of soils	**Abbreviation**
Charles silt loam	Ch
Colton gravely sandy loam, 0 to 8 percent slopes	CoB
Hermon-Monadnock complex, 8 to 15 percent slopes, very stony	HtC
Hermon-Monadnock complex, 15 to 45 percent slopes, very stony	HtE
Lamoine silt loam, 3 to 8 percent slopes	LaB
Lyman-Schoodic-Rock outsrop complex, very hilly, very stony	LTE
Lyman-Tunbridge compex, 0 to 15 percent slopes, very stony	LuC
Monadnock-Hermon compex, 15 to 45 percent slopes, extremely bouldery	MhE
Monadnock-Hermon-Dixfield complex, rolling, extremely bouldery	MXC
Monadnock-Hermon-Dixfield complex, very hilly, extremely bouldery	MXE
Scantic silt loam	Sa
Schoodic-Rock outcrop complex, 0 to 15 percent slopes	SfC
Schoodic-Rock outcrop complex, 15 to 65 percent slopes	SfE
Schoodic-Rock outcrop-Lyman complex, very steep	SGE
Schoodic-Rock outcrop-Naskeag complex, rolling	SKC
Udorthents-Urban land complex	Ud
Wonsqueak and Bucksport mucks	Ws

Source: The Soil Survey of Hancock County Area, Maine

I calculated the relative representation of area for each class of soil per one glossy buckthorn (relative representation of area = total area/number of glossy buckthorn) and prepared 5 ranks based on the relative representation of area per one buckthorn. Because ranks with 0 would make the ranking system more complicated, I used number 1 instead of 0 and for representation of an area per one glossy buckthorn I used number 2 to 5. ArcMap establishes break points by selecting the class breaks that make the best groups of similar values and maximize the varieties between classes (method recommended by Gordon Longsworth – pers com). I numbered the ranks as follows: number 1 for an area where there was no glossy buckthorn; number two for 17,041 m^2 and greater per one glossy buckthorn (the lowest density); number three for 12,745 – 17,040 m^2 per one glossy buckthorn; number four for 3,857 – 12,744 m^2 per one glossy buckthorn; and number five for 1 – 3,856 m^2 per one glossy buckthorn (the highest density) (Table 3).

Table 3. Soil names, total area, number of glossy buckthorns per each polygon, relative representation of area per one glossy buckthorn, and ranking system

Soils	**Area (m^2)**	**Number of glossy buckthorns**	**Area per one glossy buckthorn**	**Rank**
Ch	43,240.90	1	43,241	2
CoB	36,211.50	0	0	1
HtC	204,475.00	12	17,040	3
HtE	47,838.40	1	47,838	2
LaB	279,070.00	126	2,215	5
LTE	103,614.00	0	0	1
LuC	589.15	0	0	1
MhE	235.00	0	0	1
MXC	35,557.30	0	0	1
MXE	233,225.00	0	0	1
Sa	63,717.60	5	12,744	4
SfC	44,359.20	0	0	1
SfE	108,601.00	0	0	1
SGE	634,626.00	0	0	1
SKC	29,938.00	0	0	1
Ud	1,389.14	0	0	1
Ws	420,353.00	109	3,856	5

Using the *Soil Survey of Hancock County Area, Maine* (1998), I added important information about soils into the attribute table. The information included drainage, permeability, depth, plant competition, and pH.

Drainage is characterized as “runoff, or surface flow of water, from an area” (*Soil Survey of Hancock County Area, Maine, 1998)*. Four different features of drainage were represented there: flooding, ponding, percs slowly, and deep to water. Because drainage for the class of soil Udorthents-Urban land complex is variable, I used the expected value which was “percs slowly.” I added areas of the same features and numbers of glossy buckthorns in those areas and calculated a relative representation of area of each feature of drainage per one glossy buckthorn. In addition, I compared those numbers with intervals for the names of soil. As a result, I ranked for drainage.

Permeability, the second feature, is characterized as "the quality of the soil that enables water to move downward through the profile. [It] is measured as the number of inches per hour that water moves downward through the saturated soil" (*Soil survey of Hancock Country Area, Maine, 1998*). I classified permeability from one to seven: number one – very slow (< 0.06 in/hr.); number two – slow (0.06 – 0.2 in/hr); number three – moderately slow (0.2 – 0.6 in/hr); number four – moderate (0.6 – 2 in/hr); number five – moderately rapid (2 – 6 in/hr); number six – rapid (6 – 20 in/hr); number seven – very rapid (> 20 in/hr). Because there were various permeabilities for each classification of soil and its depth, I used the average value with the highest percent of occurrence in the scale. I ranked permeabilities using the same method as for drainage based on the classification of soils' intervals.

The third feature was the ***depth of soils***. There were three different depths: (1) 0 – 152.4 cm; (2) 0 – 165.1 cm; (3) 0 – 94 cm (values are recalculated from inches to centimeters). Similarly, I ranked soil depth as in the previous case (Table 4).

Table 4. Ranks of features of soils - drainage, permeability, and depth

Soils	**Drainage**	**Rank - drainage**	**Permeability - classes**	**Rank - permeability**	**Depth (cm)**	**Rank - depth**
Ch	flooding	2	moderate	4	0-165.1	4
CoB	deep to water	2	rapid	1	0-165.1	4
HtC	deep to water	2	moderately rapid	2	0-165.1	4
HtE	deep to water	2	moderately rapid	2	0-165.1	4
LaB	percs slowly	5	slow	5	0-165.1	4
LTE	deep to water	2	moderately rapid	2	0-152.4	1
LuC	deep to water	2	moderately rapid	2	0-94	1
MhE	deep to water	2	moderately rapid	2	0-165.1	4
MXC	deep to water	2	moderately rapid	2	0-165.1	4
MXE	deep to water	2	moderately rapid	2	0-165.1	4
Sa	percs slowly	5	slow	5	0-165.1	4
SfC	deep to water	2	moderate	4	0-152.4	1
SfE	deep to water	2	moderate	4	0-152.4	1
SGE	deep to water	2	moderately rapid	2	0-152.4	1
SKC	deep to water	2	rapid	1	0-152.4	1
Ud	percs slowly	5	moderate	4	0-165.1	4
Ws	ponding	5	moderate	4	0-165.1	4

Source of drainage, permeability - classes and depth: Soil Survey of Hancock County Area, Maine (1998)

The fourth feature was the severity of ***plant competition*** for each classification of soil. There were three different plant competition levels: (1) slight, (2) moderate, and (3) severe. In the *Soil Survey of Hancock County Area, Maine (1998)*, there was sometimes more than one plant competition level for a single soil. In that case, I took an average or selected the higher one (e.g. from slight and moderate competition I chose moderate). As with previous features, I ranked soils for plant competition.

The fifth feature was the ***pH*** of the soils. I set data into 10 classes: (1) extremely acid – pH below 4.5; (2) very strongly acid – pH 4.5 – 5; (3) strongly acid – pH 5.1 – 5.5; (4) medium acid – pH 5.6 – 6; (5) slightly acid – pH 6.1 – 6.5; (6) neutral – pH 6.6 – 7.3; (7) mildly alkaline – pH 7.4 – 7.8; (8) moderately alkaline – pH 7.9 – 8.4; (9) strongly alkaline – pH 8.5 – 9; (10) very strongly alkaline – pH 9.1 and higher. Because the soil survey sometimes had data for the pH of soils in a broader range which included more of the classes and also had slightly different classes for different depths of soils, I used class for the average value (Table 5).

Table 5. Ranks of features - plant competition and pH

Soils	**Plant competition**	**Rank - plant competition**	**pH**	**Rank - pH**
Ch	severe	5	strongly acid	4
CoB	slight	1	strongly acid	4
HtC	moderate	2	very strongly acid	2
HtE	moderate	2	very strongly acid	2
LaB	severe	5	medium acid	5
LTE	moderate	2	very strongly acid	2
LuC	moderate	2	strongly acid	4
MhE	moderate	2	very strongly acid	2
MXC	moderate	2	very strongly acid	2
MXE	moderate	2	very strongly acid	2
Sa	severe	5	medium acid	5
SfC	slight	1	very strongly acid	2
SfE	slight	1	very strongly acid	2
SGE	slight	1	very strongly acid	2
SKC	moderate	2	very strongly acid	2
Ud	slight	1	slightly acid	1
Ws	severe	5	strongly acid	4

Source of plant competition and pH: Soil Survey of Hancock County Area, Maine (1998)

Land cover

At first, I converted raster grid format of land cover layer (Appendix 2) into vector format and consequently I followed the same procedure as with the soils. I merged the same land cover types of polygons into one, recalculated the total area (in m^2) for each type of land cover, and subjoined numbers of GPS points for each type. I calculated relative representation of area of each land cover type per one glossy buckthorn (relative area = area/number of glossy buckthorn). Similarly with soils, I prepared 5 ranks based on relative representation of area per one glossy buckthorn. The ranks were number 1 for an area with no glossy buckthorns; number 2 for 8,680 m^2 and more area per one glossy buckthorn (the lowest density); number 3 for 8,021 – 8,679 m^2 per one glossy buckthorn; number 4 for 2,398 – 8,020 m^2 per one glossy buckthorn; and number 5 for 1 – 2,397 m^2 per one glossy buckthorn (highest density).

Some GPS point also appeared on polygons of roads/runways. There is a low (or rather zero) probability that plants would grow on roads. Appearance of points in this polygon could be caused by the inaccuracy of the GPS unit. Because of that, I assigned number 1 to roads/runways polygon (Table 6).

Table 6. Land cover

Type	**Area (m2)**	**Number of glossy buckthorns**	**Area per one glossy buckthorn**	**Rank**
Mixed forest	1,233,232.25	133	9272	2
Regenerating forest	210,921.45	88	2397	5
Roads/runways	168,415.67	21	8020	1
Wetlands	104,148.77	12	8679	3
Deciduous forest	41,143.37	0	0	1
Evergreen forest	12,151.63	0	0	1
Grassland/herbaceous	5,774.63	0	0	1
Heavy partial cut	273,209.83	0	0	1
Light partial cut	42,712.64	0	0	1
Medium intensity developed	29.90	0	0	1
Scrub/shrub	156,628.24	0	0	1
Unconsolidated shore	1,302.59	0	0	1
Wetland forest	35,535.06	0	0	1

Slope

Although elevation can be an important factor in small area such as Great Meadow, on a larger scale (e.g. MDI) it is not relevant. Yet slope is the more important feature, because suitable conditions for glossy buckthorn can include wetlands on higher elevation with smaller value of percent of slope. From the elevation grid of MDI using toolbar 3D Analyst, I generated the percent of slope. According to the ArcGIS Desktop tool: "The 'Slope' tool calculates the maximum rate of change between each cell and its neighbors." If the slope angle equals 45 degrees, it is 100 percent. I searched the area of GMW to find the lowest degree of slope. Then I searched which degree of slope has the biggest occurrence of glossy buckthorn and what values of slope are the highest for its occurrence. I excluded outliers. In this case, I ranked numbers 1 and 5. Number 1 was for area where glossy buckthorn did not appear (100 percent of elevation and more), and number 5 was for area where it appeared (from 0 to 100 percent of elevation). Using the “Reclassify” tool, I wrote numbers 1 and 5 into these intervals.

Final model

Finally, I constructed the predictive model of the occurrence of glossy buckthorn in GMW (Figure 2). The first input to the model was the physical, chemical, and biological characteristics of the soils – drainage, permeability, depth, plant competition, and pH. All of this information was in an attribute table of soils in polygon shape. I used the “Feature to Raster” tool to transform polygons into raster. Using the “Weighted Sum” tool where I added the raster maps of all features of soils, I created a new raster map to predict the probability of finding glossy buckthorn on different types of soils. In the “Weighted Sum” tool, I gave twice as much weight to the features of drainage and permeability which are key aspects of spread and growth of glossy buckthorn. Other features were numbered one (Figure 3).

After changing land cover layer from polygon to raster, I used the raster as an input for another “Weighted sum” tool in the model, along with the final raster maps of all soils and slope. Because I wanted all inputs to have the same weight, I assigned the number 2 to layers of land cover and slope, and the 0.3 to the soils’ layer. The raster of soils already consisted of five different features of soils with total weight of 7 (drainage and permeability had weight 2), so to have same weight for it I divided 2 by 7 which is rounded off 0.3.

When I ran this model, the result was a map with a wide range of interval numbers and a wide range of colors. To make it clearer, I reclassified the final raster map (cell size 10, 10; pixel depth 8 Bit) to get a map of five ranks.

For all of these raster maps, I used a color scheme going from yellow (lowest probability of occurrence) to dark blue (highest probability of occurrence).

Data types for soils and land cover layer are displayed in Appendix 3.

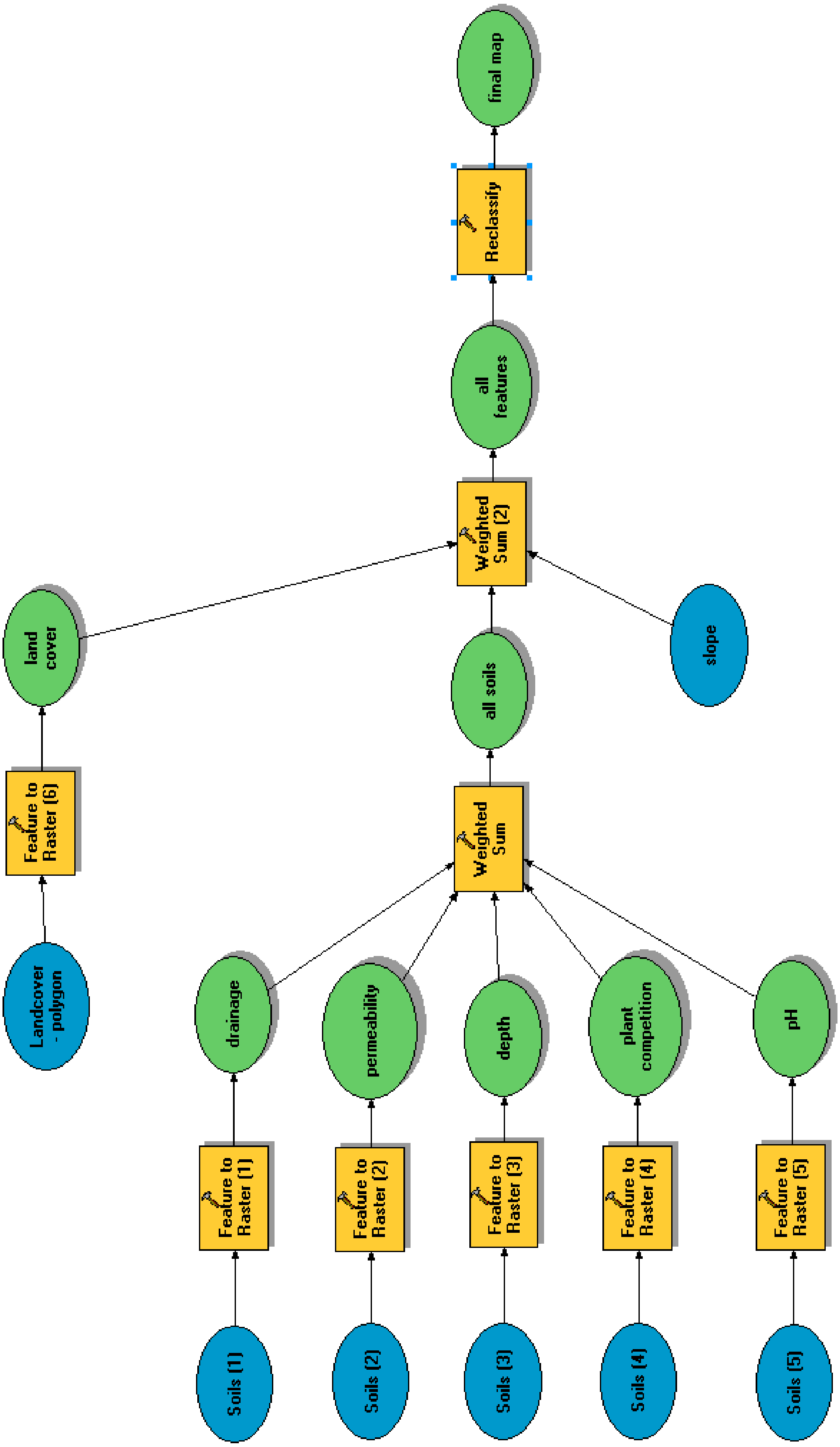

Figure 2. The whole model for Great Meadow Watershed

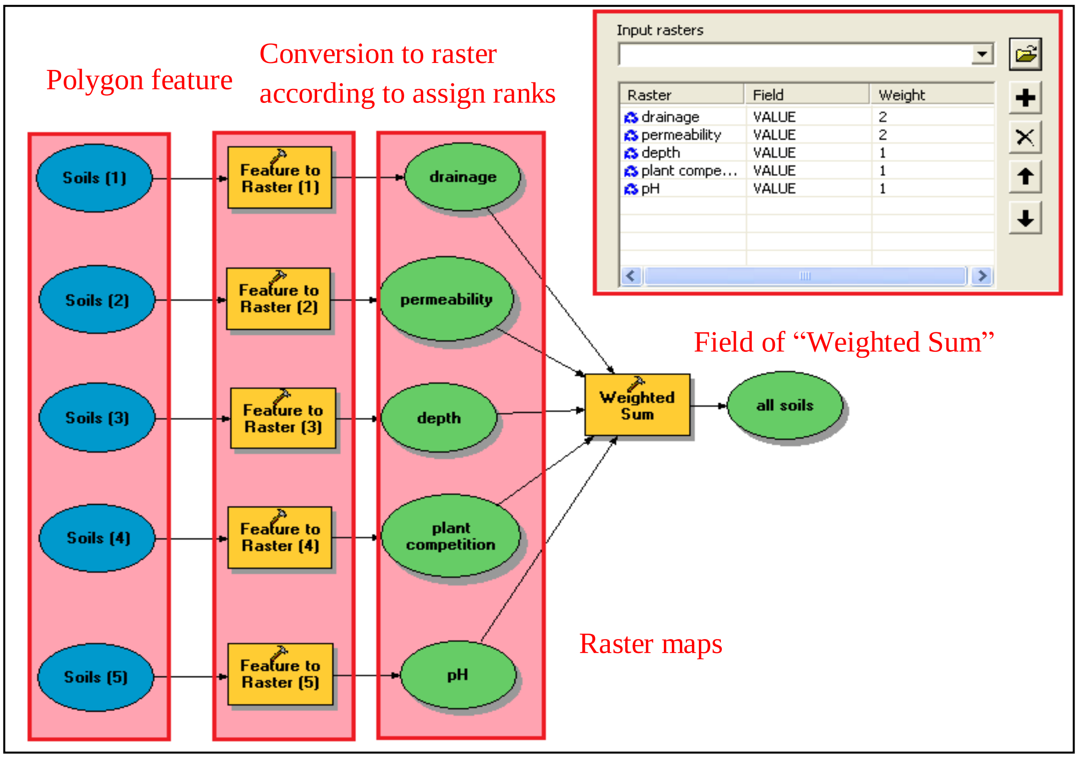

Figure 3. Part of the model with the features of soils

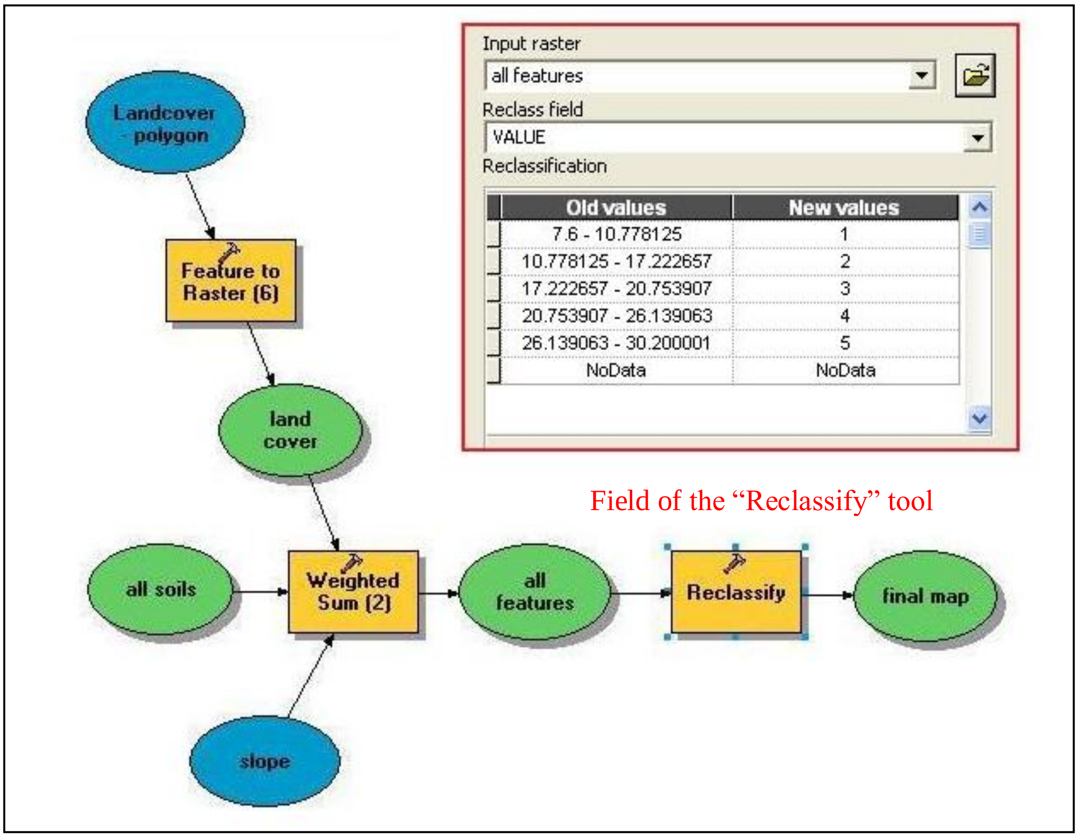

Figure 4. Part of the model with second "Weighted Sum" tool and final Reclassify tool which generates final map with five ranks

3.4.2 The predictive model for Mount Desert Island

While preparing the predictive model for MDI, I used all the known data from Great Meadow. Thus, the model for MDI is essentially an expansion of the GMW model. The basic three layers were soils, land cover, and slope.

In the attribute table for soils, I added new columns for the ranks of the different features of soils: drainage, permeability, depth, plant competition, and pH. I rewrote the numbers of ranks from soils' attribute table for the GMW; for soils that were not represented in the area of GMW, I assigned the number one. I obtained a table with all of the important values. I repeated the same process with the land cover layer (Table 7).

Table 7. Land cover of whole island

Type	Rank
Regenerating forest	5
Wetlands	3
Mixed forest	2
Unconsolidated shore	1
Evergreen forest	1
Medium intensity developed	1
Roads/runways	1
Grassland/herbaceous	1
Low intensity developed	1
Pasture/hay	1
Wetland forest	1
Scrub/shrub	1
Heavy partial cut	1
High intensity developed	1
Open space developed	1
Light partial cut	1
Deciduous forest	1
Bare land	1
Recent clearcut	1

For the layer of slope, I used the tool "Reclassify" to get two different categories. As in the case of the GMW, I assigned number 5 to a percent of slope from 0 to 100 and number 1 to a slope from 100 and above.

In the model (Figure 5), I transformed all the features of soils into raster and then used "Weighted Sum" to combine all soils. As in the model for GMW, I assigned number two to drainage and permeability and number one to the other features. I used another "Weighted Sum" tool to link soils with land cover and slope. Values for features were 2 for land cover and permeability and 0.3 for soils. Subsequently, I used the tool “Reclassify” to derive a final raster map with just five classes.

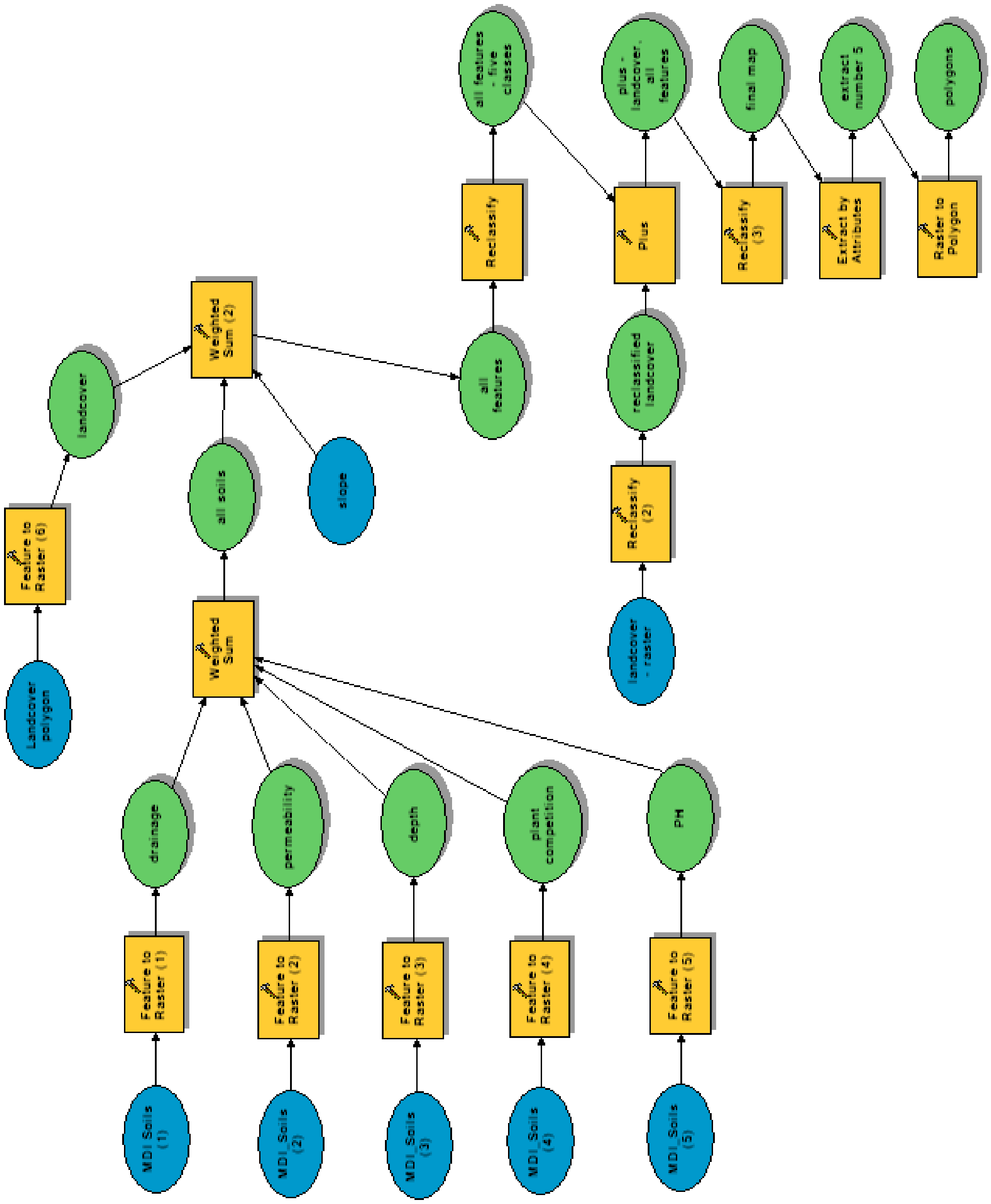

Figure 5. The predictive model of occurrence of glossy buckthorn on Mount Desert Island

The final raster map could have been complete at this point, but spots of dark blue appeared on the roads, parking lots, and other developed areas where there is zero probability that glossy buckthorn would grow. Therefore, I added another “Reclassify” tool into the model and reclassified the land cover raster layer: I assigned number 100 to the developed areas (high, medium and low intensity, open space developed, and roads/runways) and number 50 to the rest of the land cover types (Figure 6).

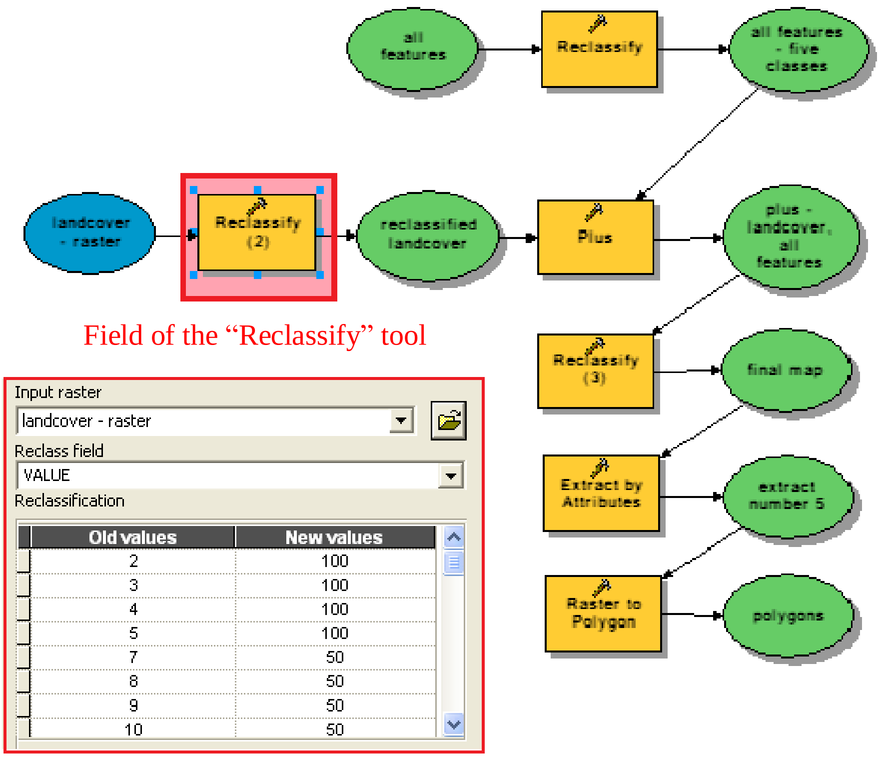

Figure 6. Reclassified land cover raster layer: developed area number 100, other land cover type number 50

By using the “Plus” tool, I compiled the reclassified layer of land cover and final raster map into five classes. The “Plus” tool counted values of both layers ending up with a layer of values 51, 52, 53, 54, 55, 101, 102, 103, 104, and 105. Numbers 51 to 55 were on undeveloped area, numbers 101 to 105 were placed on developed area. I used another “Reclassify” tool and assigned number one to all developed area and number 51, which is the lowest probability of appearance of glossy buckthorn, on undeveloped area. I assigned numbers 2 to 5 to numbers 52 to 55 on undeveloped area (Figure 7).

I generated a final raster map of the probability of the occurrence of glossy buckthorn on MDI with a color scheme from yellow (the lowest probability, number 1) to dark blue (the highest probability, number 5).

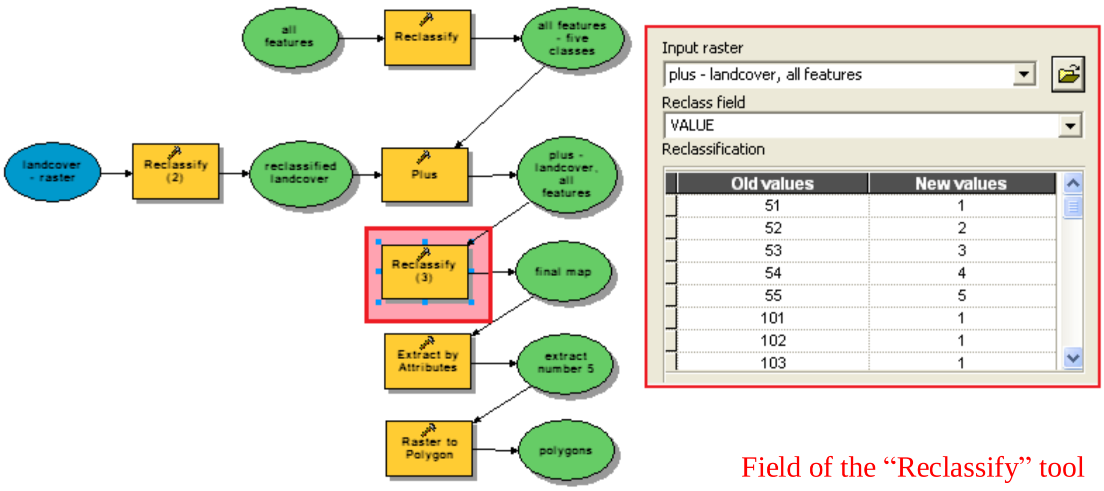

Figure 7. "Reclassify" tool for creation of final map with ranks 1 to 5, including developed area as number 1

Finally, I prepared a map with random points to check the utility of my model in the field. I added another tool to my model – "Extract by Attributes" – in order to extract all fields with number five (the highest probability) and changed them to the polygons (tool "Raster to Polygon"). Then I added an Acadia National Park (ANP) layer and used the "Clip" tool to determine the highest occurrence polygons which created a new layer – polygons within park boundary. Using "HawthsTools," I generated 20 random points on MDI within the ANP polygons (because of the availability of private properties on the rest of the island) of the highest probability of finding of glossy buckthorn.

I put the coordinates of 20 random points into GPS. I created radial plots with a radius of 20 meters around each of these points. Finally, I checked for the presence or absence of glossy buckthorns in these plots.

4 RESULTS

4.1 Great Meadow Watershed

After running every single part of the model, I procured ranked maps of all the features of the soils (Appendix 4), a cumulative map of soils, a map of land cover, and a map of slope (Appendix 5). Two final maps combine all of these properties – one with a wide range of colors and another reclassified map with five classes (Appendix 6). These final maps can be used to manage glossy buckthorn in GMW. However, to manage such a small area, I would recommend using the map with a wider range of colors.

Colors in the scale range from yellow (the lowest probability of occurrence) to dark blue (the highest probability of occurrence).

4.2 Mount Desert Island

In similar fashion, I created ranked maps for MDI – including all features of the soils (Appendix 7), a cumulative map of soils (Appendix 8), a map of land cover (Appendix 9), and a map of slope (Appendix 10). I also created a final map of all features compiled together by the "Weighted Sum" tool with the same significance (Appendix 11). After running the other steps of the model, I developed a final reclassified map with five classes, including developed areas (Figure 8). The color scheme is the same as for GMW – yellow for the lowest probability of occurrence, dark blue for the highest probability of occurrence.

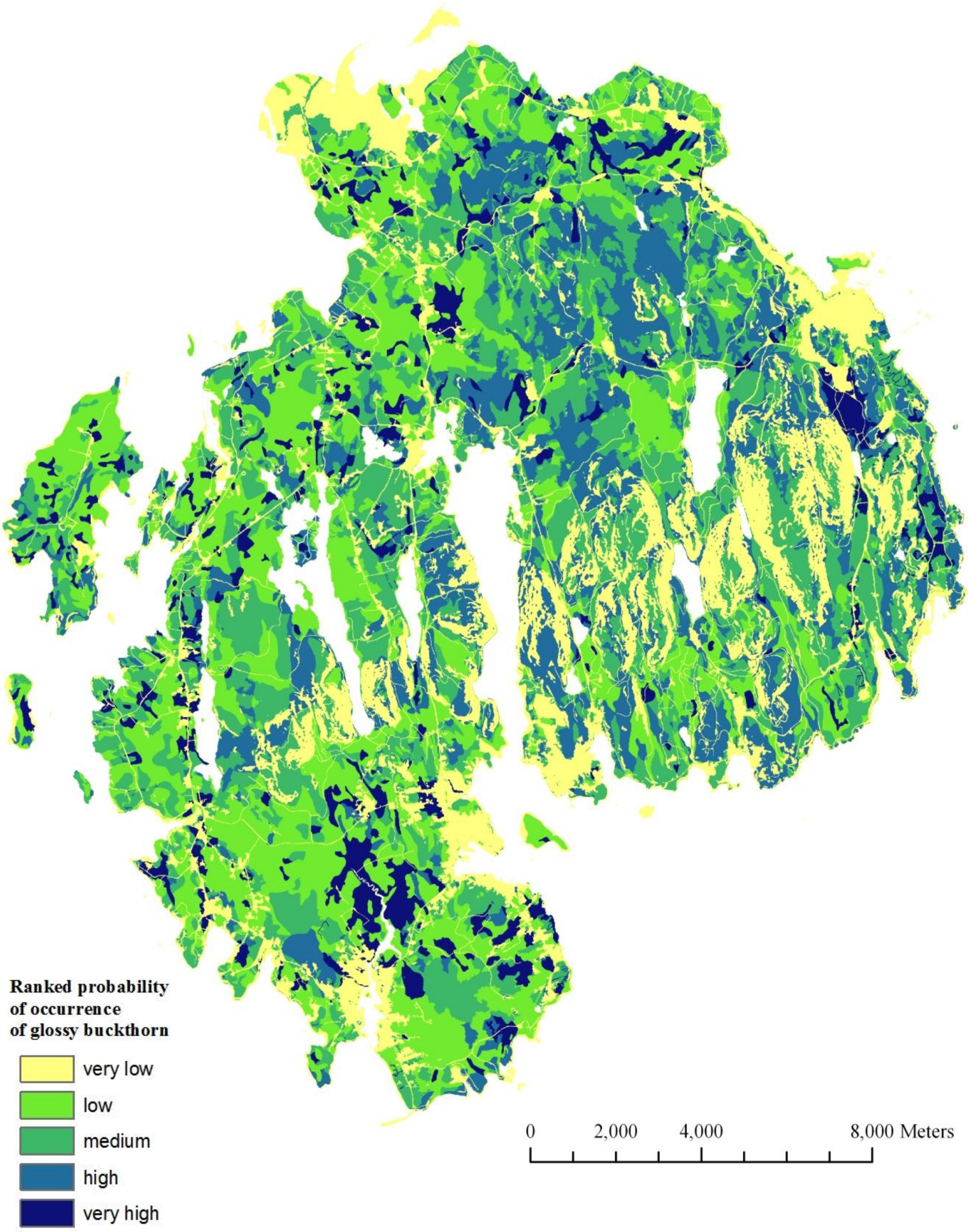

Figure 8. Final map with five classes of the probability of occurrence of glossy buckthorn with developed areas (e.g. roads) ranked as number 1.

4.3 Sampling points

I checked all the randomly generated points and sampling areas around them within a radius of 20 meters which were generated in the polygons of the highest probability of occurrence of glossy buckthorn. In these radial plots, I looked for presence or absence of glossy buckthorn and for presence or absence of suitable habitat for growth of glossy buckthorn. These results show how successful my predictive model was (Figure 9). I prepared a table of results (Table 8) to record the occurrence of glossy buckthorn.

Table 8. Table of occurrence of glossy buckthorn on the sampling points

Number	**Occurrence yes/no**	**Suitable habitat yes/no**	**Soil type**	**Land cover**
1	No	No	Sa	*Evergreen forest*
2	No	Yes	Sa	Mixed forest
3	No	Yes	Ws	*Evergreen forest*
4	No	No	Ws	Mixed forest
5	No	No	Ws	*Evergreen forest*
6	No	No	Ws	*Wetland forest*
7	Yes	Yes	LaB	Mixed forest
8	No	No	SKC	Regenerating forest
9	Yes	Yes	Sa	Regenerating forest
10	Yes	Yes	LaB	Mixed forest
11	No	No	Ws	*Evergreen forest*
12	No	Yes	Ws	*Evergreen forest*
13	No	Yes	Ws	*Evergreen forest*
14	Yes	Yes	Ud	Mixed forest
15	Yes	Yes	LaB	Mixed forest
16	No	Yes	Ws	*Evergreen forest*
17	No	Yes	Ws	*Evergreen forest*
18	No	No	SGE	Regenerating forest
19	No	Yes	Ws	*Evergreen forest*
20	No	Yes	Ws	*Wetland forest*

Land cover types which were ranked 1 are italic

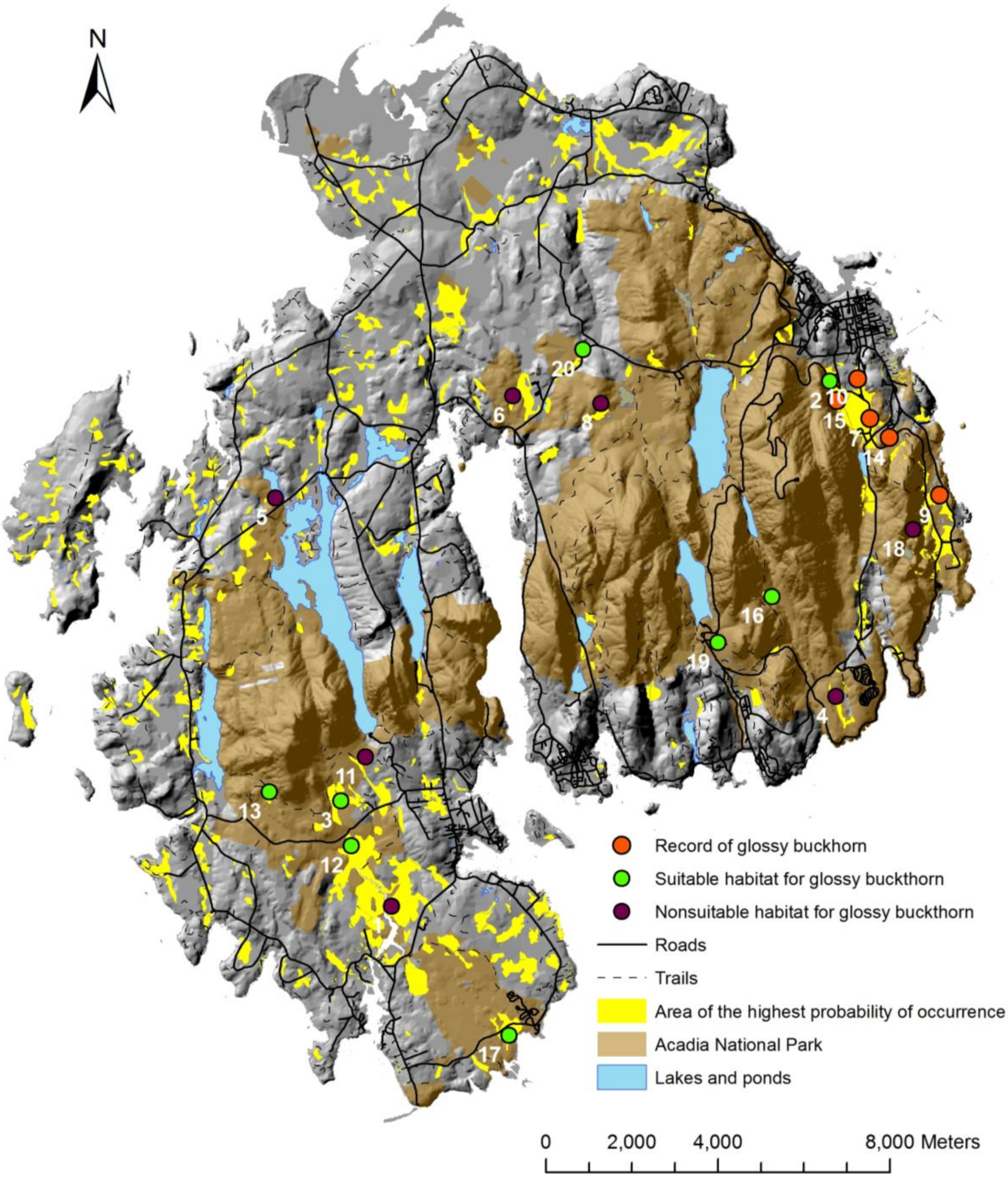

Figure 9. The results of the field check with 20 sampling points

The sampling point number 1 is in a coniferous forest with sphagnum moss and herbacious level. These are not suitable conditions for growth of glossy buckthorn. The sampling point number 2 is a typical habitat of glossy buckthorn – wet soil, small slope, and deciduous forest. However, I did not find any representatives. Point number 3 is in a wet coniferous cedar forest with vegetation of sphagnum moss and alder and small pools and streams; these appeared to be suitable conditions for glossy buckthorn. Point number 4 is in a coniferous forest. Although the sampling point does not indicate suitable conditions, there are places close to it with mixed wet forest and a more developed herbacious level. I did not find any representatives. Point number 5 is in a break in a spruce coniferous forest with maple saplings; this place is not wet enough to support growth of glossy buckthorn. Point number 6 is in a wetland with sphagnum moss within the coniferous forest. The soil is probably too acidic for glossy buckthorn. Point number 7 is situated in a light deciduous forest with wet soil, and glossy buckthorn grows throughout the area. Point number 8 is located in the coniferous forest; however, the area around the polygon is an old beaver dam with wet areas suitable for glossy buckthorn. Point number 9 exemplifies the best conditions for glossy buckthorn with short deciduous forest, wet soil, and a stream. This location is quite far (around 3 km) from the base habitat of infestation, Great Meadow. I found three short representatives there. Point number 10 is an area north of Great Meadow with typical conditions for glossy buckthorn in terms of soil quality and land cover; glossy buckthorn grows throughout the area. Point number 11 is in a high coniferous forest with wet soil and cover of sphagnum moss. Point number 12 is in the forest with streams, wet areas, sphagnum moss, and some alder. Point number 13 is located in a wet coniferous cedar forest with sphagnum moss and pitcher plants. Point number 14 is another typical habitat for glossy buckthorn with many representatives; it is in a deciduous forest with wet soil. Point number 15 is in a young deciduous forest on the margins of Great Meadow, which indicates characteristic habitat and includes many glossy buckthorns. Point number 16 is a wet coniferous forest with some deciduous trees with a cover of sphagnum moss. Point number 17 is an area with typical conditions for glossy buckthorn; it is a wet, mixed forest with sphagnum moss cover and seedlings of many different species. Point number 18 has a typical land cover; however, it is situated in a higher elevation with dry soil. Point number 19 is in a wet cedar forest with many ponds and streams. The cover of alder and sphagnum demonstrates suitable conditions. Point number 20 is in a characteristic wetland area with different species growing in association with glossy buckthorn.

Of the 20 sampling points, I found glossy buckthorn in 5 of them and suitable habitat in 13 of them. This indicates that the success of finding glossy buckthorn was 25 percent and 65 percent for finding a suitable habitat.

The land cover of the 5 sampling points with occurrence of glossy buckthorn was mixed forest in 80 percent and regenerating forest in 20 percent. None of the sampling points that were generated in the area with unsuitable land cover had record for glossy buckthorn. Nevertheless, suitable habitat on these land cover types was found in 70 percent. These land cover types included evergreen forest and wetland forest.

None of the sampling points was generated on area with higher slope than predicted.

The soils within the plots with occurrence of glossy buckthorn were: Lamoine silt loam, 3 to 8 percent slopes; Scantic silt loam; and Udorthents-Urban land complex. Where the drainage is percs slowly, permeability is mostly slow, depth is 0 – 165.1, plant competition is mostly severe, and pH is mostly medium acid (Table 9).

Table 9. Soil features within the plots with occurrence of glossy buckthorn

Soil	**Drainage**	**Permeability**	**Depth**	**Plant competition**	**pH**
LaB	percs slowly	slow	0-165.1	severe	medium acid
Sa	percs slowly	slow	0-165.1	severe	medium acid
Ud	percs slowly	moderate	0-165.1	slight	slightly acid

5 DISCUSSION

I designed a predictive model for the occurrence of glossy buckthorn on MDI, based on the GPS data from GMW, which can help ANP biologists to manage the invasions of glossy buckthorn on the island. This model includes different features such as soils, land cover and slope, with various impact on the spread of invasive species. The model was accurate in finding glossy buckthorn in 25 % of the sampling points according to field checks. When selected for suitable habitat, the model was accurate in 65 %.

This model is developed according to the data for GMW, a watershed in the eastern part of MDI. Data (GPS points) collected within an area of invasive species' distribution for which the model is developed, may more accurately represent its potential distribution. These GPS points can provide more information than points developed from the native range (Mau-Crimmins et al., 2006). Jarnevich and Reynolds (2011) also described the importance of selection of points in the actual habitat of dispersion and further extension to the entire modeled location.

As an input data for designing the predictive model, I used presence-only data from the ANP biologists for GMW, which is the only managed area in the park. Many studies use presence-only data (Raimundo et al., 2007; Mau-Crimmins et al., 2006) for predictive modeling because obtaining species absence is often very time and resource-demanding. Since plants do not occupy every possible site they could, presence data have higher significance (Franklin, 1998). However, in their study Václavík and Meentemeyer (2009) stressed the importance of having presence/absence data, because according to them presence-only models might be over-predictive if invasive species are in a later phase of invasion.

The choice of layers included in the model was well-founded, especially the soil features. After generating 20 sampling points in the polygons with the highest probability of occurrence (according to model), I found glossy buckthorn present in 5 plots with 3 different soils: Lamoine silt loam, 3 to 8 percent slopes; Scantic silt loam; and Udorthents-Urban land complex. Lamoine silt loam and Scantic silt loam are poorly drained soils with high percentage of clay (Soil Survey of Hancock County Area, Maine, 1998). Johnson et al. (2006) suggest that finer-textured soils (high percentage of clay) are more favorable for invasion than sandy soils with coase texture. The higher invasibility of these soils may be caused by higher water-holding capacity.

In my research I found glossy buckthorn in mixed forests and regenerating forests, which is in concordance with its natural occurrence in acidic deciduous bush communities, willow marsh shrublands, blackthorn and buckthorn shrubs, alder marsh woodlands, summer-green deciduous forests, birch-oak forests, snow-heather pine-forests, and bog bilberry pine-forests (Klotz et al., 2002).

Gillham et al. (2004) included for creating GIS models of invasive species the layer of distance from disturbances. Burnham and Lee (2009) and Johnson et al. (2006) point out that distribution of glossy buckthorn is higher in disturbed areas (gaps) than in undisturbed forests. Majority of MDI is occupied by Acadia National Park where the only main disturbance in this area was a great fire outbreak in 1947. It caused changes in land cover and replacement of deciduous species by conifers (National Park Service, 2011). A layer with fire disturbance can be added into the model, for further research.

While disturbance layer can help to improve the model, other layers named by Bushing et al. (1997), Gillham et al. (2004), and Jarnevich and Reynolds (2011) – annual precipitation, elevation, solar insolation and aspect – would not make any difference, because of the relatively small area of the island. Similarly, distance from water (Gillham et al., 2004) and flow direction (Peterson et al., 2003; Mau-Crimmins, 2006;) are not essential conditions for growth of glossy buckthorn. Although, it prefers wetland habitats and location close to water (Possessky et al., 2000; Catling and Porebski, 1994; Frappier et al., 2003).

According to the ANP botanists, the only area which is intensively infested by glossy buckthorn is Great Meadow, where the infestations have been recorded for years. On the other hand, there were no records for other areas on the island. This may also explain why I did not find glossy buckthorn in places further away from Great Meadow. It cannot be distinguished which areas can potentially be invaded but have not been yet, and which are the true absence areas, where my model might fail. There might be other variables reducing the distribution, such as competition for resources, geographic barriers to dispersal (Jarnevich and Reynolds, 2011), or dispersal constrains (Václavík and Meentemeyer, 2009) which were not included in the model.

There may appear some inaccuracies in model caused by the imprecision of GIS layers and noncomplex input data (the occurrence of glossy buckthorn in GMW) collected by the ANP botanists. The land cover layer is basic and does not include the possibility of succession. Also, the boundaries between soil layers in reality are not that distinct. I have taken preliminary data from 20 random sampling points within the predicted high probability polygons. However, more sampling points are needed for proper evaluation of the model (Peterson et al., 2003; Mau-Crimmins et al., 2006, Václavík and Meentemeyer, 2009).

6 CONCLUSION

My predictive model is only a first step for designing complex solution in prediction of the occurrence of invasive species on MDI. More sampling points are needed to calibrate the model for elaborate prediction of glossy buckthorn on MDI. These sampling points should occur in areas of the highest probability of occurrence as well as in areas where the probability is low. Consequently, based on the presence/absence data, more effective predictive model for invasive species can be developed. The advantage of my model is in its size of extended area. Predictive models for occurrence of invasive species are often extended to the areas of entire states or countries (Peterson et al., 2003; Václavík and Meentemeyer, 2009; Jarnevich and Reynolds, 2011) which lowers their precision.

This model, based on simple ranking system, can be further used by botanists in managing areas invaded by shrubs with similar ecological needs. It is a basic tool which is aimed to preliminarily predict the occurrence of an invasive species in a minimal area. The results already showed entirely new areas, invaded by the glossy buckthorn, about which the ANP botanists did not know. Therefore, this model can help the ANP botanists with further management of glossy buckthorn on MDI in particular.

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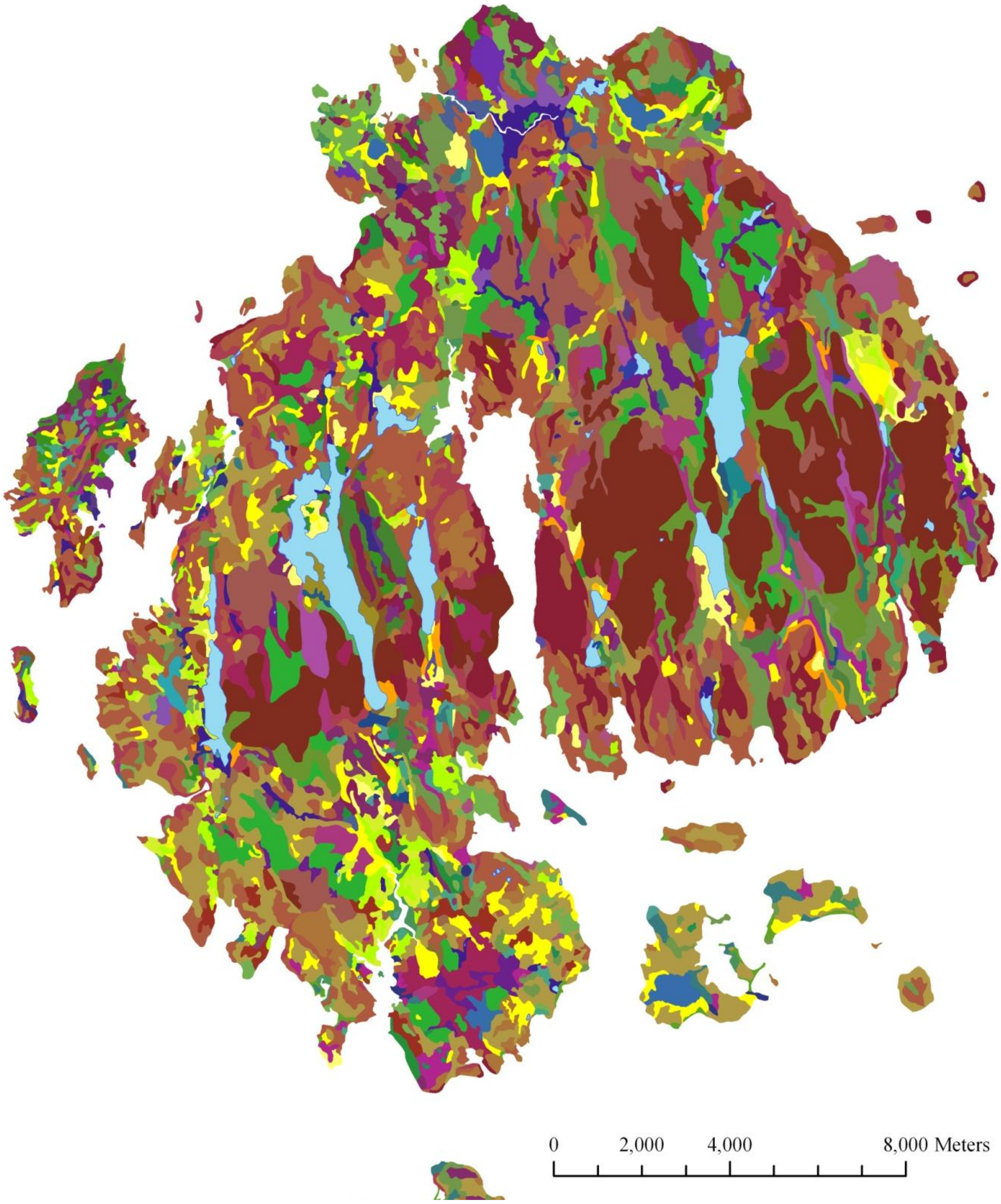
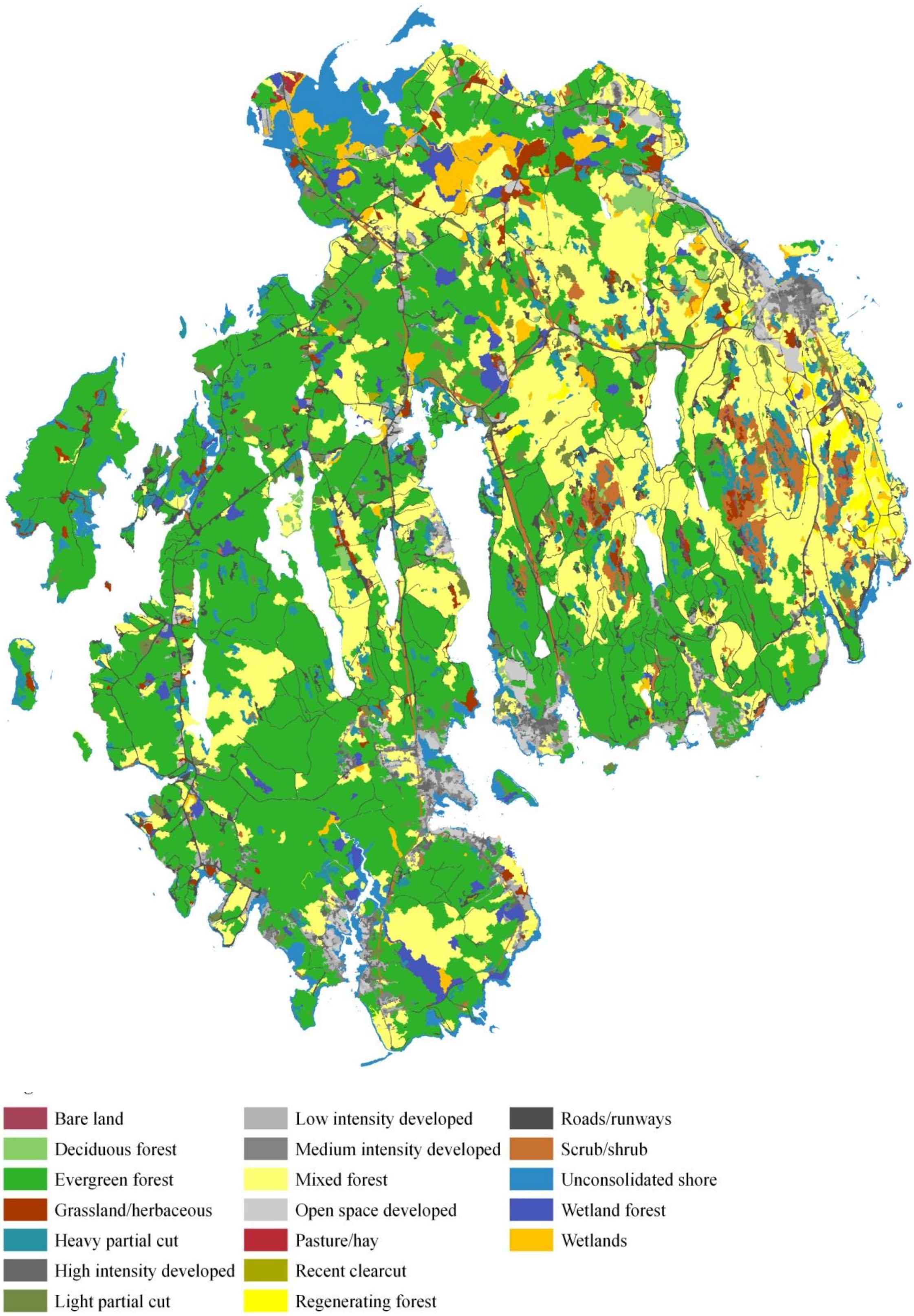
8 APPENDICES



Appendix 1. Soil classes


Adams loamy sand, 0 to 8 percent slopes
Adams loamy sand, 8 to 15 percent slopes
Biddeford muck
Brayton fine sandy loam, 0 to 8 percent slopes, rubbly
Brayton fine sandy loam, 0 to 8 percent slopes, very stony
Brayton-Colonel association, gently sloping, rubbly
Buxton silt loam, 15 to 30 percent slopes
Buxton silt loam, 8 to 15 percent slopes
Charles silt loam
Colton gravelly sandy loam 15 to 45 percent slopes
Colton gravelly sandy loam, 0 to 8 percent slopes
Colton gravelly sandy loam, 8 to 15 percent slopes
Dixfield fine sandy loam, 3 to 8 percent slopes
Dixfield fine sandy loam, 8 to 15 percent slopes
Dixfield fine sandy loam, 8 to 15 percent slopes, very stony
Dixfield-Colonel complex 3 to 8 percent slopes, very stony
Dixfield-Colonel complex, 3 to 8 percent slopes
Dixfield-Colonel-Tunbridge complex, gently sloping, very stony
Gouldsboro silt loam
Gouldsboro-Beaches complex
Hermon-Colton-Rock outcrop complex, 3 to 15 percent slopes, very stony
Hermon-Monadnock complex, 15 to 45 percent slopes, very stony
Hermon-Monadnock complex, 3 to 8 percent slopes
Hermon-Monadnock complex, 3 to 8 percent slopes, very stony
Hermon-Monadnock complex, 8 to 15 percent slopes
Hermon-Monadnock complex, 8 to 15 percent slopes, very stony
Hermon-Monadnock-Dixfield complex, strongly sloping, very stony
Kinsman loamy sand
Lamoine silt loam, 3 to 8 percent slopes
Lamoine-Scantic complex, 0 to 8 percent slopes
Lamoine-Scantic-Buxton association, gently sloping
Lyman-Brayton complex, 0 to 15 percent slopes, very stony
Lyman-Brayton-Schoodic complex, rolling, very stony
Lyman-Schoodic complex, 15 to 45 percent slopes, very stony
Lyman-Schoodic-Rock outcrop complex, very hilly, very stony
Lyman-Tunbridge complex, 0 to 15 percent slopes, very stony
Lyman-Tunbridge-Schoodic complex, rolling, very stony
Marlow fine sandy loam, 15 to 25 percent slopes
Marlow fine sandy loam, 15 to 45 percent slopes, very stony
Marlow fine sandy loam, 8 to 15 percent slopes
Marlow fine sandy loam, 8 to 15 percent slopes, very stony
Marlow-Dixfield association, steep, very stony
Marlow-Dixfield association, strongly sloping, very stony
Monadnock-Hermon complex, 15 to 45 percent slopes, extremely bouldery
Monadnock-Hermon complex, 3 to 15 percent slopes, extremely bouldery
Monadnock-Hermon-Dixfield complex, rolling, extremely bouldery
Monadnock-Hermon-Dixfield complex, very hilly, extremely bouldery
Naskeag-Schoodic complex, 0 to 8 percent slopes, very stony
Naskeag-Schoodic-Lyman complex, undulating, very stony
Nicholville very fine sandy loam, 3 to 8 percent slopes
Nicholville very fine sandy loam, 8 to 15 percent slopes
Pits, gravel and sand
Scantic silt loam
Scantic-Biddeford association
Scantic-Lamoine complex, 0 to 8 percent slopes, very stony
Scantic-Lamoine-Dixfield complex, gently sloping, very stony
Schoodic-Rock outcrop complex, 0 to 15 percent slopes
Schoodic-Rock outcrop complex, 15 to 65 percent slopes
Schoodic-Rock outcrop-Lyman complex, very steep
Schoodic-Rock outcrop-Naskeag complex, rolling
Sheepscot sandy loam, 0 to 8 percent slopes
Sheepscot sandy loam, 3 to 8 percent slopes, very stony
Sheepscot sandy loam, 8 to 15 percent slopes, very stony
Sheepscot-Rock outcrop complex, 0 to 8 percent slopes
Tunbridge-Lyman complex, 3 to 8 percent slopes
Tunbridge-Lyman complex, 8 to 15 percent slopes
Udorthents-Urban land complex
Waskish and Sebago soils
Water
Wonsqueak and Bucksport mucks
Wonsqueak muck, flooded
Wonsqueak, Bucksport and Sebago soils



Appendix 2. Land cover

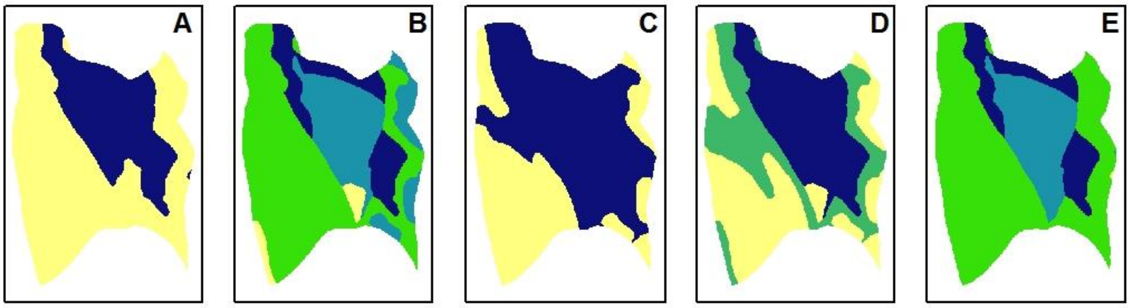
A

Field Name	Data Type
Shape	Geometry
AREA	Float
PERIMETER	Float
HCSOILS20K	Long Integer
HCSOILS2_1	Long Integer
ME611A_UTM	Long Integer
MUSYM	Text
rank_name	Short Integer
rank_perm	Short Integer
rank_plant	Short Integer
rank_depth	Short Integer
rank_drain	Short Integer
rank_pH	Short Integer

B

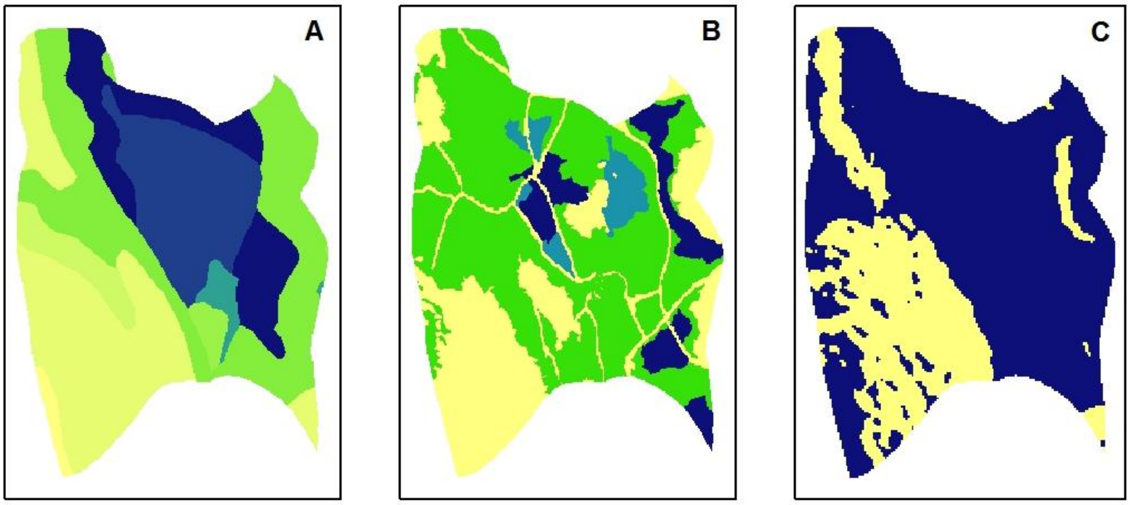
Field Name	Data Type
FID	Object ID
Shape	Geometry
ID	Double
GRIDCODE	Double
value	Double
type	Text
rank	Short Integer

Appendix 3. Data types for soils (A) and land cover layer (B)



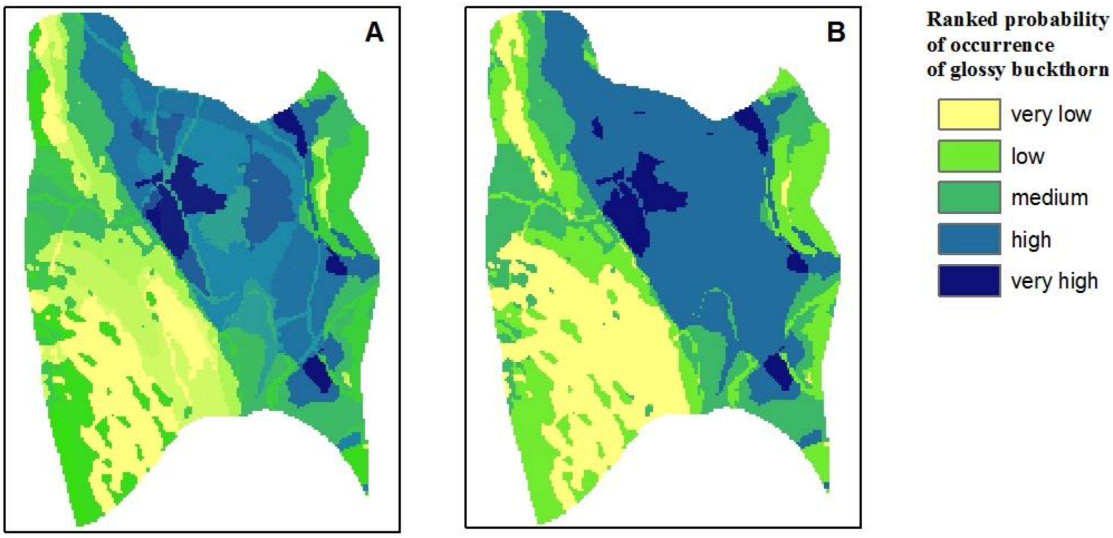
Appendix 4. Features of the soils: (A) drainage, (B) permeability, (C) depth, (D) plant competition, (E) pH

0 500 1,000 2,000 Meters



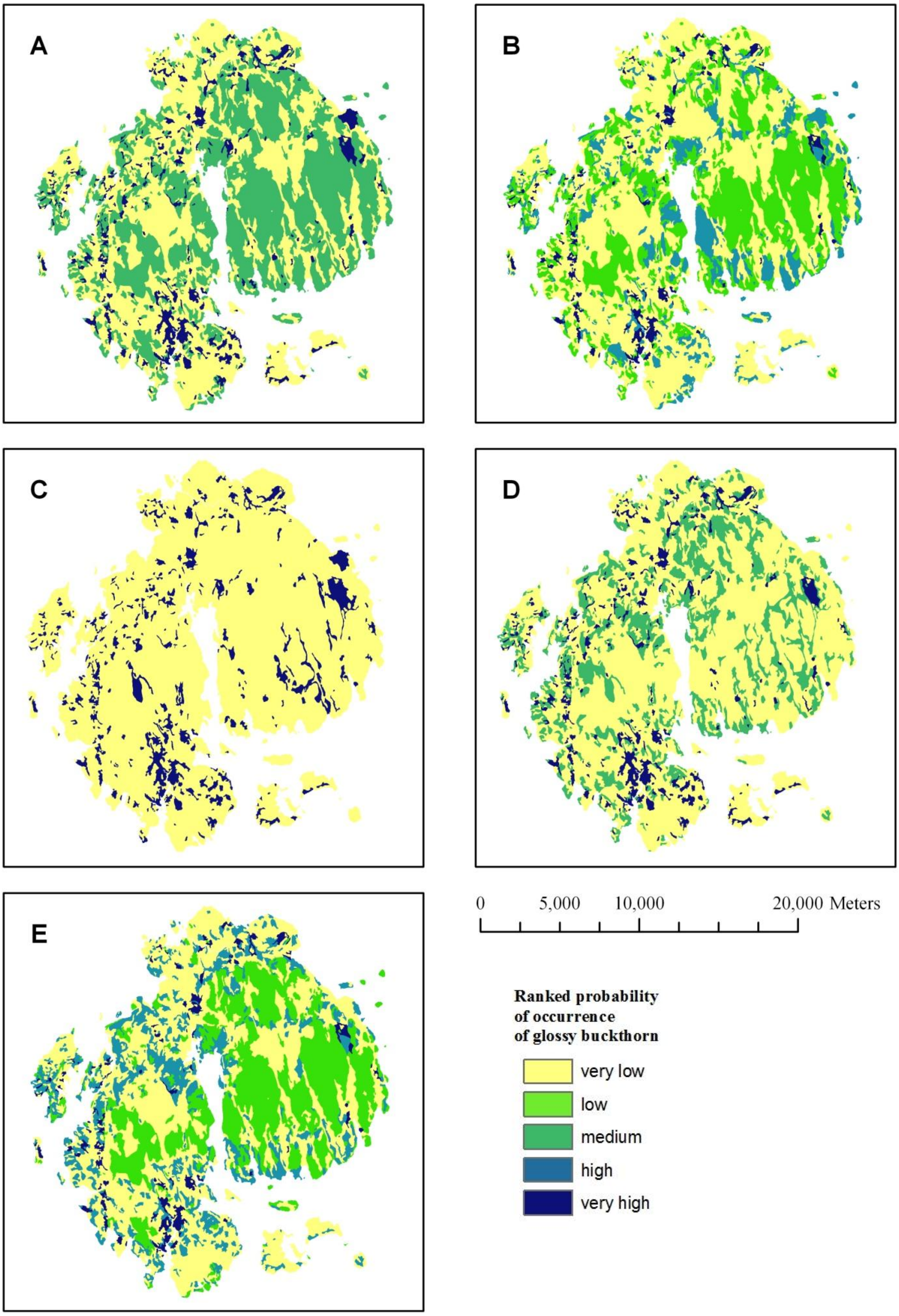
Appendix 5. Input layers for entire model: (A) cumulative map of soils, (B) land cover, (C) slope

0 250 500 1,000 Meters

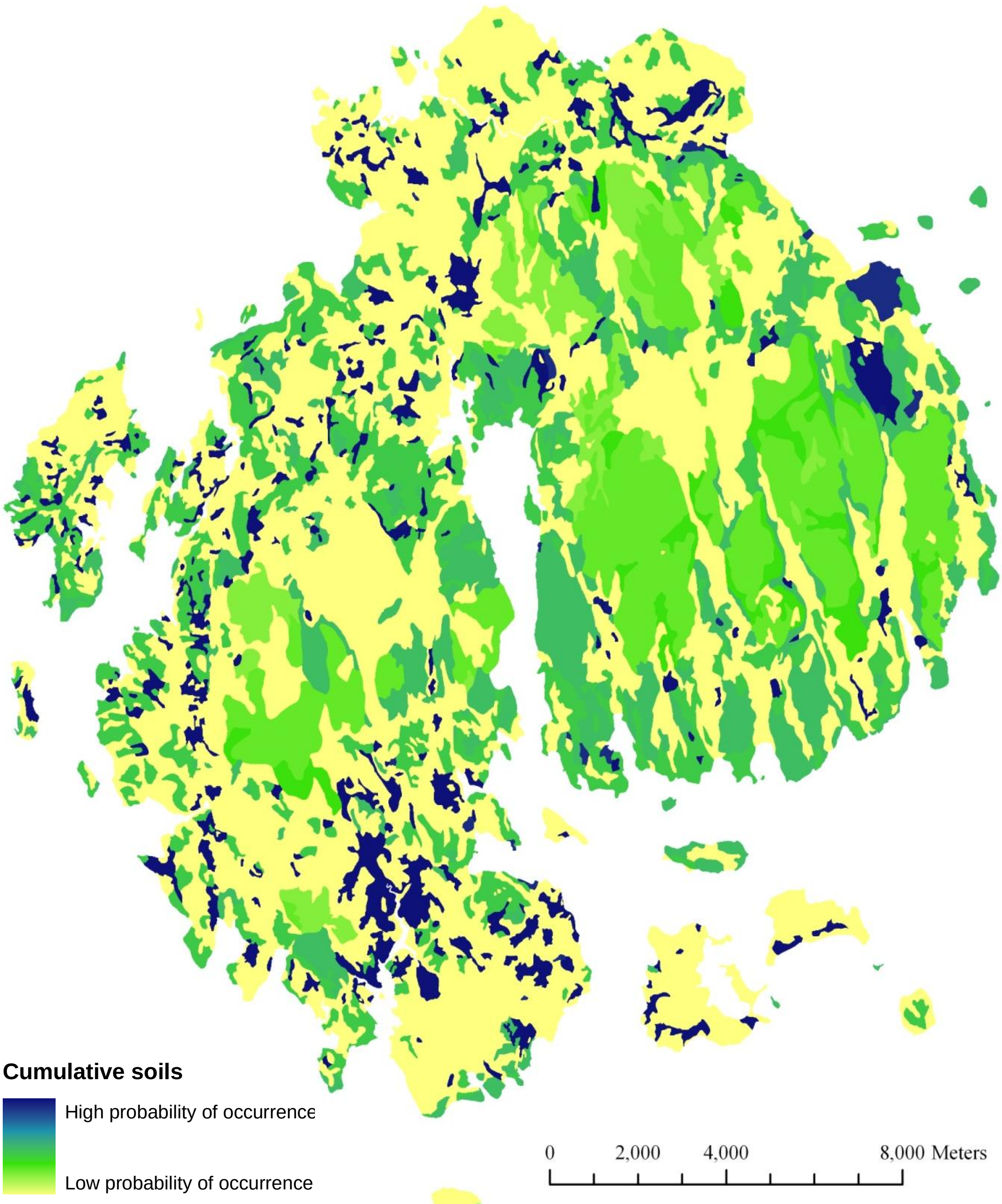


Appendix 6. Final maps: (A) final map with wide range of colors, (B) reclassified map with 5 classes

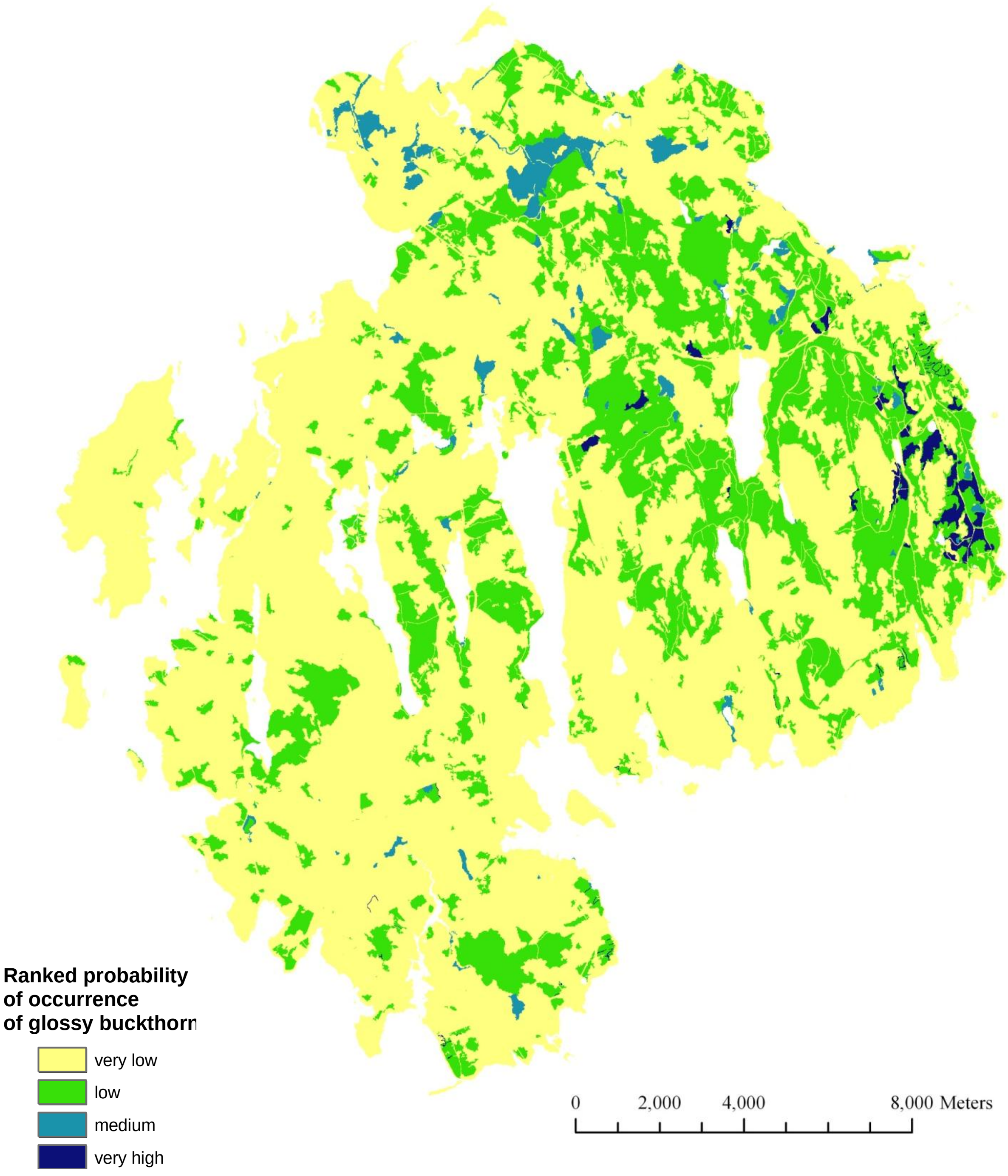
0 250 500 1,000 Meters



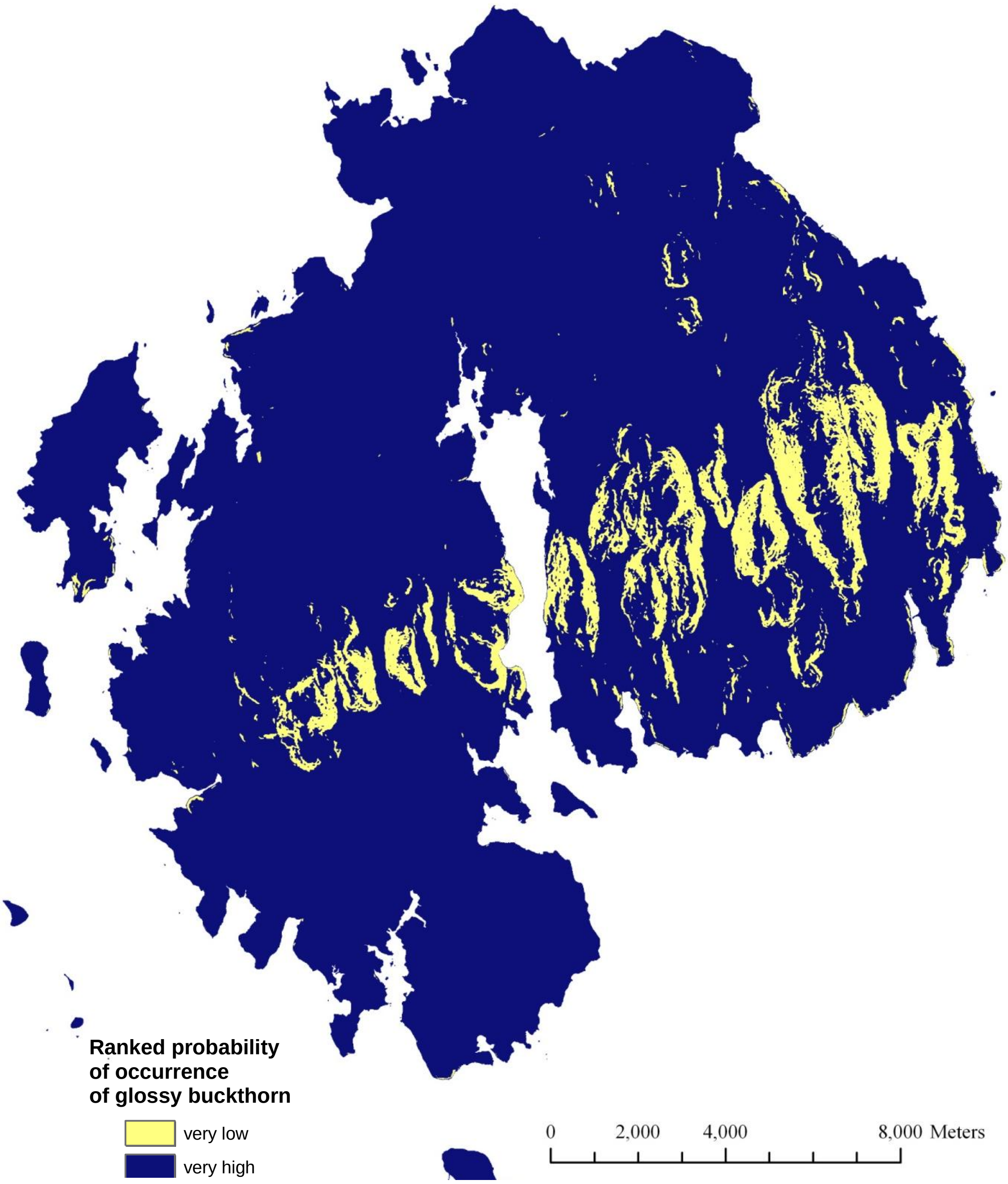
Appendix 7. Ranked features of the soils: (A) drainage, (B) permeability, (C) depth, (D) plant competition, (E) pH



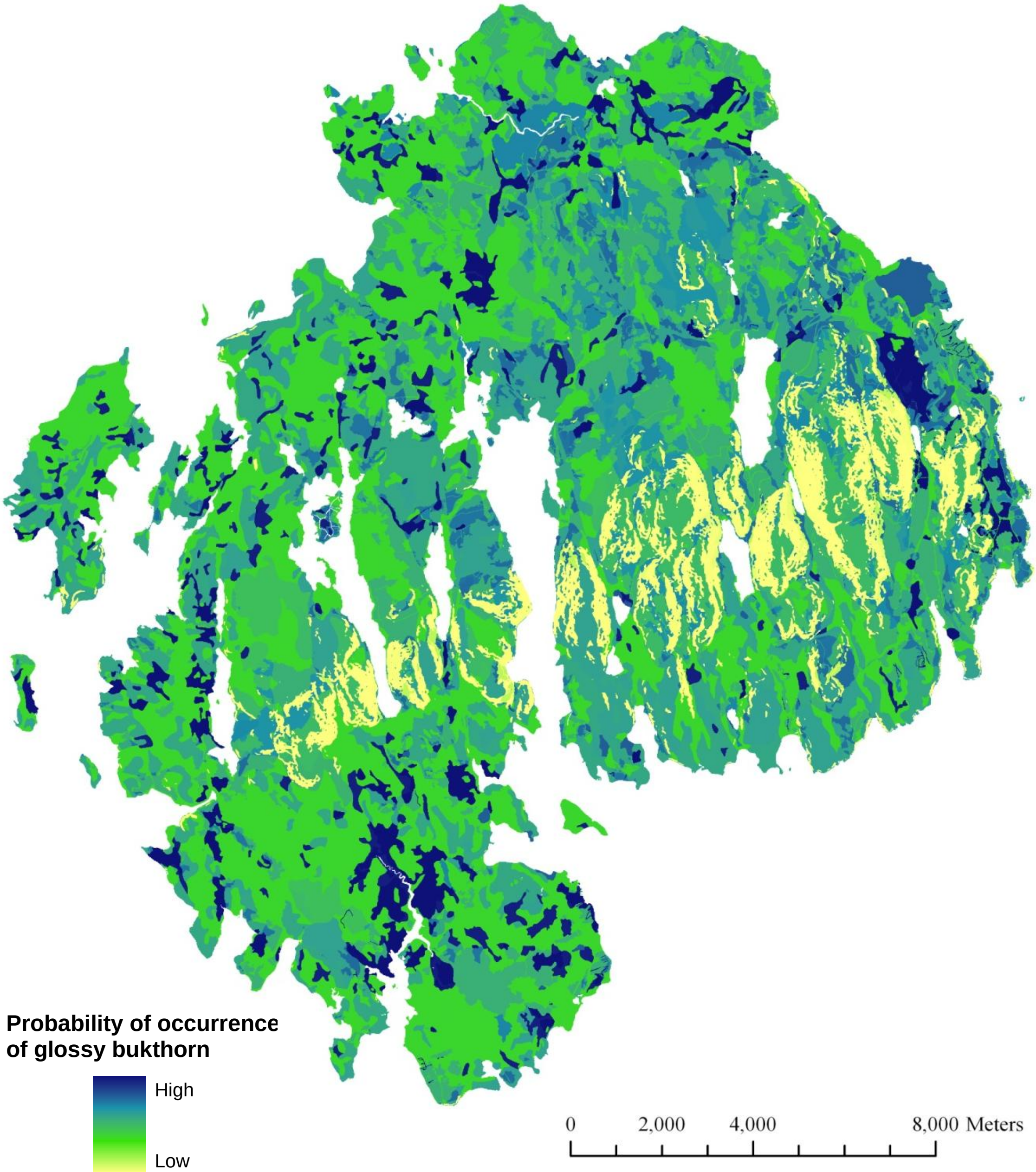
Appendix 8. Cumulative map of soils



Appendix 9. Ranked map of land cover



Appendix 10. Ranked map of slope



Appendix 11. Final map of all features weighted together with wide range of colors