Factors Contributing to Ecological Value of Wetlands in Rhode Island:

With a Protocol for Identifying Wetlands of High Ecological Value

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SUMMARY

This report develops a protocol for evaluating freshwater wetland habitats for their exemplary value, termed "highest ecological value" (WHEV), for the protection of wildlife, native plants, and biological diversity. In conducting our literature searches, we concluded that there are few readily applicable strategies for assessing wetlands strictly for the ecological functions they provide, and in particular for those that are of the highest value to wildlife. The proposed list of factors and the protocol for identifying WHEV in Rhode Island were developed through a) review of concepts and models in the literature; b) review of prior ecological research and ecological assessment protocols in Rhode Island; and c) consultation with a technical committee of scientists and wetland managers. This report highlights significant ecological values that wetlands in Rhode Island hold, and the need for the conservation of the biodiversity potential within the state's wetland systems.

BACKGROUND and APPROACH

In 2017, the Rhode Island Natural History Survey with funding received through RIDEM was tasked with developing a protocol to identify wetlands of high ecological value—hereafter "WHEV". As the Rhode Island Department of Environmental Management (RIDEM) regulates land use under the State's Freshwater Wetlands Act (R.I.G.L., Section 2-1-18 et seq.) Rhode Island recognizes that all wetlands are of "**ecological value"** for supporting the state's flora and fauna (RI 2014). The statutory phraseology "ecological value" refers to a subset of the phenomena frequently referred to in ecology as "functions." Richardson (1994) used the term "**wetland functions**" to encompass any position or role held by wetlands in the operation of specific biological and ecological systems (e.g. providing the physical conditions for breeding, biological productivity for foraging, connectivity for dispersal). He used the term "**wetland values**" to describe any role played by wetlands that specifically improves the well-being of people (e.g. flood control, recreation). These usages are widely shared by state and federal wetlands managers (e.g. U.S. ACE 1999).

Wetland functions and values, in Richardson's sense, may be broadly organized into five categories based on Rhode Island's Rules and Regulations Governing the Freshwater Wetlands Act (Rule 4.0 Definitions), on evaluations of wetland ecological functions noted by other states, and on review of the scientific literature. The five broad categories are:

a) Wildlife, Wildlife Habitat and Biological Diversity
b) Water Quality Protection and Improvement
c) Groundwater Recharge and Discharge
d) Flood Water Attenuation

e) Microclimate Regulation and Carbon Sequestration

In isolation, each of these categories is a significant and legitimate concern for regulators, planners, managers, and conservationists and as such they are recognized in Rhode Island regulations. The continued provision of these five functions and values by any particular wetland derives from the state of underlying variables in that wetland such as its hydrology, biogeomorphology, habitat structure and connectivity, among others. This is why connections can be made back and forth among the different categories, for instance a) certain wildlife and b) certain groundwater conditions effectuate e) carbon sequestration. Because of its inherent interest and importance recognized in Rhode Island's Freshwater Wetlands Act and because of the connections to all other categories, this report is concerned primarily with **Wildlife, Wildlife Habitat and Biological Diversity** and the wetland functions that pertain to it. This reflects recent recognition that biological diversity is a function of habitat diversity (VT 2017; Montana 2011; Tiner 2013; AETG 2012; Anderson and Ferree 2010), and is key to sustaining wildlife and plants in a natural context.

a) Wildlife and Wildlife Habitat and Biological Diversity
As stated in the RIDEM Rules and Regulations, Administrative Findings (Rule 2.0 Authority, Findings and General Administration), regarding functions performed by freshwater wetlands:

> *"Freshwater wetlands are important areas for the production and maintenance of a diversity of wildlife. Wetlands provide habitat for individual species and communities of animals and plants. Animals include both game and non-game species, which may be either obligate or facultative, and which may be permanent residents, or seasonal or transient in nature. Wetlands serve as travel corridors; nesting, feeding, resting, nursery and brood-rearing sites; drinking water sources, and escape cover; and provide seasonal breeding, migration and over-wintering habitat for wildlife. Wetlands provide critical habitat for some plant and animal species, and provide habitat for rare animal and rare plant species."*

Frequently, a high percentage of a state's rare and endangered plants are wetland dependent (Neiring 1988). Among species listed by the United States government, as Federally Threatened and endangered: 50% of listed animals are wetland-dependent (USFWS 2009). RIDEM defines rarity (Rule 4.0 Definitions), when used in the context of species and freshwater wetland types as:

> *"…those invertebrate and vertebrate animals or plant species or those freshwater wetland types that are listed as threatened, endangered, of special interest or of special concern under the Department's Rhode Island Natural Heritage Program; by the Department's Division of Fish and Wildlife; or under the federal Endangered Species Act."*

Structural complexity of the habitat, expressed by the diversity of wetland classes and the degree of spatial and geomorphic diversity within the wetland system provides multiple niches and opportunities for wildlife to locate areas for feeding and shelter, and locations for nesting, denning, and egg laying. Wetter areas are more likely to maintain species with finer niches and to maintain productivity needed to support higher species densities (Sheil et al. 2016).

Wetland systems with intact hydrologic connections within a watershed function to maintain surface water levels during periods of drought, while those that support long hydroperiods, such as palustrine aquatic beds and semi-permanently flooded wetlands are particularly valuable for obligate wildlife species, and waterfowl (VT 2017). Systems that are shaded by forest canopy maintain cool water temperature during summer months. The forest communities are further recognized as valuable suppliers of woody debris (Tiner 2003). Dead biomass can play a significant role in nutrient flows, community stability, trophic specializations and resulting species diversity (Sheil et al. 2016). In aquatic systems, decomposing leaves and twigs break down into small particles of organic material. Detritus and woody debris, which are often associated with older wetland systems, support a high degree of biodiversity (Gold 2017). The debris creates micro-habitats and serves as the principal food for many small aquatic invertebrates and forage fishes. Lowland alluvial soils, comprising parent materials transported to their location by water, often show high levels of nutrient accumulation and possess intrinsically higher moisture-holding capacity due to their texture and high organic matter content (Sheil et al. 2016). Species diversity is positively correlated with moisture availability at multiple scales.

b) *Water Quality Protection and Improvement*

RIDEM Rules and Regulations, Administrative Findings (Rule 2.0 Authority, Findings and General Administration), describe the function of freshwater wetlands with regards to water quality as:

> *"Water Quality: Freshwater wetlands protect and maintain water quality by retaining and removing nutrients; filtering and removing pollutants; removing sediments; producing oxygen; reducing turbidity; maintaining or modifying stream flow; maintaining temperature and oxygen regimes in both standing and flowing surface waters."*

One of the most important functions of wetlands is their ability to help maintain good water quality in rivers and other waterbodies (Cohen et al. 2016; Richardson 1994). Wetlands do this in several ways: 1) removing and retaining nutrients, 2) processing chemical and organic wastes, and 3) reducing sediment loads to receiving waters. Wetlands are particularly good water filters. Due to their position between upland and deep water, wetlands can both intercept surface-water runoff from land before it reaches open water and help filter nutrients, wastes, and sediment from flooding waters (Tiner 1989).

Freshwater wetlands are required habitat for freshwater and anadromous fish, breeding amphibians, many reptiles, aquatic invertebrates, mammals, birds, and plant species, and the chemical and structural properties of the habitat's soil and water are fundamental to most species (Anderson and Ferree 2010). Vegetative composition and complexity of habitat structure influences the relative efficacy of wetlands to perform water quality functions. The presence of dense persistent vegetation in the adjacent upland habitat also has a positive influence on the long term role of wetlands to improve water quality (Miller and Golet 2001) . The ability of a watercourse to trap and retain sediment is greatly enhanced by meanders, variability in topography, and vegetated banks (Miller and Golet 2001). Opportunities for flowing water to interface with variable features within the watercourse, improves water quality. RIDEM identifies Special Resource Protection Waters that are high quality surface waters which have significant ecological functions for wildlife and critical habitats (RIDEM 2009).

Wetlands with fluctuating water tables, such as seasonally flooded lentic systems, are best able to cycle nitrogen and other nutrients (Tiner 2003). Soil origin and composition play a significant role in the processes of denitrification of groundwater. Outwash and alluvial soils have greater abilities to denitrify groundwater than glacial till soils. They have a greater percentage of organic matter; they meander over time, and bury organic layers (Gold 2017). Wetlands with high amounts of organic matter have the potential for an abundance of microflora, which are the driving force behind chemical transformation, and which perform the function of nutrient cycling (Gold 2017). Riparian forests dominated by wetland have a greater proportion of groundwater (with nitrate) moving within the biologically active zone of the soil, which allows for greater potential uptake by plants and microbes (Nelson et al. 1995).

c) Groundwater Recharge and Discharge
Groundwater recharge and discharge are important processes that contribute to a variety of wetland functions and values. RIDEM Rules and Regulations, Administrative Findings (Rule 2.0 Authority, Findings and General Administration), describe the function of freshwater wetlands with regards to groundwater recharge and discharge as:

> *Surface Water and Groundwater: Freshwater wetlands provide and maintain surface and groundwater supplies by acting as recharge or discharge areas, and, in the case of some ponds, acting as surface water reservoirs. Although groundwater recharge and discharge functions and values may vary seasonally, freshwater wetlands, either individually or cumulatively, may be an important factor in replenishing ground and surface water supplies, maintaining stream flows, transporting surface waters, and storing and distributing surface waters and groundwater during periods of drought.*

Hydrology is a core determinant of wetland type, habitat, and processes (McLaughlin and Cohen 2013). Exchanges of water between wetlands, adjacent aquifers, and the atmosphere are among the most important wetland functions (McLaughlin and Cohen 2013). The ability of a wetland to maintain surface water supplies is critical for the stability of habitat for aquatic life (VT 2017). This function is intrinsically tied to landscape position, topography, and geology. Most wetlands are areas of groundwater discharge (Tiner 1989), and where hydrologic connectivity is intact they contribute to the maintenance of water levels in streams and rivers that make up the watersheds of Rhode Island.

The potential of wetlands to function as sources of water for groundwater recharge are influenced by topographic location, seasonality, precipitation, soil type, and degree of seasonal water table fluctuation (Cohen et al. 2016; Tiner 1989). Isolated wetlands surrounded by glacial till uplands play an important role in collecting rainwater and groundwater that has filtered through upland substrate, which contributes later in the growing season to groundwater supplies, as do wetlands with temporary or seasonally flooded water regimes. The ecological value of groundwater as a source of discharge elsewhere in the hydrologic system, contributes to the maintenance of base flow of surface waters (Whiting 1998) and sustainability of aquatic life.

The unique hydrologic conditions and cycles associated with isolated seasonal wetlands, such as vernal pools, coincide with the breeding cycles of numerous frogs, salamanders, and invertebrates, and serve as the only habitat available to breeding amphibians. These organisms require adjacent upland habitat for dormant periods or adult life forms (Karraker 2017). Intact forested habitat contributes to the sustainability of these populations by providing undisturbed habitat and food resources. Forested habitat which has been present on the landscape for a long time has provided suitable upland habitat for multiple generations of amphibians and reptiles. RIDEM recognizes these wetland systems within the Rules and Regulations governing the Freshwater Wetlands Act as:

> *"Special Aquatic Sites: A body of open standing water, either natural or artificial, which does not meet the definition of pond, but which is capable of supporting and providing habitat for aquatic life forms, as documented by the:*
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> > *A. Presence of standing water during most years, as documented on site or by aerial photographs; and*
> > *B. Presence of habitat features necessary to support aquatic life forms of obligate wildlife species, or the presence of or evidence of, or use by aquatic life forms of obligate wildlife species (excluding biting flies)".*

d) Floodwater Attenuation
In public policy, flood water attenuation is one of the most frequently articulated wetland values. Appropriately, RIDEM Rules and Regulations, Administrative Findings (Rule 2.0 Authority, Findings and General Administration), describe the function of freshwater wetlands with regards to flood water attenuation as:

"Flood Protection: Freshwater wetlands protect life and property from flooding and flood flows by storing, retaining, metering out and otherwise controlling flood waters from storm events. Wetlands also control the damaging impacts of flood flows by providing frictional resistance to flood flows, dissipating erosive forces, and helping to anchor the shoreline".

Wetlands play an important role in regulating aquifers through groundwater and surface water exchange. Wetlands have often been referred to as natural sponges that absorb flooding waters, storing flood waters that overflow riverbanks or surface water that collects in isolated depressions (Whiting 1998). Trees and other wetland plants, organic matter, as well as meandering channels and vegetated banks, slow the velocity of storm waters and extend the period of release, as well as recharging groundwater, lowering flood heights and reduce the water's erosive potential. Among the key factors affecting storage are soil porosity, permeability, and the width of the floodplain. Beaver dams greatly enhance the ability of a wetland to store floodwaters, and as a result of this function contribute to the overall productivity and hydrologic stability of the wetland system (Law et al. 2017). Beavers, as a result of damming and retaining a portion of floodwaters and streamflow, create habitat that is open to sunlight, which due to the density of plant material and rate of decomposition generate a high volume of organic matter (Gold 2017). Aquatic life inhabiting downstream wetlands benefit from the gradual flow of nutrients and woody debris generated within the floodwater attenuated by beaver dams (VT 2017; Gold 2017). As do the beaver, a range of other factors also contribute to the maintenance of geomorphic stability of habitat for aquatic life (VT 2017), and allow for greater opportunities of groundwater recharge and subsequent discharge when local water table levels drop (Miller and Golet 2001).*e) Microclimate Regulation and Carbon Sequestration*

While not a recognized function listed under the RIDEM Rules and Regulations, there is a growing appreciation for the function of freshwater wetlands as microclimate regulators, and their role in sequestering carbon (Erwin 2009; Zedler and Kercher 2005). Wetlands affect local and regional temperatures via the effects of evapotranspiration and latent heat exchange. Hydrologic exchanges between wetlands, adjacent aquifers, and the atmosphere are among the most important wetland functions (McLaughlin and Cohen 2013). These functions are important for sustaining wetland dependent species and for moderating long-term climactic conditions, which benefit all life.

Storage of soil carbon contributes to regulating and mitigating the impacts of atmospheric levels of carbon (Nahlik and Fennessy 2016) and holds ecological value for the potential of sustained health of wildlife and plants. Soil carbon serves to transform nutrients and maintain water quality, and contributes to system productivity by supporting biological diversity (Richardson 1994).

The anoxic conditions characteristic of wetland soils slow decomposition and lead to the accumulation of organic matter. As a result, wetlands can accumulate large carbon stores, making them an important sink for atmospheric carbon dioxide and holding up to or, in some cases, even more than 40% soil carbon (Nahlik and Fennessy 2016).

Microclimate regulation and carbon sequestration are gaining recognition recently as important wetland functions (Cohen et al. 2016; Tiner 2013; Erwin 2009; Richardson 1994), and is often included as a productivity function. The function is especially significant in light of predicted climate change impacts to wetlands, and the sustainability of wetland habitats. According to wetland and climate scientists (cite here), wetland ecosystems will be impacted by climate change for several reasons: 1) Flora and fauna in wetlands are especially sensitive to small, permanent changes in water levels. For example, lowering long-term, mean water levels even a few inches in a wetland can make the difference between a forested, shrub, or "fresh meadow" or a wetland and dry ground. 2) Wetlands have often been fragmented and cut off hydrologically from other wetlands and aquatic ecosystems by dams, dikes, fills, roads, drainage, and other landscape level alterations. Due to this fragmentation, wetland plants and animals cannot naturally "migrate" to other locations in response to temperature and water level changes. 3) Many wetlands are already severely stressed due to hydrologic changes, water pollution, changes in sediment regimes, and other anthropogenic activities (Erwin 2009).

Of the five categories of wetland value, one, Wildlife and Wildlife Habitat and Biological Diversity, is the locus of Richardson's concept of Wetland Functions and the primary concern of this inquiry into assessing "ecological value" in a wetland. As noted above, the state of Wildlife and Wildlife Habitat and Biological Diversity in any particular wetland depends on the states and interactions of underlying conditions such as hydrology, biogeomorphology, habitat structure and connectedness. For example, in a particular wetland there is a certain combination of hydrologic regime and geomorphology that supports a population of significant species or a significant ecological process. The presence of any underlying condition or significant species alone is irrelevant, the first because hydrology by itself is not a wetland function and the second because without the right hydrology the species presence is not sustainable. Wetland functions are specifically for the well-being of ecological systems and the organisms they support, community/wildlife habitat, and biodiversity (Richardson 1994). The "ecological value" resides in the relationships among the underlying conditions and therefore, a protocol to assess the function of a wetland needs to focus on indicators (direct or surrogate) for certain states and combinations of underlying conditions.

Evaluation, based on underlying characteristics, often at landscape scale, reflects a shift in focus for wetland practitioners from protection of a single wetland, to a holistic focus on the ecosystem (Enser 2009). Schemes developed elsewhere have identified important underlying wetlands characteristics such as diversity, distinctiveness, vital habitat, naturalness, and representativeness as contributory to ecological value (Jones 2004; Aquatic Ecosystems Task Group 2012). This direction is consistent with that of ecologists who focus on the landscape drivers of biodiversity (Ruddock et al. 2013; Anderson and Ferree 2010). In each geophysical setting, functioning ecosystems that allow for processes and dynamics, including species turnover (Anderson and Ferree 2010) need to be present in order to sustain biodiversity and allow for the adaptive capacity of the system.

Through this review, we identify the following six characteristics as particularly germane to assessment of ecological value in Rhode Island wetlands:

a) Hydro-geomorphic Connectivity
b) Biological and Geomorphic Diversity
c) Size and Size of Contiguous Natural Communities
d) Longevity and Integrity of Natural Habitat Composition
e) Presence of Rare or Uncommon Species
f) Rarity of Natural Community Type

a) Hydro-geomorphic Connectivity

Hydrologic connectivity is a key element of the groundwater function in wetlands, and is inherently tied to landscape position. Intact hydrologic connections ensure the continuity of downstream surface water flows, maintain wildlife corridors, and allow the nutrient benefit of woody debris from headwaters and upstream wetlands to be distributed. Large and complex wetland systems are often dominant features of a landscape, and are defined by the limits of the watershed. Many contribute to riverine systems that connect inland wetlands to estuarine and marine systems. Wetland systems with extensive hydrologic connections have a high potential to provide habitat for a diversity of wildlife and plant species due to the number and diversity of wetland classes likely to be present along the hydrologic corridors. Connectivity is expected to be a critical factor in the future as hydrologic changes are realized as a result of climate change (Gold 2017).

The significance of a wetland's landscape position and condition are extremely important when assessing urban wetlands. Wetlands in urban settings represent remnants of once larger communities. Water quality, structural complexity and degree of shading by adjacent upland habitat affect the ability of the wetland to function as a sustainable site of refugia for wetland plants and resident or migratory animal species. While potentially stressed by their position on the landscape, such wetlands may have high ecological value as the only remaining habitat available for local wildlife and plants.

b) Biological and Geomorphic Diversity

Biological diversity is reflected in wetlands that are capable of supporting the full range of natural diversity potential of a wetland type or region. In Rhode Island, geomorphological heterogeneity has been shown to be linked to biodiversity (Nichols et al. 1998), which suggests that wetland habitat characteristics such as diversity of classes and spatial and geomorphic diversity within the system are valuable criteria for assessing wetlands of high ecological value. Overall structural diversity of habitat and connection to other structurally diverse habitats allows systems to sustain biological diversity. Ecological Land Units, as described by Ruddock (et al. 2013), provide one basis for determining structural diversity at the landscape level. However, in performing an evaluation, it is important to also consider the degree of hydrologic or geomorphic alteration, degree and type of alteration to surrounding habitat, and the presence of exotic species. Anthropogenic disturbance, surrounding land use, presence of biologic pests and pathogens, and the dominance of habitat by invasive species, can all function to minimize the biological diversity potential (Ruddock et al 2013), in spite of the spatial and structural values present.

c) Wetland Size and Size of Contiguous Natural Communities

While it is generally agreed that wetland science lacks a science-based size limit to establish significance for the performance of any wetland function (Tiner 2003), practitioners and ecologists agree that for wildlife habitat and biodiversity functions, continuity of habitat and wetland size correlate with wildlife value (Jones 2004; Tiner 2003). Landscape factors, such as degree of fragmentation and hydrologic connectivity, affect habitat functionality, as do topographic position, and surrounding land uses.

In the case of wildlife habitat and biodiversity functions, it is accepted that as wetland size increases, so does wildlife value. Evaluation of contiguous forest cover in Rhode Island shows that large wetland-upland forest complexes of 250 acres or more contain approximately 59% of the state's freshwater wetland habitat (Kutcher 2017). Landscape conditions, such as the degree of fragmentation, hydrologic connectivity, topographic position, and surrounding land use can influence a wetland's potential value for biological diversity.

d) Longevity and Integrity of Natural Habitat Composition

The longevity and integrity of natural habitats represents an important metric for the ability of a wetland community to support rare and relatively uncommon wetland dependent species, as well as those that form the basis of Rhode Island's floral and faunal populations. The relative age of wetland classes present within a system also has implications for carbon storage functions and for contributing woody debris to downstream portions of the wetland. Dead biomass can play a significant role in nutrient flows, community stability, trophic specializations and resulting species diversity (Gold 2017). Additionally, undisturbed canopies and intact native plant communities have a greater potential to be resistant to colonization by non-native species, and provide the food resources and structural habitat needed by many wildlife species.

e) Presence of Rare or Uncommon Species

It is frequently noted that a high percentage of rare and endangered plants are wetland dependent (Neiring 1988). Wetland habitat presents a unique set of environmental conditions, which are tolerated by a unique set of organisms, and provides the only habitat where they are successful. In Rhode Island, 45% of the state's rare plants are found in wetland habitats, and 28% of the wildlife species considered as Species of Greatest Conservation Need (GCN) (RI 2015) are obligate wetland species. This figure from the RI Wildlife Action Plan (RIWAP) includes 100% of the GCN freshwater fish, amphibians, and non-arthropod invertebrates (freshwater mussels and snails), and 44% of all GCN invertebrate arthropods (beetles, damselflies etc.).

f) Unique Wetland Habitat Type

Habitats with unique and uncommon environmental conditions are often associated with rarity of species. For example, the unique hydrologic conditions and cycles associated with isolated seasonal wetlands, such as vernal pools, coincide with the breeding cycles of numerous frogs, salamanders, and invertebrates, and serve as the only habitat available to breeding amphibians. In addition peatlands, because of the specific ecological parameters that created them, exhibit longevity and high integrity of natural habitat composition. When compared to other wetland types, peatlands are relatively rare on the landscape. Because they are uncommon, and because they are difficult or perhaps impossible to restore, conservation emphasis is often placed on preservation of peatland habitats (Miller and Golet 2001).

NOMENCLATURE, TECHNICAL ADVISORS, AND PRIOR WORK

This work results from discussions with scientists and wetland managers in Rhode Island and elsewhere as well the review of research and other ecological assessment protocols in use here and elsewhere. Through this process, we developed HEV criteria intended to be practical for field application, supportable by reference to scientific literature, and reproducible across sites, users, and time.

Nomenclature of wetland types in this report follows the Rhode Island Ecological Community Classification (RIECC) (Enser et al 2011) which is the basis for ecological community mapping available through the Rhode Island Geographic Information Systems (RIGIS). Some grouping, splitting, simplification or introduction of new classes was required to accommodate terms in use by RIDEM, such as the term Special Aquatic Systems, which is used by RIDEM to describe vernal pools.

Initial discussions regarding the ecological value of wetlands took place with a Technical Advisory Committee (TAC) comprised of the following people: Richard W. Enser, Ecologist and past Rhode Island Department of Environmental Management (RIDEM) Natural Heritage

Program Coordinator; Dr. Arthur J. Gold, University of Rhode Island (URI); Dr. Nancy E. Karraker, (URI); Christopher Mason, Principal, Mason Associates; Dennis Skidds, National Park Service; and Martin Wencek, RIDEM Freshwater Wetlands. Prior to meeting, a literature search was conducted to inform our basis for establishing criteria. Two documents proved useful and were presented to the TAC for discussion: *Correlating Enhanced National Wetlands Inventory Data with Wetland Functions for Watershed Assessments: A Rationale for Northeastern U.S. Wetlands (Tiner 2003),* and *State of Vermont Wetland Rules, Chapter 30, Section 5, amended 2017 (VT 2017)*. The two documents were relevant for our purposes in that they describe freshwater wetland types and classes that hold the greatest potential to perform ecological functions that are of value to wetland dependent wildlife, plants, and biological diversity.

The literature review included work conducted in Rhode Island to assess wetland habitat, wildlife functions and values, and conservation opportunities, as well as research conducted elsewhere, to evaluate habitat factors contributing to ecological functions and biological diversity. Additional sources such as the Rhode Island Natural History Survey's RI Rare Plants List (2016), the RI Breeding Bird Atlas 2.0 (Enser 1992), the 2015 RIDEM State Wildlife Action Plan (RIDEM 2015), the RI Wetlands Priority Plan (App. B in Ocean State Outdoors 2009), and Natural Communities of Rhode Island (Enser and Lundgren 2006) were consulted for data regarding unique natural communities, rare and endangered plants and wildlife, and avian use of forested wetland habitat during the breeding season.

Tiner (2003) identified two basic types of wetlands as having potential to provide significant habitat for wildlife: 1) large wetlands (≥ 20 acres) regardless of wetland vegetative cover, and 2) smaller diverse wetlands (10-20 acres with multiple cover types). Vegetated wetlands that lie within contiguous un-fragmented habitat and clusters of isolated wetlands located within an upland matrix, also represent wetlands that have potential to be highly valuable for wildlife (Enser 2017, Karraker 2017). Tiner (2003) goes further to identify four wetland types that should be considered as valuable for supporting high levels of biological diversity: 1) wetland types that are scarce or relatively uncommon in a watershed, 2) individual wetlands that possess several different cover types (i.e. naturally diverse wetland complexes), 3) complexes of large wetlands, and 4) regionally unique or uncommon wetland types. "Large" wetlands are further described by Tiner as typically larger than 100 acres.

Golet (1972) designated several wetland types as highly performing for wildlife, these included: 1) wetlands with rare, restricted, endemic, or relict flora and/or fauna, 2) wetlands with unusually high visual quality and infrequent occurrence, 3) wetlands with flora and fauna at the limits of their range, 4) wetlands with several seral stages of hydrach succession, and 5) wetlands used by great numbers of migratory waterfowl, shorebirds, marsh birds, and wading birds. Golet (et al. 1994) further concluded that the two most important aspects of a wetland's habitat value were its ability to support a diversity of wildlife species (including rare, threatened, or endangered species) and its capacity to support large populations of these species. The relative ability of a wetland ecological unit to perform this function was considered to be the yardstick for habitat evaluation (Golet et al. 1994).

Enser (2011) states that "*although the entire Rhode Island landscape has been altered by anthropogenic processes to varying degrees, a particular feature of natural communities is a lack of naturalized, nonnative plants. In fact, the best examples of most natural communities contain only native species*". The Rhode Island Natural Heritage Program report *Natural Communities of Rhode Island* (Enser and Lundgren 2006), describes eight unique natural community types. Six of which are freshwater wetland communities (see Table 3 below). The listed natural communities are considered to be unique in Rhode Island and throughout New England, and contain biological features of critical importance to maintaining the state's biodiversity (State of RI 2009).

Table 1 Unique freshwater wetland communities, adapted from Ocean State Outdoors (2009)

Natural Community	**Characteristic Features**	**Landscape Position**
Open peatlands (bogs and fens)	Wetlands with <50% canopy cover	Poorly drained depressions, often isolated in upland landscape
Atlantic white cedar swamps	Evergreen trees or mixed deciduous	Poorly drained depression, occasionally along streams
Coastal Plain Pond shores	Gravelly shores with fluctuating water tables	Morainal kettle holes and depressions
Floodplain forests	Hardwood forests on mineral soil	Low terraces of river floodplains
Sea level fens	Tidal marshes receiving fresh groundwater seepage	Inland side of coastal lagoons adjacent to glacial moraine
Freshwater tidal marshes	Tall marsh communities	Upper reaches of tidal rivers

Ruddock (et al. 2013) concluded that their *"analysis indicated that spatial variation in ELUs is positively correlated to plant species richness and community diversity."* In a similar study, Nichols (et al. 1998) concluded that across a suite of discontinuous landscapes, varying in size and disturbance regime, geomorphological heterogeneity and biodiversity were intrinsically linked. Ruddock (et al. 2013) further states that while protecting high species richness was one conservation goal, that protecting 1) representative species and communities, 2) rare and endangered species, 3) landscape structures such as corridors or buffers, and 4) landscapes that provide unique or important ecosystem services, were equally important.

Several mapping projects in Rhode Island contributed significantly to our developing thoughts on ecological value in wetlands. These enhance the use of the National Wetlands Inventory for evaluating wetland habitat for its ecological functions (Golet et al. 1994) and landscape assessment of biological diversity potential based on physical properties of the landscape (RIRPP 1995), among others. For this report, Dr. Peter V. August of the URI Coastal Institute and Environmental Data Center, was consulted regarding his past work with both Dr. Frank C. Golet, on a “GIS-based Assessment of Freshwater Wetland Wildlife Habitats in the Pawcatuck River Watershed of Rhode Island”, and Kevin Ruddock of The Nature Conservancy, RI Chapter on “Ecological Land Units” (Ruddock et al. 2013) , which informed discussion on the value of structural diversity and connectivity, for sustaining biodiversity.

In addition, RIGIS, through the Resource Protection Project (RIRPP 1995), quantified and mapped “Large and Complex Freshwater Wetlands”. Although RIGIS recognizes that small wetlands have ecological value, their analysis was limited to wetland systems larger than 1 acre in size. The RIGIS metrics provide useful criteria which can be applied to the identification of WHEV. Wetland classes were based on hydrological, geomorphological, chemical, or biological factors. Table 2 below provides the criteria used in the RIGIS calculations to determine "Large and Complex Freshwater Wetlands" based on a collective rank greater than 14.

*Table 2 RIGIS Criteria for Defining Large and Complex Freshwater Wetlands (see clarifications below *, **, ***)*

Criterion		**Ranking**
Size	> 50 acres	6
	> 25 acres and <= 50 acres	4
	> 1 acres and <= 25 acres	2
Class Diversity		
Class Richness	3 classes or more	3
	2 classes	2
	1 class	1
Class Evenness*		
	> 0.7	3
	> 0 and < 0.7	2
	0	1
Surface Water Connection		
	adjacent to both stream and pond	3
	adjacent to either stream and pond	2
	adjacent to neither stream and pond	1
Surrounding Habitat Type		

	surrounded by > 95% natural land	3
	surrounded by > 95% natural land	2
	surrounded by > 95% natural land	1
Proximity to Other Wetlands		
Distance to Nearest Wetland**	≤ 50 meters	2
	> 50 meters	1
Inverse Distance Weighted Sum***	> 500	2
	≤ 500	1

** Class evenness is a statistic that expresses on a scale of 0.0 to 1.00 the equitability of the total areas of those wetland classes that comprise each wetland unit.*
***Distance to nearest wetland is the minimum straight line distance to the nearest wetland that is at least one-half as large as the wetland being evaluated.*
****Inverse distance weighted sum is a statistic that represents the relative amount of wetland within 500 meters of an evaluated wetland, with proportionately greater weight given to those areas that are closer to the evaluated wetland. The raw sum is divided by the total area of the 500 meter zone surrounding the evaluated wetland so that the results for different wetland units can be compared directly.*

Recognition of significantly important habitat types and rare species in Rhode Island represent historic dedication of the state's land managers, biologists, and ecologists, to designate priorities for protection. In 2014, members of the Rhode Island biological community convened to revise the State Wildlife Action Plan, identifying a total of 454 Species of Greatest Conservation Need (SGCN) across all wildlife taxa, and 64 plant species which are globally and regionally (throughout New England) rare, and emblematic of specific habitats. Roughly 27% of the listed wildlife species utilize freshwater wetlands as their primary habitat, and 28% of the plant species are found only in freshwater wetlands. Beyond the inclusion of plants in the State Wildlife Action Plan, the most recent update of *Rhode Island Rare Plants 2016* (Enser 2016) lists 414 plant species that are rare in the state. Of the listed species, 188 (or 45%) are found only in freshwater wetland habitats. In 2006, the Rhode Island Natural Heritage Program defined more than 50 natural community types in the state (Enser and Lundgren 2006), eight of which are considered to be unique in Rhode Island and throughout New England, and which contain biological features of critical importance to maintaining the state's biodiversity (RI 2009). Among the eight unique community types, six are freshwater wetland communities.

Dr. Frank Golet and others (1994) worked with the URI Environmental Data Center (EDC) to develop a GIS-based method to assess the capacity of an individual wetland evaluation unit (defined as a *wetunit*) to support a diversity and abundance of wetland wildlife. Following their work with Golet, the EDC participated in the ad hoc committee for the Rhode Island Resource Protection Program (1995) to develop a series of GIS maps detailing statewide resources and identifying important natural resources areas.   A component of the project was the development of criteria to identify “Large and Complex Freshwater Wetland Systems” within the state. The metrics incorporated were: hydrologic connectivity, wetland size, class richness, and surrounding habitat type.

Contemplating the potential impacts of climate change on the composition of plant and animal communities, Ruddock et al. (2013) developed a measure of geophysical complexity based on Ecological Land Units (ELUs). Their work examined richness among plant species, ecological communities, and ELUs, and found that landscape features with a high degree of geophysical diversity correlated to a greater variety of ecological community types and plant species diversity. Significantly, the measure of ELUs provides resource managers with a tool for identifying landscape features that are likely to support diverse floral and faunal assemblages despite the impacts of climate change (Ruddock et al 2013). The tool incorporates map overlays depicting areas of poorly drained soil and large complex freshwater wetlands, which have the potential for consideration as WHEV.

RESULTS AND DISCUSSION

Based on our research, the recommended approach to identify WHEV focuses on observable indicators of intact relationships between underlying conditions and desirable biological or ecological phenomena. In order to assess wetlands’ ecological value, therefore, we must identify measurable (scalar or binary) indicators that correlate consistently with functional wetland systems in Rhode Island. The protocol developed assesses wetlands by counting those indicators: higher counts will be associated with higher ecological value and some proportion of those will be wetlands of **High Ecological Value**.

In consideration of the relative significance of wetland community type for the ecological value and degree to which it is in a bi-directional relationship with other factors (e.g. habitat, water quality, hydrology, and productivity for the flora and fauna), this report presents several characteristics that can be applied to the evaluation of a wetland’s ecological value: 1) landscape context, which includes connectivity to surrounding uplands, and hydrologic connectivity between wetland systems, 2) biological diversity and spatial variation, which includes the number of plant communities, structural vegetation types, habitat containing old growth characteristics, hydrologic classes, and geomorphology, 3) rarity, which includes documentation that the habitat supports state (and/or federally) listed rare plants and animals, species of Greatest Conservation Need (according to the State Wildlife Action Plan), is an ecologically unique community type for the region or state, and 4) the size of the wetland, and/or size of contiguous natural habitat containing the wetland.

In the context of landscape setting, certain wetland types are considered to be highly functional for the conservation of biological diversity and maintaining wildlife habitat and/or are highly vulnerable to climatic or anthropogenic change and/or are rare or unique in Rhode Island. Included are those wetland types identified as rare or unique in Rhode Island, which are highly vulnerable to changes that are climatic or anthropogenic. These wetland types should be considered as having high ecological value for wildlife, plants, and biological diversity.

Freshwater wetlands whose landscape position affords intact hydrologic connections and connectivity to upland natural communities, those with spatial, geomorphic, structural, and species diversity, and those which represent or support unique environmental conditions or rare species can be said to have functions that provide high ecological value for present and future populations of wildlife and plants compared to wetlands that do not. The wetland characteristics associated with systems that support biological diversity meet these descriptions.

Criteria identified as being directly connected to the value of a wetland for wildlife habitat and sustainment of biological diversity are given below. Use of these as indicators of ecological value is recommended. The numerical order does not necessarily imply importance. Each criteria is later numerically applied in table form (see Tables 4 and 5) to the above wetland types and landscape characteristics, which are highly functional for their ecological value and potential to provide opportunity for wildlife and biodiversity. Each of the criteria provides a protocol for the basis of an evaluation to determine if a wetland should be considered of high ecological value:

Indicators of ecological value:

Technical advisors and research associate each indicator with certain categories of important ecological functions:

- D=Biological diversity
- F=Fish and aquatic macro-invertebrates
- M=Bird and/or mammal habitat
- H=Herptile and insect habitat
- U=Unique wetland type or rare species habitat

1. DMH Wetlands located within large (>250 acres) unfragmented complexes
2. DMH Large wetlands (>20 acres, excluding open water)
3. DFMHU Wetlands with one or more heritage element occurrences having a rank (EO Rank) of "C" or higher
4. D Diverse wetlands (with 3 or more wetland classes with ½ acre minimum size)
5. D Wetland systems with spatial and geomorphic diversity (>24 ELUs)
6. DFMU Tidal freshwater emergent wetlands (riverine or palustrine) (RIECC II.A.2)
7. DM Shrub swamp (RIECC II.A.4)

8. DFM Semi-permanently flooded, deep emergent wetlands, and vegetated aquatic beds not dominated by Phragmites: emergent marsh, semi-permanently flooded (deep) (RIECC II.A.2.a), esp. when connected to substantial riverine/lacustrine systems (see also 14, coastal plain pond shore, below)
9. FMHU Seeps, springs, and forested headwater wetlands supporting perennial streams (RIECC II.C.3 except vernal pools, for which see 12 below, plus forested headwater wetlands)
10. MU Forested wetlands with old growth characteristics (full canopy, substantial woody debris, etc.) (RIECC II.C, in part)
11. FMHU Beaver impoundments and beaver-impounded wetlands not dominated by Phragmites
12. HU Vernal pools (RIECC II.C.3, in part) in areas with clusters of vernal pools
13. H Small, isolated, seasonally or semi-permanently flooded wetlands in forested wetlands
14. FMU Coastal plain pondshore (RIECC II.A.1)
15. U Atlantic white cedar swamp (RIECC II.C.2.d)
16. U Open peatlands (RIECC II.B)
17. U Any wetland located with areas of limestone geology
18. U Any wetland isolated within an urban/suburban build community (RIECC I.G.2)
19. FU Forested wetlands containing or bordering coldwater streams
20. M Unconsolidated shores of perennial surface waters
21. FH Native aquatic beds

Table 3 High Ecological Value Indicators: Available Data

Indic-ator	Short Name	GIS data available and useful	GIS data require analysis to be usable	GIS data are Outdated, Incomplete, or Unavailable	Sources
1	Unfragmented Landscape	X			T. Kutcher, unpublished data
2	Large Size		X		RIGIS ECC 2011
3	Rare Species	X		I	DEM-RINHS, EO data
4	Wetland Type Diversity		X	I O	RIGIS Wetlands 1993, RIGIS ECC 2011
5	Geomorphic Diversity	X			www.edc.uri.edu/elu
6	Tidal Freshwater		X	U	
7	Shrub Swamp	X			RIGIS ECC 2011
8	Emergent Wetlands	X			RIGIS ECC 2011
9	Seeps, Springs, Headwaters		X	U	
10	Old Growth Forest			U	
11	Beaver Impoundments			U	
12	Vernal Pool Clusters		X	I	DEM, unpublished data

13	Isolated Wetlands in Upland		X	I	RIGIS ECC 2011
14	Coastal Plain Pondshore			I	
15	White Cedar Swamps			O I	RIGIS Wetlands 1993
16	Open Peatlands			O I	RIGIS ECC 2011
18	Limestone Wetlands		X		RIGIS ECC 2011
19	Isolated Urban Wetlands		X		RIGIS LULC 2011
20	Coldwater Steam Buffers		X		RIGIS ECC 2011, RIGIS Coldwater Streams
22	Unconsolidated Shores			U	
23	Aquatic Beds			U	

APPLICATION OF INDICTORS

While all wetlands are important to people and the environment, certain wetlands have an inherently-high capacity to support healthy and diverse ecological communities. The 23 factors listed in Table 3 indicate wetlands of high ecological value and can be applied to systematically identify wetlands of outstanding value to wildlife, wildlife habitats, and biological diversity. The use of Geographic Information Systems (GIS) will greatly facilitate the identification of WHEV wetlands on scales ranging from individual wetlands to statewide assessments. Seven of the indicators can be readily identified using available GIS data. Identification of another seven indicators requires GIS analysis of existing data (i.e. overlay or proximity analysis), and for 12 indicators, GIS data are lacking, outdated, or incomplete, indicating the need for remote or field data collection to put them into use. For example, the Rare Species indicator relies on Rhode Island Natural Heritage data, which have not been systematically updated since the state defunded the Natural Heritage program over a decade ago. Other indicators denoted as incomplete (I) or outdated (O) in Table 3 require recent, finer-scale mapping than is currently available through state habitat mapping datasets, whereas those denoted as unavailable (U) are either too transient to capture with typical GIS mapping (Beaver Impoundments, Aquatic Bed) or require field-based data to map. Even with its limitations, GIS remains a useful tool for managers to screen wetlands for a number of WHEV indicators.

The TAC recommends that the occurrence of any single indicator listed in Table 3 should signify WHEV status. It may be reasonable to assume that the occurrence of additional WHEV indicators would indicate increased ecological value over any one alone. However, we make no assertions that any single or group of indicators indicates greater WHEV than any separate indicator(s), even as it may be reasonable to assume that any wetland with multiple indicators represented is likely to possess outstanding ecological value. Furthermore, considering well-accepted species- area relationships, indicators based on area, such as Unfragmented Landscape and Large Size are likely to have other indicators (particularly relating to diversity) associated with them.

We therefore recommend (1) using GIS to overlay as many indicators as available to screen for WHEV and (2) using the presence of multiple indicators as a probabilistic proxy for incrementally higher ecological value, or otherwise (2b) applying indicators that are most relevant to the given project; (3) additional indicators can then be documented in the field. For projects requiring specific wetland types or settings associated with indicators lacking GIS data, other sources of information will need to be used.

GAPS and NEXT STEPS

Selection of WHEV criteria focused on identifying factors indicating ecological value and did not qualify those factors by data availability and utility, resulting in indicators that are not readily usable. While most WHEV indicators listed in Table 3 as incomplete, outdated, or unavailable can be identified during a site visit, they could, in most cases, be more-broadly identified using GIS analysis or additional data collection. Actions that could be taken to put these indicators into broader utility are as follows:

- Adding detail to, or ideally updating, the RI Ecological Community Classification (ECC2011) dataset would increase the utility of indicators that are based on wetland class (i.e. vegetation community type), such as (4) wetland type diversity, (12) vernal pool clusters, (14) coastal plain pondshore, (15) white cedar swamps, and (16) open peatlands. The RI Ecological Community Classification system outlines several levels of detail that were not captured in the 2011 GIS mapping effort due to limited funding for classifying the imagery. The RIGIS Wetlands 1993 dataset has greater community-level detail but is outdated and has issues with spatial and data accuracy.
- (3) Rare Species: RI Natural Heritage (including rare species) data need to be continually updated as new element occurrences of rare and important species are discovered and as species migrate to and from the area. Currently, rare species data are co-managed among four partners including RINHS, DEM, University of Rhode Island Environmental Data Center, and the Nature Conservancy. Dedicated funding to support systematic and consolidated Natural Heritage data management would improve the quality and accessibility of the data.
- Several indicators could be better utilized on all spatial scales using GIS analysis. For example, (2) wetland size could be calculated for wetland systems by aggregating adjacent wetland polygons that form a contiguous wetland unit. Likewise, (19) isolated urban wetlands and (20) coldwater stream buffers could be selected from the RIGIS 2011 land use-land cover (LULC) dataset using a combination of aggregation and proximity analysis. (12) Vernal pools clusters, (22) unconsolidated shores, and (23) aquatic beds could be identified through aerial photo-interpretation for specific areas or broad regions.

We recommend field-testing the indicators and protocol detailed in this report. Funding has been secured through an EPA Wetland Program Development Grant to test the protocol on 20 freshwater wetlands in the summer of 2018. The project will identify WHEV across RI using multiple indicators as a proxy for high ecological value. Indicators will be identified initially using GIS and will be confirmed or expanded through site visits. The project will assess the utility of this protocol for identifying WHEV and will characterize human impacts on these important natural systems.

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Table 4 Wetland Classes and descriptions used by RIGIS and RIDEM

Inland Wetland and Deepwater Habitat Classes
Riverine tidal: deep or shallow marsh
Riverine non-tidal: deep or shallow marsh
Lacustrine open water: aquatic beds
Palustrine open water: aquatic beds
Special aquatic sites: vernal pools
Emergent wetland: deep or shallow marsh, or wet meadow
Emergent wetland: emergent fen or bog
Scrub-shrub wetland: shrub swamp, tall shrub swamp
Scrub-shrub wetland: shrub fen or bog
Forested wetland, coniferous: Atlantic white cedar swamp or bog
Forested wetland, deciduous: wooded swamp
Forested wetland, dead