Rhode Island DEM Freshwater Wetland Monitoring and Assessment, Year 5

INTEGRATING RAPID ASSESSMENT WITH BIOLOGICAL AND LANDSCAPE INDICATORS OF FRESHWATER WETLAND CONDITION

Final Report

Prepared for
Rhode Island Department of Environmental Management
Office of Water Resources

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Providing Ecosystem Science and Information

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Contents

Tables

Figures

Executive Summary

The State of Rhode Island Department of Environmental Management (DEM) and the Rhode Island Natural History Survey (RINHS) are working to develop methods to characterize freshwater wetland condition pursuant to the *Rhode Island Freshwater Wetland Monitoring and Assessment Plan* (WMAP) with support and guidance from the United States Environmental Protection Agency (EPA). EPA endorses a three-level, tiered approach to wetland monitoring and assessment that integrates (Level 1) landscape, (L2) rapid, and (L3) intensive assessment methods to promote program flexibility and interoperation among data types. WMAP outlines a five-year timeline for program development that focuses on the development of a rapid assessment method (RAM; L2) and incorporates L1 and L3 methodologies. From 2006 to 2010, DEM and RINHS developed and tested a Rhode Island-specific RAM, RIRAM. The current version, RIRAM v.2.10, is an evidence-based rapid assessment method that evaluates freshwater wetland condition by rating and summing stress intensity and wetland integrity. Prior studies have indicated proper functionality of RIRAM, but thus far no studies have directly compared RIRAM v.2.10 data to L3 biological data, which would serve in its validation.

This present study aims to validate and integrate RIRAM data with intensive (L3) and landscape (L1) assessment data following the tiered approach. The study utilized existing statewide Odonata (L3) and impervious cover (L1) datasets, and newly-acquired RIRAM (L2) data to develop and test Odonata and impervious cover as indicators of freshwater wetland condition with the goals of: validating RIRAM, demonstrating RIRAM efficacy in establishing wetland reference conditions, expanding the State's freshwater monitoring-and-assessment toolbox, assessing the utility of the existing datasets, and demonstrating a protocol for developing and testing reference-based assessment tools using the tiered approach.

RIRAM was conducted at 51 wetland assessment units (wetunits) selected from existing study sites from the Rhode Island Odonata Atlas (RIOA), spanning a gradient of surrounding land use intensity. Development of an *Odonata index of wetland integrity* (OIWI) utilized the concept of species conservatism, which relates to species sensitivity to human disturbances. A preliminary Coefficient of Conservatism (CC) was developed for each of 135 Odonata species using Odonata and landscape data associated with 510 independent RIOA sites. The preliminary CCs were applied to generate a working OIWI for each wetunit. RIRAM and working OIWI data were applied in an inter-validation analysis of the two methods. RIRAM data were then applied *A Posteriori* to refine the CCs and OIWI for further application. Next, an impervious surface area (ISA) analysis was conducted for the 51 wetunits. A recent statewide impervious cover dataset was clipped to 1000' surrounding each wetunit and % impervious surface area (ISA) was calculated for each wetunit. Percent ISA values were compared with RIRAM and OIWI values to analyze the utility of ISA as an L-1 indicator of wetland condition and to support the prior inter-validation analyses.

RIRAM Index scores ranged from 37.9 to 100 indicating a broad range in wetland condition among the wetunits. RIRAM Index values and working OIWI values were strongly correlated. Additionally, OIWI strongly discriminated among RIRAM-derived reference designations representing reference standard, intermediately-disturbed, and degraded conditions, indicating excellent sensitivity as a bioindicator. Recalculation of OIWI with *A Posteriori*-refined CCs further strengthened OIWI correlation with RIRAM. A clustered, steep drop-off in both RIRAM and OIWI index values with increasing surrounding ISA suggested that considerable wetland degradation occurred in landscapes having less than 10% ISA. Box and whisker analysis strongly supported this finding and indicated that reference standard wetlands occurred primarily below 2% surrounding ISA and wetlands in landscapes with ~10% or greater ISA were likely to be degraded.

Building on earlier findings, this study applies a *weight of evidence* approach to establish RIRAM validity based on RIRAM's relationship with independent indicators. RIRAM's strong relationships with the working OIWI and % ISA strongly support previous work demonstrating RIRAM's proper function in generating an effective and valid index of wetland condition, and demonstrate its efficacy in establishing meaningful reference categories. Findings also demonstrate the effectiveness of OIWI as a single-metric bioindicator and indicate the utility of adult Odonata in the assessment of freshwater wetland condition. Further findings suggest that ISA provides an effective surrogate for human influence, providing a reliable and repeatable L1 indicator of wetland condition that is on par with more-complex, weighted landscape models. In addition, findings identify ISA thresholds in relation to wetland condition that can be represented as follows: <2% indicated least-disturbed condition; 2%-10% indicated intermediately-disturbed (i.e. degrading) condition; and >10% indicated most disturbed (i.e. degraded) condition. Other findings of this report may suggest the following: uplands surrounding breeding areas should be considered core Odonata habitat; surrounding land use, fluvial inputs, buffer degradation, and filling were the dominant stresses affecting Odonata habitat integrity; and, wetlands are not perpetually effective at buffering the impacts of increasing ISA because their functionality may be exhausted by the process.

In summary, this study clearly demonstrates the precision, validity, and utility of RIRAM and further establishes it as an efficient, reliable, and effective tool that can be used in addressing multiple objectives. The study also expands the freshwater wetland monitoring and assessment toolbox for the State, demonstrating the efficacy of a reliable and repeatable L1 assessment method and a valid L3 bioindicator of wetland condition, utilizing existing data. Access to distinct assessment levels will provide flexibility to address specific monitoring and assessment needs, while their use in combination could be applied in circumstances where increased reliability or defensibility is desired. This project could act as a rough template for future studies aimed toward developing and testing wetland monitoring and assessment tools using the tiered approach.

1. Introduction

1.1 Background

1.1.1 Rhode Island Freshwater Wetland Monitoring and Assessment Plan

The State of Rhode Island Department of Environmental Management (DEM) and the Rhode Island Natural History Survey (RINHS) are working to develop methods to characterize freshwater wetland condition pursuant to the *Rhode Island Freshwater Wetland Monitoring and Assessment Plan* (hereafter WMAP; NEIWPCC and DEM 2006). The work is being conducted with continued support and guidance from the United States Environmental Protection Agency (EPA) and in accordance with the *Rhode Island freshwater monitoring and assessment quality assurance project plan – year 5 continuation* (DEM 2010). The Year-5 work that is the focus of this report builds upon work conducted from 2006 through 2010 (DEM 2006; Kutcher 2009, 2010a, 2010b, and 2011).

WMAP identifies gaps and needs in freshwater monitoring and assessment and outlines a strategy to meet those needs. The strategy includes the development, application, and integration of monitoring and assessment methods designed to address a set of short- and long-term objectives regarding wetland condition. WMAP-identified short-term objectives involve monitoring and assessing wetland impacts due to water withdrawals, loss or degradation of buffer habitat, and invasive species intrusion; and include prioritizing wetlands for protection. Long-term objectives involve compiling a long-term dataset aimed at evaluating trends in wetland condition, identifying causes and sources of wetland degradation, evaluating wetland management and protection programs, and identifying wetland policy improvements (NEIWPCC AND DEM 2006).

1.1.1 Tiered Approach to Wetland Monitoring and Assessment

EPA endorses a three-level *tiered* approach to wetland monitoring and assessment that integrates landscape, rapid, and intensive assessment methods (U.S. EPA 2006). Each level represents a distinct methodology that carries an anticipated level of effort and associated level of expected data reliability (Table 1). The tiered approach promotes a flexible, comprehensive, and coordinated strategy to data collection, analysis, and application. This supports validation and interoperation among various data types and allows users to present assessment outcomes in a *weight of evidence* context, which can greatly lend to their defensibility.

Table 1: EPA-recommended three-level approach to wetland monitoring and assessment

Level 1: Landscape Assessment	Use GIS and remote sensing to gain a landscape view of watershed and wetland condition. Typical assessment indicators include wetland coverage (NWI), land use and land cover.
Level 2: Rapid Wetland Assessment	Evaluate the general condition of individual wetlands using relatively simple field indicators. Assessment is often based on the characterization of stressors known to limit wetland functions e.g., road crossings, tile drainage, ditching.
Level 3: Intensive Site Assessment	Produce quantitative data with known certainty of wetland condition within an assessment area, used to refine rapid wetland assessment methods and diagnose the causes of wetland degradation. Assessment is typically accomplished using indices of biological integrity or hydrogeomorphic function.

Source: U.S. EPA 2006

1.1.3 Development of a Rapid Assessment Method

EPA has recommended that states develop a rapid assessment method (RAM) as an initial and central component in a wetland monitoring and assessment program (U.S. EPA 2006). RAMs can provide low-cost, high-resolution data that can be applied to address state-identified objectives, report on wetland condition, inter-validate among landscape and intensive monitoring data, and identify reference conditions for reference-based monitoring (U.S. EPA 2002a).

WMAP outlines a timeline for RAM development from 2006 to 2011. Initially, two RAMs were selected for a pilot study to assess their utility in addressing the State's monitoring objectives. These were (1) the *Ohio Rapid Assessment Method* (ORAM; Mack 2001) and (2) the *Delaware Rapid Assessment Procedure* (DERAP; Jacobs 2003). In 2006, DEM conducted the two RAMs in a single drainage basin that ranged in land use intensity from rural to urban (DEM 2006). The work involved the strict application of ORAM protocols, while DERAP was applied as an ancillary checklist. In 2007 (Year 2), findings and recommendations of 2006 investigations were incorporated into efforts by DEM and RINHS to enhance and adapt the two methods for use in RI. ORAM and DERAP were modified *a priori* to improve their regional and functional relevance and were applied at 54 sites in another RI drainage basin. The protocols were further modified *a posteriori* based on justifications and analyses detailed in the Year-2 report (Kutcher 2009). The outcomes of those efforts included a Rhode Island-specific RAM, RIRAM v.1, which was further developed, demonstrated, and validated in Year 3.

A second version of RIRAM, RIRAM version 2 (v.2) was developed and piloted alongside RIRAM v.1 in Year 3. The outcomes of that effort (refer to Kutcher 2010b) resulted in a shift in focus to the new RIRAM version for subsequent development and demonstrations by the State. RIRAM v.2 was applied in Year 4 to characterize wetland resources of conservation concern and to assess its utility in identifying wetland reference conditions. In Year 5, RIRAM v.2 was applied to 51 wetland units throughout Rhode Island in an effort to integrate RAM (Level 2) data with intensive (L3) and landscape (L1) monitoring data following the tiered approach (Sec. 1.1.2). Year-5 work is the focus of this report.

1.2 RIRAM v.2.10

RIRAM v.2.10 is an evidence-based rapid assessment method that was developed to document wetland characteristics and produce relative indices of freshwater wetland condition. RIRAM indices are produced by rating and summing stressor intensity and wetland integrity, which closely follows EPA wetland monitoring and assessment guidelines (U.S. EPA 2006a). Three sub-indices evaluating landscape stresses, in-wetland stresses, and the integrity of wetland functional characteristics can be summed to generate a single index of overall wetland condition. The index (hereafter *RIRAM* index) is based on 100 possible points, comprising ten metrics, each carrying ten points. A score of 100 indicates pristine condition, and scores approaching zero would indicate extremely degraded conditions. Refer to the RIRAM v.2.10 field datasheet (App. 1).

The first section, Section A comprises five attributes that document assessment unit size, hydrologic characteristics, and habitat characteristics; classify the unit by hydrogeomorphic, vegetation, and community-based classification schemes; and identify simplified wetland values. Section A is not scored because these attributes may be largely intrinsic and thus may not indicate wetland condition per se.

Section B, the first scored section, utilizes two metrics evaluating buffer and surrounding landscape stress by estimating the proportion of land use categories within 100 and 500 feet (~30 and 150 meters, respectively). The metrics are summed to generate the *Landscape Stress* index. Section C utilizes seven metrics evaluating in-wetland stress by the intensity of the stress and the proportion of the assessment unit it affects. In-wetland stress (hereafter *Wetland Stress*) metrics are categorized by stress type and also document associated evidence, stressors, and sources of stress. Finally, Section D *Observed State* summarizes and evaluates the observed integrity of five wetland characteristics that ultimately control wetland functions and values (e.g. per U.S. ACOE 1993).

1.3 Project Objectives

WMAP program development includes the integration of landscape, rapid, and intensive assessment methods over time. DEM and RINHS have focused recent efforts toward increasing the utility, accuracy, and defensibility of RIRAM (L2), while minimizing subjectivity between users. Prior analyses have indicated that inter-user variability is low, and have documented expected correlations between RIRAM v.2 index scores and independent measures of surrounding landscape integrity (Kutcher 2009, Kutcher 2010a and b, Kutcher 2011). RIRAM v.2 index scores were found to be functionally analogous to RIRAM v.1 scores ($r_s = 0.96$, $P < 0.001$, $df = 49$), which predictably correlated with various Level-3 biological and physical indicators of wetland condition in vernal pools (Kutcher 2010a). However, thus far no studies have directly compared RIRAM v.2 data to biological indicators of wetland condition.

The WMAP timeline proposes the integration of existing intensive (L3) and landscape (L1) data in program development for Year 5. Accordingly, this study utilized existing statewide Odonata (L3) and impervious cover (L1) datasets, and newly-acquired RIRAM (L2) data to develop and test biological and landscape assessment tools that can be applied to indicate freshwater wetland condition. The process included a validation analysis of RIRAM v.2 and an assessment of the utility of the existing datasets.

The goals of this study can be summarized as follows: (1) validate RIRAM v.2 against independent biological and landscape data, (2) demonstrate RIRAM efficacy in establishing wetland reference conditions for the development and analysis of wetland assessment tools, (3) work to expand the State's freshwater wetland monitoring-and-assessment toolbox by analyzing adult Odonata and impervious cover as potential indicators of freshwater wetland condition, (4) assess the utility of the existing statewide environmental datasets, and (5) demonstrate application of the tiered approach for developing and testing reference-based assessment tools.

1.4 Adult Odonata as Indicators of Wetland Condition

1.4.1 Biological Indicators

It has been suggested that biological indicators (or *bioindicators*) are the most quantitative, objective, reliable, and accurate tools available to characterize wetland condition (U.S. EPA 2002a, 2006a; Sifneos et al. 2010). Biota can act as continuous *in situ* ecosystem monitors with unique capabilities. Bioindicators may react predictably to multiple or seemingly disparate, cumulative or synergistic environmental factors that may not be well-understood and thus may be overlooked or inaccurately represented by physical or chemical monitoring alone. And, bioindicators can potentially detect episodic events that affect the overall living condition of a system; again, periodic physical or chemical monitoring may not capture such events. Finally, a bioindicator may quantify a shift in biological composition that represents a direct change in wetland functionality, whereas physical indicators are often indirect.

Bioindicators have been applied in the development of numerous single and multi-metric indicators of biological integrity (IBIs) to characterize wetland condition. Unfortunately, due to inherent environmental variability, IBIs are not usually directly transferable from one region to another or from one wetland type to another. Often, specific IBIs must be developed for the various wetland types in a region. This can be a complex and costly process that must consider the viability (i.e. effectiveness, feasibility, efficiency, etc.) of various species assemblages as bioindicators for specific wetland types.

EPA rated six assemblages for wetland bioindicator viability based on fixed criteria. The assemblages included algae, amphibians, birds, fish, (aquatic) macroinvertebrates, and plants (U.S. EPA 2002b). EPA viability criteria considered factors such as prior application, social recognition of importance, detection and identification difficulty, *a priori* knowledge of behavior, sensitivity to various stresses, extent of applicability across wetland types, etc. for each assemblage. EPA ranked macroinvertebrates as potentially better overall wetland bioindicators than the other groups (although plants scored nearly as well). Macroinvertebrate bioindicators are now used widely in state wetland assessment programs. While macroinvertebrates received "best" scores for prior development and use, applicability to multiple wetland types, taxonomic richness, and various sensitivity criteria, they received “worst” scores for social recognition of importance, ease of identification, and ease of analysis.

1.4.3 Adult Odonata

The taxonomic order Odonata is a widespread and charismatic group of flying insects (i.e. macroinvertebrates) that includes dragonflies (suborder *Anisoptera*) and damselflies (suborder *Zygoptera*). The odonate life cycle includes an aquatic larval stage and a terrestrial-aerial adult stage. Most of the odonate life cycle is spent in the aquatic stage, which culminates with metamorphosis and emergence from the water sometime during the growing season. In Rhode Island, emergence ranges from April through October, depending on the species (V. Brown, personal communication). Adult life typically lasts one or two months. Days are spent hunting, defending territory, and breeding, while nights are spent perched on vegetation or other structure in the surrounding upland (Carpenter 1997). Breeding activities are focused around aquatic and wetland habitats; the balance of adult activity largely occurs within 200m of breeding habitat, although activity may extend well beyond this range. Bried and Ervin (2006) found that, overall, adult odonates were evenly distributed throughout a zone spanning 160m from the wetland edge, supporting a commonly-accepted view among entomologists that surrounding upland is utilized as core habitat by this group.

Odonata are widely considered to be valuable bioindicators of ecological condition and are commonly applied in key metrics of aquatic and wetland IBIs. Odonates are widespread in freshwater habitats and are important components of wetland ecosystems; they utilize a wide range of wetland types, may dominate wetland benthic and aerial invertebrate taxa, are often top predators in fishless wetland and aquatic systems, and are important prey for numerous bird and fish species (Carpenter 1997; Dunkle 2000; Bried 2005). And, Odonata may strike a valuable balance between obligate aquatic and terrestrial fauna in indicating aquatic, wetland, and buffer integrity (Clark and Samways 1996; Bried 2005; Raebel et al. 2010).

Most applications of Odonata in bioassessment of wetlands have utilized the aquatic juvenile stage; partly due to an established protocol transposed from stream monitoring and partly due to the obligate nature of the stage. However, Bried and Ervin (2006; Bried 2005) have argued that, although largely overlooked, *adult* Odonata possess certain key additional characteristics of effective bioindicators. Adult odonates are well-studied; monitoring can be conducted visually without specialized equipment; surveys are rapid and non-destructive; species can largely be identified on site; expertise can be acquired relatively quickly; and they are charismatic, which lends to their perceived social importance (Bried 2005; Raebel et al. 2010). And, relating to these factors, adult odonates are relatively cost-effective to monitor. Bried (2005) independently asked 12 experts to rate the bioindicator viability of adult Odonata according to the EPA ranking system (see Sec. 1.4.1) and found that the mean rank for adult Odonata was lower (i.e. they were equally or more viable) than the six assemblages ranked by EPA (U.S. EPA 2002b).

There are also specific limitations to utilizing adult odonates as bioindicators. Data must be collected during active flight months; and weather, which can strongly affect detectability, must be accounted for (i.e. it must be fairly calm and dry). Also, Raebel et al. (2010) have raised the concern that adult Odonata presence does not necessarily indicate successful reproduction at a given site and thus may overestimate wetland condition as Odonata habitat.

1.4.4 Rhode Island Odonata Atlas

The existing Odonata data used in this study comprise the Rhode Island Odonata Atlas (V. Brown, unpublished data from RINHS and The Nature Conservancy, available at RINHS), hereafter “RIOA”. The RIOA is a statewide inventory of adult Odonata conducted from 1998 through 2004. Professionals and trained volunteers collected and inventoried ~13,000 Odonata specimens occurring across 1090 study sites reflecting diverse wetland, deepwater, upland, and cultural habitat types. Each RIOA data point represents a voucher specimen that was captured at a known site and verified by a professional biologist (Brown 2003). The inventory identifies 137 Odonata species, covers every township in Rhode Island, and reflects all the species known to occur in the State.

1.5 Impervious Surface Area and Wetland Condition

Impervious surface area (ISA) is a landscape-scale (L1) ecological indicator used widely in the assessment of watershed and surface water condition. ISA reflects the cover of impervious surfaces such as paved roads, parking lots, rooftops, and sidewalks, which displace natural and pervious-cultural land covers, causing flashy (accelerated) runoff and reduced infiltration. Flashy runoff efficiently entrains nutrients, solids, hydrocarbons, pathogens, and other pollutants, and transports them directly to surface waters rather than through vegetation and soils, where they would be filtered before entering larger water systems. Flashy runoff conditions contribute to shoreline destabilization and flash flooding by increasing the amplitude and velocity of surface flow. Inhibition of infiltration caused by impervious cover reduces groundwater recharge, which can impact wetland water levels and lower stream base flow. ISA has been shown to reliably and strongly correlate with land use intensity and with the degradation of water quality, which has led to its widespread use in development planning (Brabec et al. 2002). Generalized ISA thresholds are often applied to characterize the condition of basins and their receiving waters; for example <10% cover has been used to indicate little or no impact, 10-30% to indicate a moderate impact, and >30% to indicate degraded conditions (e.g. Brabec et al. 2002; Zhou and Wang 2007).

Impervious cover mapping products are generally more straightforward, objective, and repeatable than land use/land cover products, which often utilize user-identified land cover classes and require some level of user interpretation in processing. Impervious cover data can be generated at high resolution through automated algorithms with minimal user interpretation, thus minimizing subjectivity and maximizing repeatability. The data comprise two objective classes: impervious and pervious. The ISA indicator is correspondingly straightforward: simply the % impervious cover in the area of concern (e.g. Zhou and Wang 2007). The objectivity and repeatability of the protocol make ISA a superior landscape monitoring and quantitative analysis tool, particularly for detecting or predicting change over time. However, ISA is limited in indicating nutrient and sediment runoff from anthropogenic *pervious* surfaces that may contribute to the degradation of water quality, such as cultivated land, turf, and new construction (Brabec et al. 2002).

Several commonly recognized functions of wetlands can directly reduce the impacts impervious cover may have on surface waters and waterways. These functions include groundwater recharge and discharge; flood flow alteration; sediment and toxicant retention; nutrient removal, retention, and transformation; and shoreline stabilization (per ACOE 1993). However, relatively little information is available on how surrounding impervious cover relates to the condition of the impact-absorbing wetlands themselves. While multi-metric landscape indices *incorporating* ISA have been shown to correlate with intensive (L3) and rapid assessment (L2) indices of wetland condition and with wetland hydrologic integrity (e.g. Carlisle et al. 2003; Kentula et al. 2004), this study specifically assesses the efficacy of ISA as a single-metric indicator of wetland condition.

2. Methods

2.1 Overview

This study developed and tested biological and landscape indicators of freshwater wetland condition and applied them to a validation analysis of RIRAM v.2.10 at 51 wetland assessment units or "wetunits" (term from Golet et al. 1994). RIRAM index scores were then applied to assess and enhance the effectiveness of those indicators.

RIRAM was conducted at each of the 51 wetunits, which were selected from existing Rhode Island Odonata Atlas (RIOA) study sites spanning a gradient of surrounding land use intensity. A preliminary Coefficient of Conservatism (CC) was developed for each Odonata species using Odonata and landscape data associated with 510 independent (excluding the wetunits) RIOA sites. The preliminary CCs were applied to generate a working Odonata Index of Wetland Integrity (OIWI) for each wetunit. Paired and binned RIRAM and working OIWI values were applied in an inter-validation analysis of the two methods. RIRAM index values were then applied to refine the OIWI for further application.

Next, an impervious surface area (ISA) analysis was conducted for the 51 wetunits. A recent, high-resolution, statewide impervious cover dataset was clipped to 1000' surrounding each wetunit and % ISA was calculated for each. Percent ISA values were compared with RIRAM and OIWI values to analyze the utility of ISA as a potential Level-1 indicator of wetland condition and to support the prior inter-validation analyses.

2.2 Site Selection

Fifty-one (51) study sites (hereafter collectively the "study sample") were selected from existing RI Odonata Atlas (RIOA) sites located throughout Rhode Island (Fig. 1). To maximize data reliability within the confines of the RIOA dataset, sites were filtered according to data meeting prescribed criteria. The first criterion required that sites occur within 50m of a mapped wetland feature, to filter out sites that could not be directly linked to a specific wetland. The second set of criteria set minimum thresholds for effort, which can influence species detectability. Specifically, a threshold for the minimum number of site visits was set at three (3) and a threshold for the minimum number of total specimens collected per site was set at ten (10); no maximum thresholds were set. Effort thresholds were set at the highest possible level that produced a reasonable number of sites from which to select a stratified study sample.

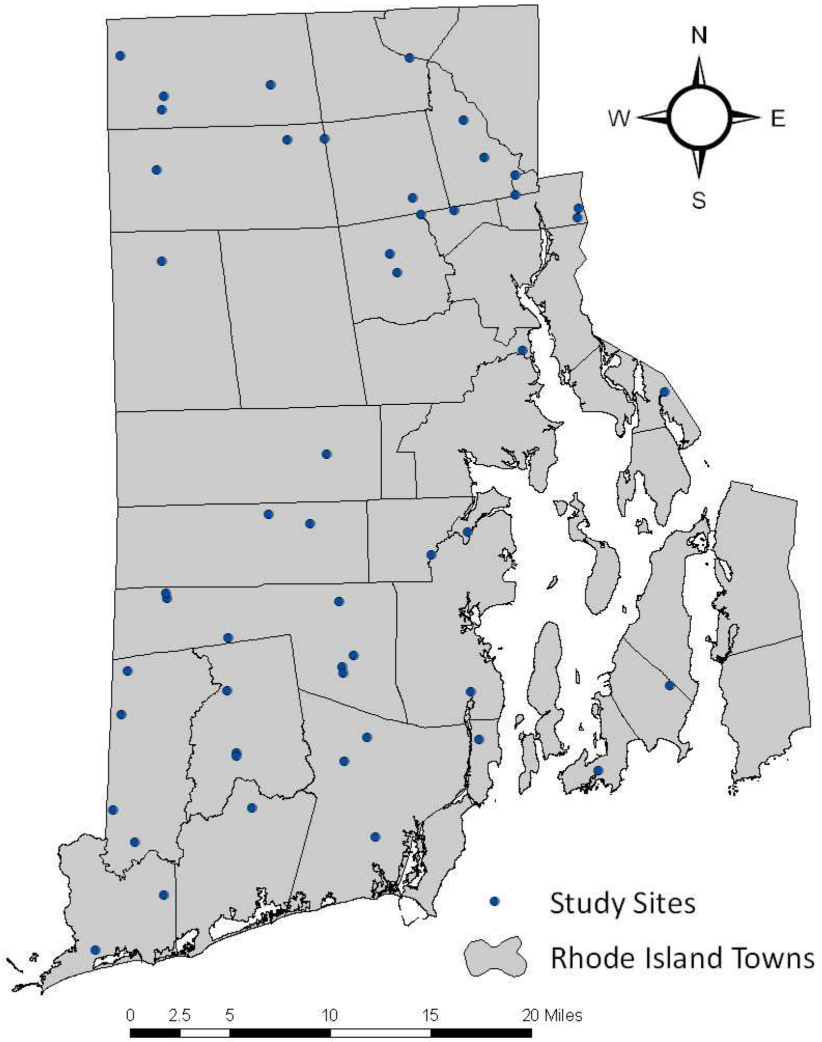

Figure 1: Fifty-one wetland assessment units selected for this study

Study-sample sites were selected from those meeting the above criteria as follows. ESRI ArcMap® GIS software and RIGIS (2010) land use data (*2003-04 Land Use for RI*) were used to generate surrounding-land-use-intensity values based on the % cultural cover (by area) within 1000’ of each RIOA data point. Land use was considered to be cultural if it was classified as Urban/built-up (LCLU code 100-199), Agricultural (200-299), or Mines-Quarries-Gravel Pits-Transitional Land (740-750) according to the RIGIS dataset per Anderson (1976) classification. Sites were sorted according to the % cultural values to produce a preliminary gradient based on surrounding land use intensity.

To ensure that reference, intermediate, and degraded conditions were each adequately reflected in the study sample, a stratified sample was selected from the gradient; specifically, 17 sites having high surrounding land use intensity values, 17 sites having low values, and 17 sites with values surrounding the median, were selected for study. The study sample was then screened to remove and replace sites comprising uplands, unvegetated waters, and engineered treatment basins. Each removed site was replaced by a site having the next closest % cultural value along the gradient. Final selections were heads-up digitized in GIS according to rules detailed in Section 2.3.

2.3 Determination of Assessment Unit Boundaries

Assessment unit (wetunit) boundaries were determined according to rules adapted from prior DEM protocols (unpublished) and described in the RIRAM Users' Guide (Kutcher 2010c). Wetunits were delineated as discrete areas of wetland habitat bounded by any combination of upland, riverine open water, or lacustrine open water. Large roads and railways lacking culverts further divided wetunits, as did narrowing of the wetland habitat to less than 50' or 10% of its width. Units were also bounded at the junction of linear (river dominated) and non-linear (e.g. basin/flat) wetlands. Open water basins smaller than 20 acres were included in wetunits, but lacustrine open waters larger than 20 acres were not. Wetlands surrounding rivers were considered a single wetunit until contiguity was broken on both sides of the channel; the river channel was included only if it was vegetated or ephemeral. Wetunits were not divided by vegetation type; thus a single wetunit could contain multiple vegetation communities.

2.4 Rapid Assessment

2.4.1 Field Investigations

RIRAM data were collected between August 30 and October 26, 2010. Study sites were accessed with written or oral permission from fee or easement owners of containing properties, or their representatives (e.g. park managers, town planners, land trust directors). Sites were accessed on foot or by canoe, when necessary. Two investigators—the principal investigator and a trained field assistant—conducted the assessments. The perimeter and multiple transects of each wetunit were assessed when possible, otherwise assessments were made by accessing and observing as many areas within and around the wetunit as possible.

Field maps of each wetunit, produced using GIS, were utilized for field orientation and determining wetland community and buffer characteristics. Each map contained a backdrop of 2008 leaf-off, color aerial photography at a scale sufficient to illustrate wetland habitats and surrounding land uses, and included a delineation of the wetunit, delineations of 100' and 500' buffer-zones, a scale bar, and other identifying information (Fig 2).

Figure 2: Sample field map for RIRAM assessment, scaled down from 8.5 × 11 in.

An interim field guide of all invasive freshwater wetland plants documented in RI was utilized in the field to help in invasive plant species identification. The guide was compiled by RINHS using information from existing data sources (RINHS, unpublished data).

2.4.2 Remote Investigations

Data obtained during field investigations were complemented using GIS analysis before data entry. The following GIS operations were undertaken; refer to RIRAM v.2.10 field datasheet (App. 1) for clarification:

- Assessment unit size was measured to answer Attribute A1.
- The RIGIS (2010) *FEMA Statewide Flood Zone Map* data-layer was overlaid to determine whether each wetland fell within a designated 100-year floodplain to partly answer Attribute A5.

- RINHS rare species geospatial data were laid over sites to determine any occurrences of state/federal threatened or endangered species, to partly answer Attribute A5.
- The RIGIS *Sewered Areas* data-layer was overlaid to support Metric 2 by determining the presence of sewers.
- The RIGIS *Community Wellhead Protection Areas* and *Non-community Wellhead protection Areas* data-layers were overlaid to support any observed evidence documented in Metric 4 by locating the estimated cone of depression associated with large groundwater pumps.

2.5 Development of an Odonata Index of Wetland Integrity

Rhode Island Odonata Atlas (RIOA) data were used to develop an Odonata Index of Wetland Integrity (OIWI). Although RIOA data were collected according to prescribed protocols, the data were not intended to be quantitative and effort per site and per visit was not standardized. Per site effort ranged from the collection of a single specimen in a single visit, to the collection of as many as 139 specimens during numerous (up to 42) visits conducted across several years. For this study, the variation in effort limited the functionality of the inventory data to *presence-absence* data (as opposed to *abundance* data), which partly determined the development process.

ESRI ArcMap® software was used for all geospatial analyses, while Microsoft Excel® spreadsheet software was used for most other computations in OIWI development.

2.5.1 Species Conservatism Applied to Odonata

Development of the OIWI utilized the concept of species conservatism. This concept was introduced by Swink and Wilhelm (1979) in their presentation of a Floristic Quality Assessment Index (FQAI), which was developed to characterize the relative naturalness of vegetation communities. Conservatism refers to a species' intolerance to change from natural environmental conditions (i.e. human disturbance). In FQAI applications, coefficients ranging from 0 to 10 are assigned, by experts applying best professional judgment, to each individual plant species, based on relative conservatism. Coefficients approaching 10 are assigned to species with a high degree of conservatism (i.e. sensitivity to disturbance), whereas those approaching 0 are assigned to species with low conservatism, such as invasive species. These *coefficients of conservatism* (CCs) are applied in FQAI utilizing one of two formulae. The original FQAI formula weights the mean CC of native species by the square root of the number of native species (N_n), as follows:

Equation 1: $\mathrm{FQAI} = \sum \mathrm{CC} / N_n \times \sqrt{N_n}$

In this formula, species richness strongly affects the index under the assumption that species richness is strongly associated with habitat quality. Characterizing relative species richness requires thorough inventory and a rigorous standardization of effort, which limited its applicability in this study.

A second, commonly applied FQA formula is simply the mean CC (Mean CC), which does not incorporate species richness and thus can be applied to *presence-absence* data. Rooney and Rogers (2002) found that this simplified formula performed as well or better in characterizing ecological quality than the original formula with additional advantages; the Mean CC is computationally simpler, is not strongly affected by sampling effort or species richness, and contains no hidden information.

Since RIOA survey effort could not be fully standardized and since prior studies have indicated that Odonata species richness variability is largely independent of wetland condition (e.g. Bried 2005; Lubertazzi 2009), the simplified formula (Mean CC) was selected for application in the OIWI. Specifically, a preliminary CC was assigned to each of 135 Odonata species identified in the RIOA. Then, using RIOA inventory data, the Mean-CC was generated for each of the 51 wetunits, based on all species observed at each unit during the entire inventory period; this equaled the OIWI value (Equation 2).

Equation 2: $\text{OIWI} = \text{Mean CC} = \sum \text{CC} / \text{N}$

Where: CC = the coefficient of conservatism for an Odonata species identified at a given site, and
N = the number of species identified at the site

2.5.2 Generation of Odonata CCs

Rather than being assigned to species based on best professional judgment (as in FQAI), preliminary Odonata CCs for the OIWI were generated empirically using independent RIOA data. Specifically, simplified Indicator Species Analysis (Dufrene and Legendre 1997) methods were used to determine CCs based on each species' relative Indicator Value (IndVal). IndVal considers each species' specificity and fidelity to a specific independent variable (such as, in this case, wetland condition). The simplified IndVal, which was developed specifically for presence-absence data, reflects the ratio of the number of sites within a treatment sub-sample (such as reference-standard wetlands) containing a given species (*i*), to the number of all sample sites containing that species, as follows:

Equation 3: $\text{IndVal} = \text{Nsites}_{ij} / \text{Nsites}_{i}$

Where: Nsites_{ij} = the number of sites in group *j* occupied by species *i*, and
Nsites_{i} = the number of all sites occupied by species *i*

Utilizing RIOA data, Equation 3 was applied to determine preliminary species CCs for the OIWI as follows. After the study sample (51 wetunits) was extracted from the dataset, the remaining RIOA sites were filtered to establish the sample to be used in generating CCs (hereafter the "training sample"). Sites not within 50m of a mapped wetland feature were removed to eliminate areas that did not specifically represent wetlands. Percent surrounding cultural land cover within 1000' was determined for each remaining RIOA site as described in Sec. 2.2. Resulting values were used as a proxy for wetland condition, under the assumption that wetland condition is strongly associated with land use. RIOA sites were then sorted according to these values. Sites within the lower quartile were utilized as group j_{LD} representing least-disturbed wetlands; sites within the upper quartile were utilized as group j_{MD} representing most-disturbed wetlands; and an equal number of sites surrounding the median were utilized as group j_{ID}, representing intermediately-disturbed wetlands.

To reflect both fidelity to least-disturbed wetlands and *infidelity* to most-disturbed wetlands, two IndVal values were generated for each species, the first, IndVal_{LD}, to represent species fidelity to least-disturbed conditions and the second, IndVal_{MD}, to represent species fidelity to most-disturbed conditions. Each respective IndVal was generated by substituting group j_{LD}, and then group j_{MD}, into Equation 3 to determine Nsites_{ij} (number of sites in group *j* occupied by species *i*), while all three groups were utilized to determine Nsites_i (number of all sites occupied by species *i*) for both IndVals. The IndVal_{MD} was then inversed ($1 - \text{IndVal}_{MD}$) to represent *infidelity* to disturbed conditions; this value was averaged with the IndVal_{LD} value and multiplied by 10 to generate the preliminary CCs (based on a scale of 0 to10 in keeping with convention). For each species *i*, this CC can be represented as:

Equation 4: $$\text{CC}_i = [(\text{IndVal}_{LD} + (1 - \text{IndVal}_{MD})) / 2] \times 10$$

For methodological comparison, a simplified CC was also generated for each Odonata species, based on the same principles but removing sites surrounding the median (group j_{ID}) from the process. A single IndVal was generated for each species by utilizing group j_{LD} (least-degraded sites) to determine Nsites_{ij} and utilizing groups j_{LD} and j_{MD} (least-degraded and most-degraded sites only) to determine Nsites_i in Equation 3. This value was multiplied by 10 to generate simplified CCs. The simplified CCs represented species fidelity to least-disturbed wetlands and, by default (due to only two groups), infidelity to most-disturbed wetlands, but did not consider species presence at wetlands in intermediate condition; this was expected to decrease their precision relative to non-simplified CCs. However, this simplified-CC method required 1/3 less training data (i.e. inventory sites) and was computationally simpler than the non-simplified method represented in Equation 4.

2.5.3 Validation

The OIWI was applied in a validation analysis of RIRAM v.2. Using non-parametric correlation and average-comparison statistics, index values of RIRAM and the working OIWI were analyzed to determine the strength of their associations. The strength of the associations indicated the extent that RIRAM and the OIWI were reflecting / responding similarly to wetland disturbances occurring in the study sample. Significant ($P < 0.05$) associations would provide evidence supporting the validity of both assessment methods in characterizing relative wetland condition (e.g. Stein et al.)

Box and whisker analysis was applied to further demonstrate RIRAM and OIWI efficacy by the degree of interquartile and median overlap. Reference bins were first established based on RIRAM 75th and 25th percentile index scores, designating reference (i.e. least-disturbed) and degraded (i.e. most-disturbed) wetunits, respectively (per Barbour et al.

1996). In comparing OIWI data between reference and degraded wetunits, no overlap of OIWI interquartile ranges would indicate high sensitivity to disturbance and excellent metric performance; some interquartile range overlap without overlap between one designation's median and the other's interquartile range would indicate good performance; a median overlapping with an interquartile range would indicate fair performance; while median overlap would indicate a poor metric performance (Barbour 1996; Vaselka et al. 2010). Good performance of OIWI would suggest its effectiveness and at the same time indicate the efficacy of RIRAM in generating a meaningful and useful gradient of relative wetland condition.

2.5.4 Refinement of Odonata CCs

After the working OIWI was evaluated in validation analyses, RIRAM data were used to bin the study sample into three groups of 17 wetunits, representing least-disturbed, intermediately-disturbed, and most-disturbed wetlands. RIOA Odonata data from these three groups were added to the training data to generate refined CCs, based on 3 groups of 187 training sites. Refined CCs were then reviewed by a recognized Rhode Island Odonata expert (V.A. Brown) to identify and address any errors, outliers, or inconsistencies in the CC values. Refined CCs were then applied to an RIOA geospatial dataset to generate a final OIWI index, and an indication of its reliability based on the number of species it was generated from, for each RIOA site.

2.6 Impervious Cover and Wetland Condition

Impervious surface area (ISA) values for a 1000'-wide zone surrounding each wetunit were generated from recent high-resolution impervious surface data, as follows. Using ESRI ArcMap® 9.3 GIS software, 1000' surrounding-area polygons were generated for each wetunit using the *Buffer* command and selecting *outside only*. Surrounding-area polygons were used to clip the RIGIS (2011) *Impervious Cover 2003-04* raster dataset. The resulting impervious surrounding-area raster data were coded and analyzed to determine the percent impervious cover in each. These values (hereafter %ISA-1000) were used in impervious cover analyses versus RIRAM and OIWI data to examine the efficacy of %ISA-1000 in indicating overall freshwater wetland condition, relative to the other indicators. In turn, %ISA-1000 was used to support validation analysis of RIRAM and OIWI using methods outlined in Sec. 2.5.3.

2.7 Statistical Analysis

Statistical analyses were conducted using WinSTAT® statistical software (2006, R. Fitch Software) appended to Microsoft Excel® spreadsheet software. Descriptive statistics of RIRAM metric and index values were generated to characterize the study sites in tables and figures. Rank-based and non-parametric methods were utilized in most statistical analyses to compensate for the ordinal nature of the assessment data and any skews or gaps that may be inherent in the samples.

Spearman rank correlation analysis was used to validate RIRAM data against OIWI data and to analyze relationships between RIRAM (L2), OIWI (L3), and ISA (L1) data. Box and whisker analysis was applied to demonstrate RIRAM utility in identifying freshwater wetland reference conditions and to analyze relationships between RIRAM, OIWI, and

ISA data. Kruskal-Wallis *H-test* analysis (non-parametric analogue of ANOVA) and Mann-Whitney *U-test* (non-parametric analogue of *t-test*) analysis (using *Bonferroni*-adjusted critical *P* values) were conducted to further support box and whisker analysis to partly determine thresholds for impervious cover associations. Graphics, including *scatterplots*, *box and whisker* charts, and *bar* charts, were generated to support analyses throughout.

3. Results

3.1 RIRAM Data

Statistics in Section 3.1 and Appendices 2 and 3 were derived from RIRAM v.2.10 data.

3.1.1 Assessment Unit Attributes and Classification

A stratified study sample of 51 wetland assessment units (wetunits) was selected from RIOA study sites according to methods detailed in Section 2.2. Wetunits ranged in size from 0.3 to 88 acres with an average size of 13 acres. The total area of wetland habitat assessed was 650 acres. The dominant wetland classes within the sample were Emergent Wetland, Forested Wetland, and Shrub Swamp, present at sites in nearly equal proportions. The dominant hydrogeomorphic classes were Connected Depression, Isolated Depression, and Floodplain-riverine, each representing 31% of the sample. Thirty (59%) of the units were interpreted to be primarily surface water-fed, while 19 (37%) were interpreted as mainly groundwater-fed.

Wetland functional values were distributed across the sample as follows: 30 (59%) units fell within FEMA-designated 100-year floodplains; 19 (37%) were located between surface waters and human land use; 45 (88%) were part of a habitat complex or corridor; 21 (41%) fell within aquifer recharge zones; 23 (45%) contained documented threatened or endangered species; 34 (67%) were determined to be relatively significant avian habitat; 36 (70%) contained a habitat type of greatest conservation need according to DEM (2005); and 7 (13%) were determined to be of educational or historical significance. Appendix 2 presents Year-5 RIRAM attribute and classification data, further summarized in chart format.

3.1.2 Summary of RIRAM Metric Data

Among the Year-5 study sample, RIRAM Index scores ranged from 37.9 to 100 with a mean of 79.2 ± 17.0 (Fig. 3; Table 2). The condition of the surrounding 100-foot buffer ranged from entirely intact to degraded, with most (72%) buffers containing less than 25% cultural cover. Surrounding land use intensity within 500 feet also ranged from pristine to degraded condition. Raised roadbeds and trails were the most common landscape stressors, followed by residential and commercial development.

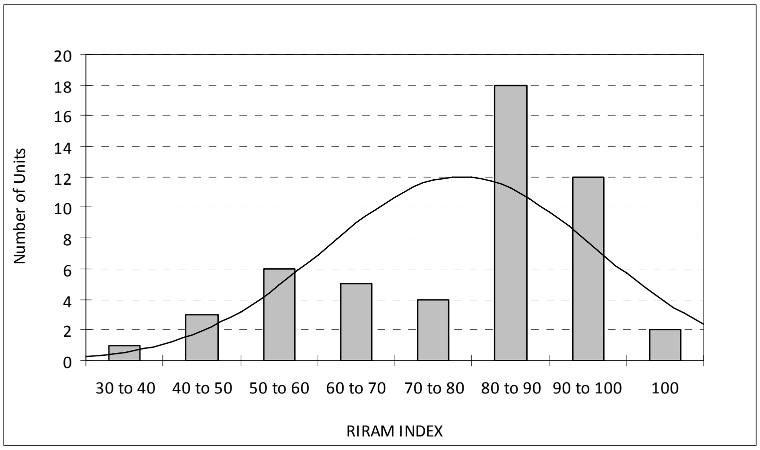

Figure 3: Distribution of RIRAM v.2.10 index values among 51 wetunits in RI. The line represents the smoothed distribution curve.

Table 2: Summary statistics of RIRAM v.2 sub-index and index scores from 51 wetunits in RI

	Landscape Stress	Wetland Stress	Observed State	RIRAM
Sample size	51.0	51.0	51.0	51.0
Mean	14.1	58.1	7.0	79.2
Std. Deviation	6.1	9.4	2.2	17.0
Skew	-0.7	-0.9	-0.4	-0.8
Minimum	1.6	32.2	2.0	37.9
Maximum	20.0	70.0	10.0	100.0
Range	18.4	37.8	8.0	62.1
5th percentile	2.7	40.4	3.3	45.5
10th percentile	3.9	41.4	3.6	51.3
25th percentile	9.8	52.2	5.5	66.7
Median	15.8	60.0	7.5	84.9
75th percentile	19.7	65.0	9.0	93.6
90th percentile	19.7	69.9	10.0	99.6
95th percentile	20.0	70.0	10.0	99.8

Twenty-eight (55%) of the wetunits were affected by some impoundment; however, only two (4%) of the units were created by an impoundment. Dams were the most common cause, impounding 17 (33%) units, largely from historic commercial and agricultural practices, followed by public roads, impounding 7 (13%) units. Impoundments acted as barriers to the movement of resources at 21 (41%) of these units. Conversely, 14 (27%) of the wetland units were affected by the draining or diversion of water, lowering flow velocities and water regimes. Drainage ditches and upstream impoundments, mostly associated with historic land uses, were the most common associated stressors.

Fluvial input sources or impacts were documented at 37 (73%) wetunits. Evidence of nutrient and sediment inputs was most prevalent. Associated stressors were most often sheet runoff and multiple/non-point runoff, mainly resulting from multiple current land uses or roads. Filling or dumping was documented at 37 (73%) of the units, as well. Wetlands were partially filled to upland grade at most of these. Road construction and site development associated with historic commercial and current recreational land uses were the most common associated stressors. Excavation or other substrate disturbances were noted at 20 (39%) of the wetunits. Two (4%) units were created by excavation; remaining disturbances were mainly associated with ditching, grading, and vehicle disturbances, mostly related to public utilities and public recreation. Twelve wetunits (24%) were affected by the cutting or removal of vegetation, primarily from the shrub and canopy strata. Clearing associated with public recreation and residential development accounted for the bulk of in-wetland vegetation cutting.

Thirty-five units (67%) contained invasive plants. Twenty invasive species were identified among the wetunits; most often found were common reed (*Phragmites australis*) and wild rose (*Rosa multiflora*) (Fig. 4). The invasive upland vine Asiatic bittersweet (*Celastrus orbiculatus*) was growing over and into wetland vegetation at nearly a quarter of the sites, as well. Invasion intensity within wetunits ranged from none-noted (0%) to >75% total cover (at one unit), while most units contained <5% total cover of invasive species. The most common stressors abutting invasive species incursions were “multiple”, roads, and clearing, primarily associated with public recreation and residential land uses. Overall, stresses most closely related to invasive species success in the study sample were surrounding land use within 500' and fluvial inputs (Table 3).

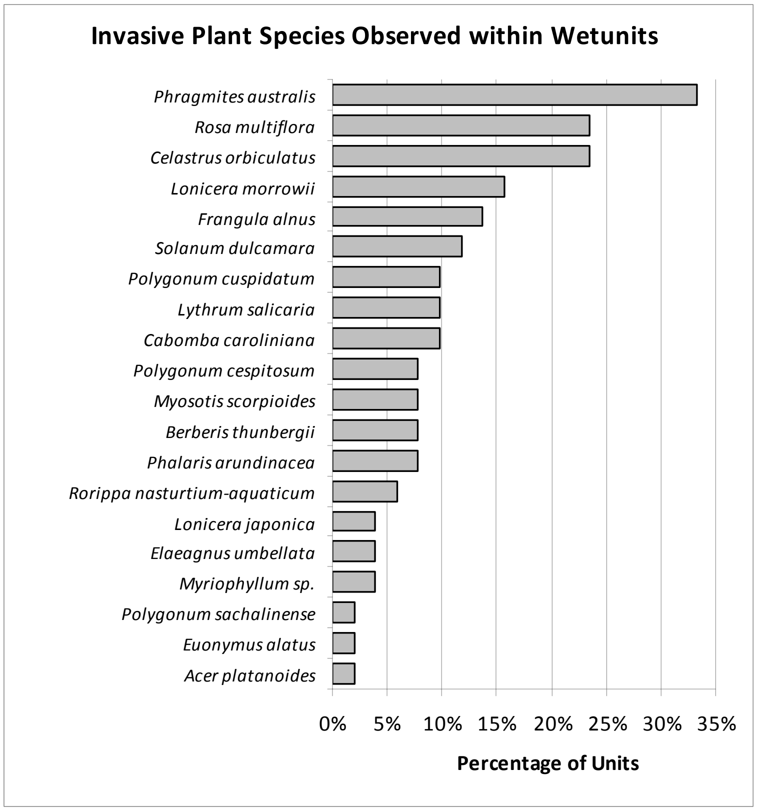

Figure 4: Invasive plant species observed growing within or over 51 wetland assessment units in Rhode Island.

Table 3: Significant Spearman rank correlation coefficients between invasive species cover and RIRAM stress metrics at 51 wetland assessment units in Rhode Island. $P < 0.01$ for all

	Invasive Species Cover
Stress Metric	r_s
1. Degradation of Buffers	-0.58
2. Surrounding Land Use	-0.68
4. Draining or diversion	0.40
5. Fluvial inputs	0.67
6. Filling and Dumping	0.53

Metric scores are further detailed per wetunit in Appendix 3 and summarized in chart format in Appendix 2.

3.1.3 Stress and Wetland Integrity

RIRAM stress data (metrics 1 through 9) were compared with RIRAM *Observed State* (metric 10), which evaluates the observed integrity of five wetland functional characteristics, to provide some insight into the relative impacts of various stresses within the sample. Surrounding land use, fluvial inputs, buffer degradation, and filling / dumping were the stresses most closely associated with *Observed State* (Table 4). *Landscape Stresses* (sum of metrics 1 and 2) and *Wetland Stress* (sum of all in-wetland stress metrics) were nearly equally correlated with *Observed State*, while *Total Stress*, which represents the summation of all landscape and in-wetland metrics, was most strongly correlated, suggesting that cumulative wetland stresses accounted for a large proportion of the variability in observed wetland integrity.

Table 4: Spearman rank correlation coefficients indicating the relative relationships between Observed State and RIRAM stress metrics and subindices. $P < 0.05$ for all except *

Stress Metric / ***SUBINDEX***	*D. OBSERVED STATE* r_s
1. Degradation of Buffers	0.81
2. Surrounding Land Use	0.89
3. Impoundment	-0.23 *
4. Draining or diversion	-0.62
5. Fluvial inputs	-0.84
6. Filling and Dumping	-0.80
7. Substrate disturbances	-0.44
8. Vegetation or detritus removal	-0.41
9. Invasive species cover	-0.74
B. LANDSCAPE STRESS	0.89
C. WETLAND STRESS	0.91
B + C. TOTAL STRESS	0.94

3.2 Adult Odonata and Wetland Condition

3.2.1 Preliminary Odonata CCs

Simplified and non-simplified preliminary CCs were generated for each of the 135 species identified in the RIOA, from two and three groups of 170 RIOA inventory sites, respectively. Non-simplified CC values (based on sites representing (1) least-disturbed, (2) most -disturbed, and (3) intermediately-disturbed wetlands) and simplified-CC values (based on sites representing (1) least-disturbed and (2) most-disturbed wetlands only) were relatively (thus functionally) nearly equivalent ($r_s = 0.95$, $P < 0.0001$, $df = 134$). However, the CCs based on all three groups were generated from a larger training sample ($n = 510$ sites, compared with 340 sites), incorporated information on intermediate disturbance, and were found to be somewhat more precise in comparative analyses (e.g. Fig. 5). Thus, from this point forward, only analyses utilizing non-simplified CCs (based on all three groups) are presented in the Results of this report.

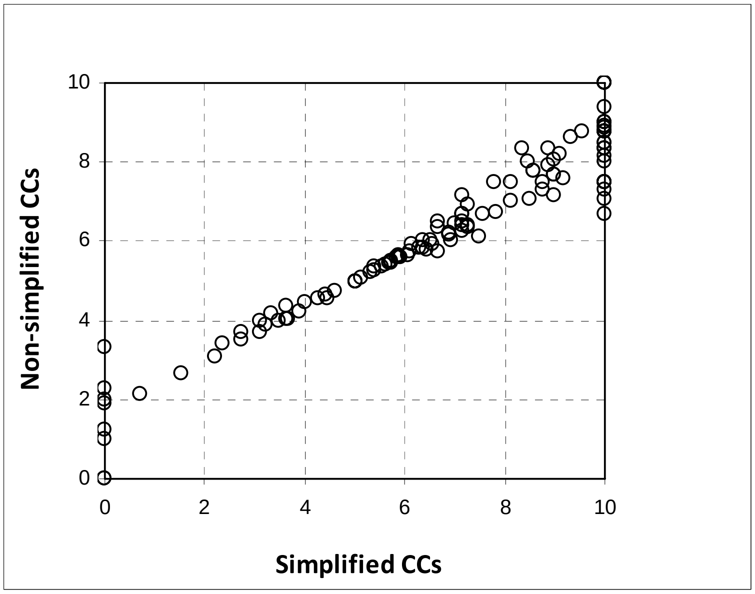

Figure 5: Comparison of 135 preliminary Odonata species CC-values generated from two groups (x axis) and three groups (y axis) to illustrate higher precision in the latter, particularly toward the value extremes.

Preliminary Odonata CCs ranged from 0 to 10 with a mean of 6.4 (Fig. 6). Species occurrence, by number of total sites, ranged from zero (0) to 116 with a median of 15, among the training sample of 510 sites. Only one RIOA species, *Libellula auripennis*, was not represented in the training sample; this was assigned a CC of 10, since it was only observed once during the RIOA inventory period at a minimally-disturbed site (based on 0% surrounding cultural land cover within 1000'). Other rare species were assigned CCs as generated, without modification, even if occurrences within the training sample were very low. In an exploratory analysis, Mean-CC values (i.e. OIWI values) generated (1) with and (2) without averaging in CCs of the rare species (i.e. those with <20 site occurrences in the RIOA) were functionally nearly identical among the 51 wetunits ($r_s = 0.99$, $P < 0.0001$, $df = 50$), indicating that the inclusion of rare species is unlikely to strongly affect OIWI outcomes. Rare-species CCs were thus retained in working OIWI development as best available information (per Karr and Chu 1997). The preliminary CCs, and the number of site occurrences each CC was generated from (as a rough measure of reliability), are listed by species in App. 4.

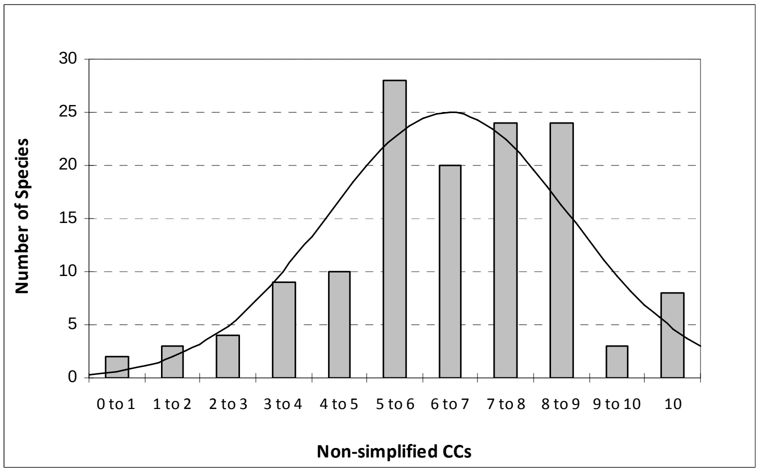

Figure 6: Distribution of preliminary Odonata CC values for 135 Odonata species, derived from the Rhode Island Odonata Atlas. The line represents the smoothed distribution curve.

3.2.2 Working OIWI values

Working OIWI values, developed from preliminary Odonata CCs, ranged from 3.74 to 7.15 with a mean of 5.90 ± 0.77 among the 51 wetunits (Fig. 7; Table 5). Number of species per wetunit ranged from 4 (among 17 specimens collected across 4 site visits) to 47 (among 124 specimens collected across 7 site visits). However, OIWI values were not correlated with any measure of sampling effort per site, including number of specimens, number of visits, and number of species, indicating that sampling effort did not significantly influence OIWI relative values (Table 6).

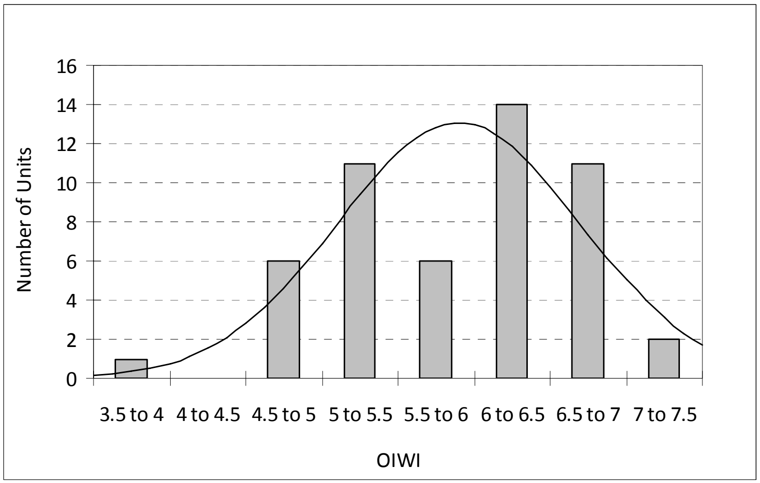

Figure 7: Distribution of working OIWI values for 51 wetunits in RI, based on data from the Rhode Island Odonata Atlas. The line represents the smoothed distribution curve.

Table 5: Working OIWI values and effort data of 51 wetland assessment units in RI

Wetunit	OIWI	Visits	Specimens	Species
		n	*n*	*n*
AUD-CARD-SWP	6.24	5	41	23
AUD-EPP-QR4	6.82	5	11	6
AUD-FISH-BRK	6.77	5	14	10
AUD-NEW-PND	5.82	4	53	24
PRV-ASHA-RIV2	5.04	6	17	13
PRV-BLRD-PARK	4.94	8	22	9
PRV-BOTH-PND	6.78	7	124	47
PRV-BRCH-STA1	6.01	6	64	36
PRV-BUTT-PND	5.32	4	20	12
PRV-CARR-PND	5.13	5	19	9
PRV-DMCR-PLAY	3.74	4	11	5
PRV-EVAN-PND	5.11	4	17	12
PRV-FORG-GRN1	6.10	18	55	23
PRV-GLAC-PND	6.16	8	54	22
PRV-GRSY-PND	6.69	8	19	7
PRV-HART-BOG	6.40	4	50	24
PRV-HUNT-STA3	5.37	5	57	21
PRV-JACK-SCPD	6.29	3	15	15
PRV-LONS-MRSH	5.13	5	15	10
PRV-MAIL-FEN	6.72	3	10	5
PRV-MITC-PND	4.85	3	25	13
PRV-MOSH-PND	4.78	10	55	17
PRV-MOW-BRK2	6.45	5	13	9
PRV-NOTT-PD1	4.50	4	16	11
PRV-PED-PND	6.46	4	28	14
PRV-PYSZ-FEN	6.26	10	34	19
PRV-R216-POW	6.28	5	16	13
PRV-SLTR-PRK0	5.49	5	16	11
PRV-SNAKE-POW	6.34	5	16	8
PRV-TEN-RIV1	5.17	10	36	19
PRV-THIR-PND	5.27	4	10	9
PRV-WAR-RES	4.95	14	43	21
PRV-WOON-STA3	5.14	10	34	16
PRV-WOON-STA4	4.95	4	22	11
PRV-XXX-PWT17	5.03	4	15	12
PRV-XXX-PWT5	5.65	6	26	15
SMA-ARC-BFFEN	7.16	8	26	17
SMA-ARC-MOON	5.93	7	13	8
SMA-ARC-RBPD	6.72	5	62	29
SMA-ARC-WD3	7.06	11	24	14
SMA-BIG-CAP	6.64	18	105	43
SMA-BUCK-PD1	5.88	6	34	21
SMA-CAR-FISH	6.29	16	37	18
SMA-CAR-WLPD	6.79	9	34	11
SMA-DUR-TEPE	6.53	5	55	29
SMA-GSW-CHIP7	6.36	3	18	11
SMA-GWMA-OKPD	5.92	7	32	19
SMA-WOO-IMP	6.24	17	99	34
TNC-CRTR-WET1	5.83	4	17	4
TNC-ELL-PND	6.64	3	14	8
TNC-XXX-QR2	6.74	30	69	37

Table 6: Spearman rank correlation coefficients of three measures of sampling effort versus working OIWI values among 51 wetland assessment units in RI

	OIWI	
	r_s	P
Number of Specimens	0.13	0.37
Number of Visits	0.17	0.23
Number of Species	0.15	0.30

3.2.3 Validation of RIRAM v.2

RIRAM Index values and working OIWI values were strongly correlated among the wetunits (Spearman rank, $r_s = 0.79$, $P < 0.0001$, $df = 50$; Fig. 8). After removing landscape metrics (which evaluate 100’ and 500’ buffers and comprise 20% of RIRAM Index) to eliminate a partial redundancy between RIRAM and OIWI (since OIWI CCs were derived using land-use bins), RIRAM and OIWI values were still strongly correlated ($r_s = 0.75$, $P < 0.0001$, $df = 50$).

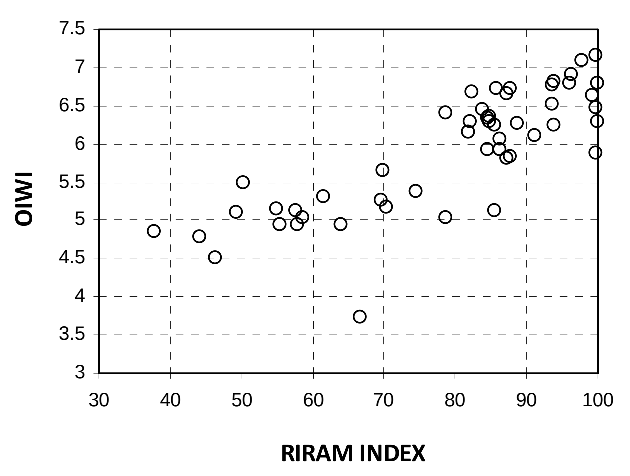

Figure 8: Working OIWI versus RIRAM Index values among the 51 wetunits in RI ($r_s = 0.79$, $P < 0.0001$)

Box-and-whisker and supporting probabilistic analyses were applied to determine if OIWI data could discriminate between RIRAM-identified reference-condition designations, on the premise that discrimination would (1) further indicate the proper function of OIWI as a wetland-condition bioindicator and (2) further demonstrate RIRAM's efficacy in establishing reference conditions for the bioassessment of wetlands. Designations were based on 25th and 75th percentile RIRAM Index scores, reflecting most-disturbed (MD; i.e. degraded) and least-disturbed (LD; i.e. reference-standard) wetunits among the study sample, respectively; all other wetunits were considered intermediately-disturbed (ID). The LD bin contained 13 wetunits ranging in RIRAM Index score from 93.6 to 100, the MD bin contained 13 units ranging in score from 37.9 to 66.7, and the ID bin contained 25 units ranging in score from 66.7 to 88.8 (Fig. 9).

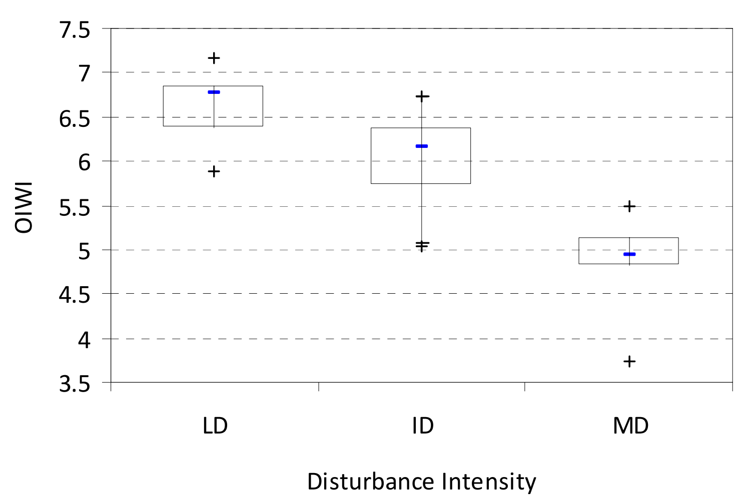

Figure 9: Box and whisker plots depicting the distribution of working OIWI values among three RIRAM-derived reference condition bins. The center dash represents the median, the box represents the interquartile range, the whiskers represent 5th and 95th percentiles, and the + symbols represent maximum and minimum values.

Interquartile ranges of working OIWI values among LD, ID, and MD bins were non-overlapping, indicating that OIWI effectively discriminated among all three of the RIRAM-derived designations. This was supported by Kruskal-Wallis *H*-test analysis (*H*

= 33.0, $P < 0.0001$, $df = 2$), which indicated a strong difference in the mean ranks of OIWI values among the three disturbance bins, and by Mann-Whitney *U*-test analysis, which indicated strongly significant differences in mean rank values between LD and ID ($Z = 3.49$, $P = 0.0005$), and between ID and MD ($Z = 4.6$, $P < 0.0001$) bins (considering a *Bonferroni*-adjusted critical *P* value of 0.015).

Neither working OIWI nor RIRAM Index values were significantly different among hydrogeomorphic (HGM) classes, including connected depressions ($n = 18$), floodplain riverine ($n = 16$), isolated depressions ($n = 14$), fringe ($n = 2$), and slope ($n = 1$) wetlands (Kruskal-Wallis, $P > 0.05$; Fig. 10). This indicates that HGM class did not strongly bias OIWI or RIRAM outcomes among the wetunits. Vegetation-based classes could not be analyzed in this way since more than one type was often represented within a single wetunit.

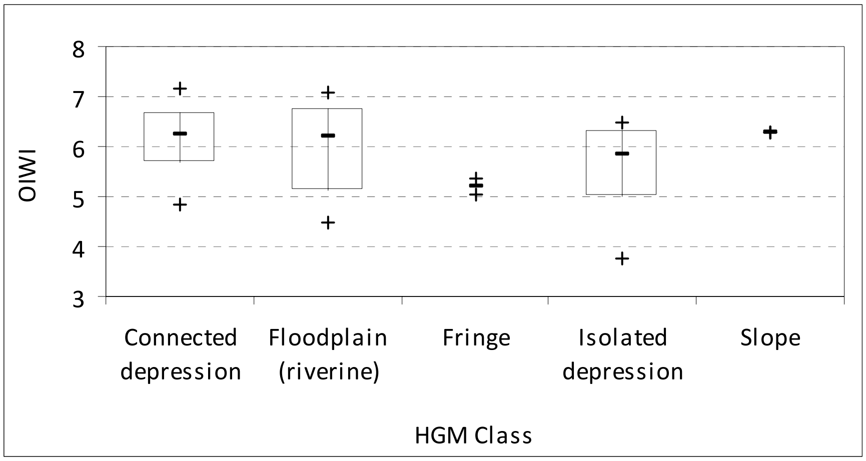

Figure 10: Box plots depicting the distribution of working OIWI values among five HGM wetland types. The center dash represents the median, the box represents the interquartile range, and the + symbols represent maximum and minimum values.

3.2.4 RIRAM-OIWI Associations

Two RIRAM landscape stress metrics were each strongly correlated with OIWI among the 50 wetunits. *Degradation of Buffers* (within 100' of the wetland edge) was more strongly correlated with OIWI ($r_s = 0.83$, $P < 0.0001$) than was any other RIRAM metric or index, including in-wetland metrics. *Intensity of Surrounding Land Use*, which evaluates land use intensity by weighted proportions in 500' buffer zone, was also strongly correlated with OIWI ($r_s = 0.80$, $P < 0.0001$). *Fluvial inputs* ($r_s = 0.70$, $P < 0.0001$) and *filling and dumping* ($r_s = 0.64$, $P < 0.0001$) were the in-wetland stresses most closely associated with OIWI values.

Integrity ranks among RIRAM wetland functional characteristics, *water and soil quality*, *habitat connectivity*, *vegetation composition*, and *habitat structure*, were nearly-evenly correlated with the OIWI (Table 7). This and a stronger correlation between the OIWI and *Observed State* (i.e. the sum of those submetrics) indicate that multiple factors contributed to OIWI variability. *Hydrologic integrity* was only moderately correlated with the index, indicating that anthropogenic disturbances to water flow and hydroperiod were not among the main drivers of OIWI variability in the study sample.

Table 7: Spearman rank correlation coefficients of RIRAM *Observed State* metric and sub-metric values versus working OIWI values among 51 wetland assessment units in RI

	OIWI	
RIRAM ***METRIC*** / Submetric	r_s	***P***
Hydrologic Integrity	0.58	<.0001
Water and Soil Quality	0.75	<.0001
Vegetation/Microhabitat Structure	0.71	<.0001
Vegetation Composition	0.70	<.0001
Habitat Connectivity	0.73	<.0001
D. OBSERVED STATE	0.81	<.0001

3.2.5 Refined CCs

RIRAM data were applied *a posteriori* to increase the precision of the working Odonata CCs. Three even bins of 17 wetunits were generated from sorted RIRAM Index values to represent least, intermediate, and most-disturbed wetlands. Binned wetunits were reintroduced into the training sample to supplement the LD, ID, and MD training bins, respectively, resulting in $n = 3 \times 187$ or 561 training sites from which to develop refined CCs. Because wetunits were among the most rigorously-sampled wetlands in the RIOA (see Sec. 2.2), and because RIRAM bin designation was based upon field-verified, high-resolution rapid assessment data, it was expected that the introduction of wetunit data in the training sample would measurably enhance the precision of the CCs and thus the OIWI in reflecting species conservancy.

Refined Odonata CCs ranged from 0 to 10 with a mean of 6.3 (Fig. 11). Species occurrence, by number of total sites, ranged from 1 to 144 with a median of 18, among the enhanced training sample of 561 sites. Refined CCs were assigned to rare species as best available information, even if species occurrences within the training sample were very low (see Sec. 3.3.1). Refined CCs, and the number of site occurrences each CC was generated from, are listed by species in App. 5.

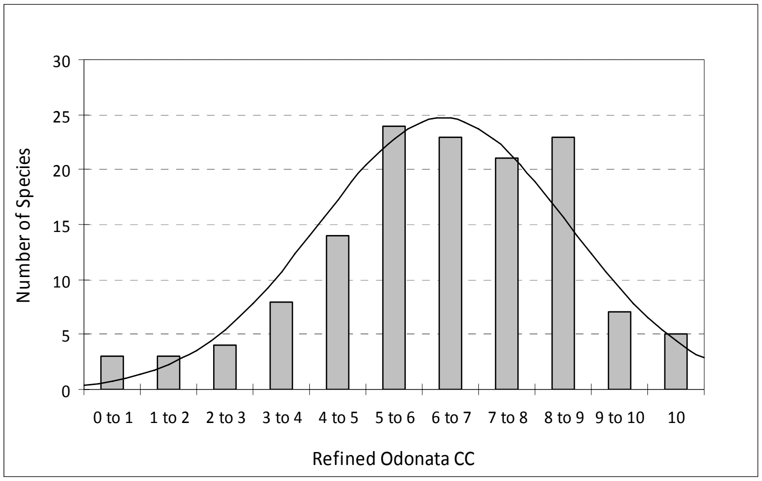

Figure 11: Distribution of refined Odonata CC values, for 135 Odonata species, derived from the Rhode Island Odonata Atlas. The line represents the smoothed distribution curve.

3.2.6 Refined OIWI

Refined OIWI values, calculated from refined Odonata CCs, ranged from 3.54 to 7.28 with a mean of 5.83 ± 0.88 among the 51 wetunits (Table 8). Recalculation of OIWI with refined CCs measurably strengthened OIWI correlation with RIRAM *Wetland Stress* (i.e. summed in-wetland stresses) and *Observed State* sub-index values and with the RIRAM Index overall (Table 9).

Table 8: Refined OIWI values and effort data from 51 wetland assessment units in RI

		Visits	Specimens	Species			Visits	Specimens	Species
Wetunit	**OIWI**	***n***	***n***	***n***	**Wetunit**	**OIWI**	***n***	***n***	***n***
AUD-CARD-SWP	6.17	5	41	23	PRV-R216-POW	6.02	5	16	13
AUD-EPP-QR4	7.12	5	11	6	PRV-SLTR-PRK0	5.30	5	16	11
AUD-FISH-BRK	6.79	5	14	10	PRV-SNAKE-POW	6.43	5	16	8
AUD-NEW-PND	5.83	4	53	24	PRV-TEN-RIV1	4.92	10	36	19
PRV-ASHA-RIV2	4.88	6	17	13	PRV-THIR-PND	5.10	4	10	9
PRV-BLRD-PARK	4.80	8	22	9	PRV-WAR-RES	4.73	14	43	21
PRV-BOTH-PND	6.82	7	124	47	PRV-WOON-STA3	4.96	10	34	16
PRV-BRCH-STA1	5.89	6	64	36	PRV-WOON-STA4	4.73	4	22	11
PRV-BUTT-PND	4.99	4	20	12	PRV-XXX-PWT17	4.88	4	15	12
PRV-CARR-PND	4.99	5	19	9	PRV-XXX-PWT5	5.31	6	26	15
PRV-DMCR-PLAY	3.54	4	11	5	SMA-ARC-BFFEN	7.29	8	26	17
PRV-EVAN-PND	4.87	4	17	12	SMA-ARC-MOON	5.94	7	13	8
PRV-FORG-GRN1	6.10	18	55	23	SMA-ARC-RBPD	6.77	5	62	29
PRV-GLAC-PND	6.24	8	54	22	SMA-ARC-WD3	7.15	11	24	14
PRV-GRSY-PND	6.67	8	19	7	SMA-BIG-CAP	6.54	18	105	43
PRV-HART-BOG	6.41	4	50	24	SMA-BUCK-PD1	5.85	6	34	21
PRV-HUNT-STA3	5.18	5	57	21	SMA-CAR-FISH	6.47	16	37	18
PRV-JACK-SCPD	5.95	3	15	15	SMA-CAR-WLPD	7.04	9	34	11
PRV-LONS-MRSH	4.92	5	15	10	SMA-DUR-TEPE	6.63	5	55	29
PRV-MAIL-FEN	6.90	3	10	5	SMA-GSW-CHIP7	6.16	3	18	11
PRV-MITC-PND	4.78	3	25	13	SMA-GWMA-OKPD	5.80	7	32	19
PRV-MOSH-PND	4.68	10	55	17	SMA-WOO-IMP	6.14	17	99	34
PRV-MOW-BRK2	6.27	5	13	9	TNC-CRTR-WET1	6.15	4	17	4
PRV-NOTT-PD1	4.33	4	16	11	TNC-ELL-PND	6.74	3	14	8
PRV-PED-PND	6.57	4	28	14	TNC-XXX-QR2	6.69	30	69	37
PRV-PYSZ-FEN	6.34	10	34	19					

Table 9: Spearman rank correlation coefficients of RIRAM v.2.10 Index and sub-index values versus working and refined OIWI values at 51 wet assessment units in RI

	Working OIWI		Refined OIWI	
Sub-index / Index	r_s	*P*	r_s	*P*
B. LANDSCAPE STRESS	0.84	<0.0001	0.84	<0.0001
C. WETLAND STRESS	0.73	<0.0001	0.77	<0.0001
D. OBSERVED STATE	0.81	<0.0001	0.83	<0.0001
RIRAM INDEX	0.79	<0.0001	0.82	<0.0001

3.4 Impervious Surface Area and Wetland Condition

Percent impervious surface area within the surrounding 1000’ of the wetunits (%ISA-1000) ranged from 0.00 to 62.4 with a mean of 10.0 ± 14.0 and a median of 3.28 (Fig. 12; Table 10). Percent ISA-1000 was strongly negatively correlated with all RIRAM indices and with the refined OIWI among the 51 wetunits (Fig 13; Table 11). An expected, very strong correlation was found between ISA and the functionally related RIRAM *Landscape Stress* (LS) sub-index. However, the data indicate that this is not the sole mechanism driving ISA-RIRAM covariance. Percent ISA-1000 strongly correlated with *RIRAM minus Landscape*; *Observed State*; *Wetland Stress*; and OIWI indices, as well as with several individual RIRAM metrics (Tables 11 and 12).

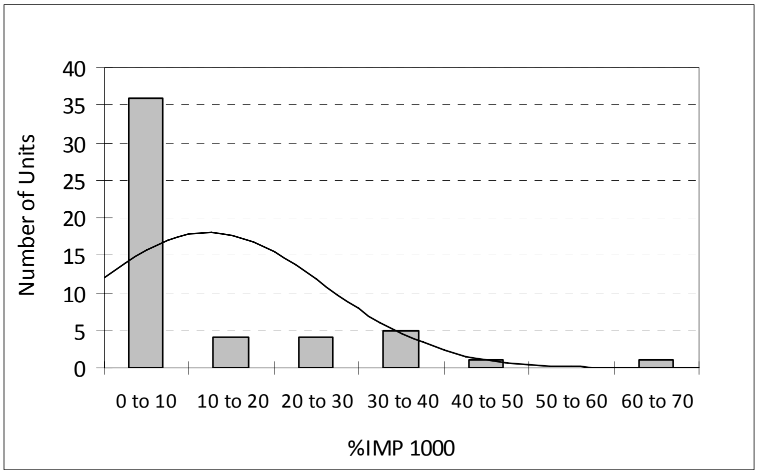

Figure 12: Distribution of percent impervious area within 1000’ of 51 wetland assessment units in Rhode Island. The line represents the smoothed distribution curve.

Table 10: Percent impervious surface area (ISA) within 1000’ of 51 wetland assessment units in Rhode Island. ISA values were derived from impervious cover data based on 2007 imagery (RIGIS 2011).

Wetunit	% ISA	Wetunit	% ISA	Wetunit	% ISA
AUD-CARD-SWP	0.4	PRV-JACK-SCPD	1.6	PRV-XXX-PWT17	41.1
AUD-EPP-QR4	2.9	PRV-LONS-MRSH	18.9	PRV-XXX-PWT5	20.1
AUD-FISH-BRK	1.6	PRV-MAIL-FEN	2.0	SMA-ARC-BFFEN	0.0
AUD-NEW-PND	3.3	PRV-MITC-PND	6.7	SMA-ARC-MOON	8.3
PRV-ASHA-RIV2	4.8	PRV-MOSH-PND	62.4	SMA-ARC-RBPD	0.8
PRV-BLRD-PARK	13.2	PRV-MOW-BRK2	5.9	SMA-ARC-WD3	0.7
PRV-BOTH-PND	0.3	PRV-NOTT-PD1	33.8	SMA-BIG-CAP	0.7
PRV-BRCH-STA1	3.2	PRV-PED-PND	0.5	SMA-BUCK-PD1	0.7
PRV-BUTT-PND	12.2	PRV-PYSZ-FEN	3.1	SMA-CAR-FISH	0.0
PRV-CARR-PND	4.2	PRV-R216-POW	5.0	SMA-CAR-WLPD	0.0
PRV-DMCR-PLAY	21.0	PRV-SLTR-PRK0	30.8	SMA-DUR-TEPE	0.6
PRV-EVAN-PND	37.9	PRV-SNAKE-POW	1.6	SMA-GSW-CHIP7	1.5
PRV-FORG-GRN1	0.2	PRV-TEN-RIV1	24.7	SMA-GWMA-OKPD	1.2
PRV-GLAC-PND	6.3	PRV-THIR-PND	4.8	SMA-WOO-IMP	0.5
PRV-GRSY-PND	2.7	PRV-WAR-RES	5.5	TNC-CRTR-WET1	3.6
PRV-HART-BOG	22.7	PRV-WOON-STA3	37.8	TNC-ELL-PND	1.1
PRV-HUNT-STA3	13.2	PRV-WOON-STA4	34.9	TNC-XXX-QR2	0.8

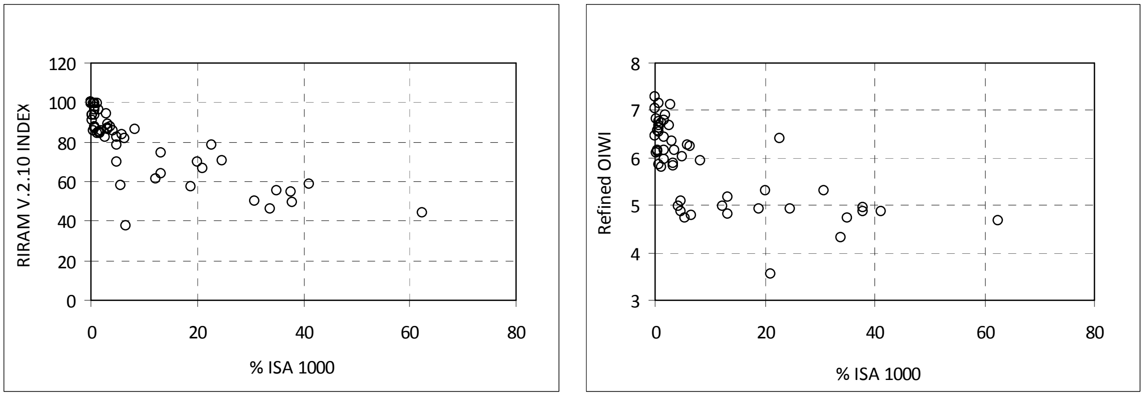

Figure 13: Scatterplots depicting the relationship between % impervious surface area within 1000' (%ISA-1000) and two measures of wetland condition among 51 assessment units in Rhode Island. Correlation coefficient values are presented in Table 11.

Table 11: Spearman rank correlation coefficients of % ISA within 1000' versus RIRAM v.2.10 Index and sub-index values and refined OIWI values at 51 wet assessment units in RI

	% ISA	
	r_s	***P***
RIRAM V.2.10 INDEX	-0.88	<0.0001
B. LANDSCAPE STRESS	-0.92	<0.0001
C. WETLAND STRESS	-0.79	<0.0001
D. OBSERVED STATE	-0.85	<0.0001
RIRAM* Minus *LS	-0.81	<0.0001
Refined OIWI	-0.76	<0.0001

Table 12: Spearman rank correlation coefficients of % ISA within 1000' versus RIRAM v.2.10 metric values at 51 wet assessment units in RI. NS = not significant considering a *Bonferroni*-adjusted critical *P* value of 0.006

	% ISA-1000
Metrics	***r_s***
Stresses	
1. Degradation of Buffers	-0.87
2. Surrounding Land Use	-0.91
3. Impoundment	NS
4. Draining or diversion	0.52
5. Fluvial inputs	0.81
6. Filling and Dumping	0.73
7. Substrate disturbances	0.43
8. Vegetation or detritus removal	NS
9. Invasive species cover	0.67
Functional Characteristics	
Hydrologic Integrity	-0.55
Water and Soil Quality	-0.81
Vegetation/Microhabitat Structure	-0.67
Vegetation Composition	-0.72
Habitat Connectivity	-0.85

The clustered, steep drop-off in both RIRAM and OIWI index values with increasing ISA-1000 (Fig 13) suggests that considerable wetland degradation occurred in landscapes having less than 10% ISA. Box and whisker analysis supports this finding. Reference designations reflecting RIRAM Index-derived reference (LD; *n* = 13), intermediate (ID; *n* = 25), and degraded (MD; *n* = 13) wetlands were applied to examine where these categories fall in relation to ISA-1000. Figure 13 indicates that: reference wetlands occurred primarily below ~1 % surrounding ISA; the majority of intermediately disturbed wetlands ranged between 1% and 6% ISA; and wetlands in landscapes with ~13% or greater ISA were likely to be degraded (Fig. 14). Similarly, reference designations, derived from refined OIWI quartile values and representing LD (*n* = 13), ID (*n* = 25), and MD (*n* = 13) categories according to Odonata conservatism, indicate that: reference wetlands occurred primarily below ~2 % surrounding ISA; the majority of intermediately disturbed wetlands occurred between 1% and 7% ISA; and wetlands in landscapes with ~10% or greater ISA were likely to be degraded (Fig. 15).

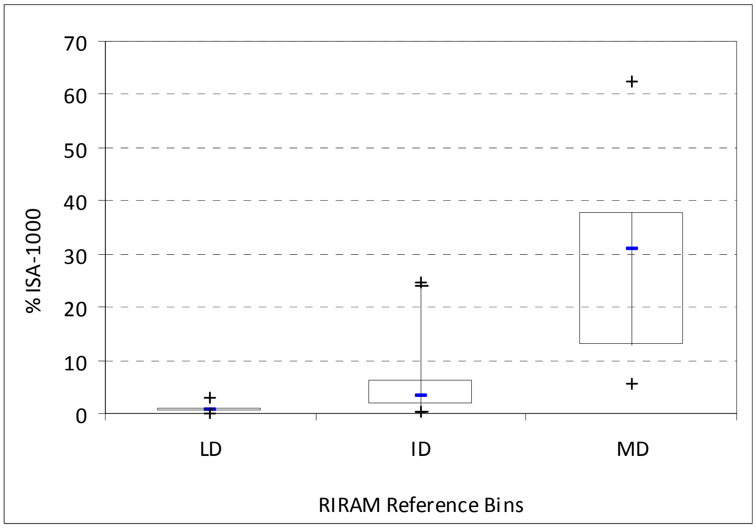

Figure 14: Box and whisker plots depicting the distribution of % ISA values among three RIRAM-derived reference condition bins. The center dash represents the median, the box represents the interquartile range, the whiskers represent 5th and 95th percentiles, and the + symbols represent maximum and minimum values.

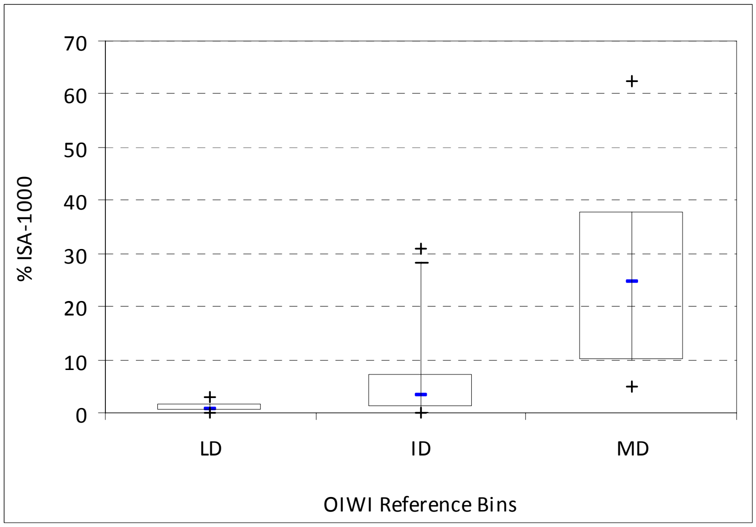

Figure 15: Box and whisker plots depicting the distribution of % ISA values among three OIWI-derived reference condition bins. The center dash represents the median, the box represents the interquartile range, the whiskers represent 5th and 95th percentiles, and the + symbols represent maximum and minimum values.

By both RIRAM and OIWI index measures, all LD wetlands occurred in landscapes with less than 3% surrounding ISA; and LD and MD distributions were entirely non-overlapping along the % ISA gradient, suggesting consistency among all measures in discriminating among wetland condition designations (Figs. 14 and 15). These findings were supported by Kruskal-Wallis *H*-test (non-parametric ANOVA analogue); mean rank of % ISA differed among RIRAM-derived LD, ID, and MD bins ($H = 32.8$, $P < 0.0001$, $df = 2$) and among OIWI-derived bins ($H = 26.7$, $P < 0.0001$, $df = 2$). Mann-Whitney *U*-test analysis further indicated that the mean rank of % ISA differed among *all* bins for both indices ($Z = 2.78$ to 4.23, $P < 0.015$ for all), considering a *Bonferroni*-adjusted critical P value of 0.015.

4. Discussion

4.1 Study Sample Implications

The study sample was drawn from the RIOA, which targeted likely Odonata habitats throughout Rhode Island. Specifically, the sample was drawn from a stratified subset of the RIOA sites, where the subset was based on the site being a wetland and meeting sampling effort criteria, and stratification was based on surrounding land use intensity. Otherwise, the drawing was non-targeted. Although it was not drawn from all potential Odonata habitats in a strictly random manor (which was beyond the immediate scope of this study) this sample may provide a reasonable representation of Odonata habitat for Rhode Island, and likely represents the best available information of this type for the State.

RIRAM Index values indicate that the study sample included wetland habitats ranging in condition from nearly-pristine to very-degraded. Index distributions support earlier assertions that RIRAM index scores follow an approximate academic grading curve, making the interpretation of results intuitive for users (Kutcher 2010b and 2011). Index values did not differ among the HGM classes; sites were nearly-evenly distributed among connected depressions, isolated depressions, and floodplain riverine wetlands, but flat and slope wetlands were poorly represented. This sampling inequality is likely a result of RIOA efforts targeting natal Odonata habitats (i.e. wetlands with long-hydroperiod pools or ponds, or along rivers) over other wetland types. It is unknown whether this limits the applicability of the results of this effort to HGM wetland-types best represented in this study, but respective cautions should be taken until this has been determined through further study.

Analyses in this report suggest that surrounding land use, fluvial inputs, buffer degradation, and filling-dumping were the dominant stresses affecting the overall integrity of the wetunits, according to the *Observed State* index. These same four stresses were also most closely correlated with OIWI (-), % impervious surface area (+), and invasive species cover (+). Prior applications of RIRAM v.2 have reported the relative dominance of other stresses including invasive species cover, draining or diversion of water, impoundment, and substrate disturbances (Kutcher 2010b and 2011a), suggesting that the prevalence of this suite of stresses is specifically representative of the study sample. To the extent that the study sample represents core habitat for Rhode Island's Odonata (wetlands containing odonates, plus the surrounding upland), it may follow that these are the stresses most strongly affecting Odonata habitat integrity and species composition in the State.

4.2 RIRAM v.2.10 Validation

RIRAM's strong correlations with the working (independent) OIWI ($r_s = 0.79$, $P < 0.001$) and %ISA-1000 ($r_s = 0.88$, $P < 0.001$) clearly indicate that these three independent indices reflected a strongly connected or overlapping set of variables; in this case a wide range of ecological variables associated with wetland condition, which is evaluated by RIRAM. This strongly supports previous work demonstrating RIRAM's proper function in generating an effective and meaningful relative index of wetland condition. Credibility for this assertion lies in the distinctly different premises and mechanisms each method operates under. Foremost, each method was independently developed applying separate, established ecological principals, setting a solid expectation that each would indicate relative wetland condition, independently. RIRAM was developed on the premises that the cumulative effects of multiple prevailing stresses can largely determine wetland condition (e.g. U.S. EPA 2002a; Sifneos et al. 2010) and that wetland condition is a state of change from full integrity (i.e. ability to perform expected functions; e.g. Fennessy et al. 2004; U.S. EPA 2006a), among others; OIWI was developed on the premises that species composition, with regard to conservatism, can predictably respond to wetland condition (e.g. Andreas et al. 2004; Micacchion 2004), that indicator species can be identified through empirical analysis of monitoring data (Dufrene and Legendre 1997), and that Odonata may be reliable indicators of overall wetland condition (e.g. U.S. EPA 2002b; Bried and Ervin 2006); and % ISA-1000 was applied under the premises that the % of surrounding impervious surface is strongly associated with surface water degradation and that wetland condition is strongly associated with surrounding landscape integrity (e.g. Karr and Chu 1997; U.S. EPA 2006a; Kutcher 2010a, 2010b, and 2011a). Also, the methods evaluate condition by largely separate mechanisms. RIRAM measures wetland condition by summarizing and evaluating in-wetland and directly adjacent stresses, and observable wetland integrity; OIWI measures biological response to wetland condition; while %ISA-1000 measures a largely indirect indicator of stress.

The correlation of RIRAM and OIWI is comparable or stronger than correlations found in similar studies comparing freshwater wetland rapid assessment data to independent L3 data. Andreas et al. (2004) reported a fairly strong correlation between the Ohio Rapid Assessment Method (ORAM) and FQAI scores ($r \sim 0.72^*$, $P < 0.001$) among 157 wetlands of various types in Ohio, while Ervin et al. (2006) found a modest correlation between FQAI and an Anthropogenic Activity Index among 53 wetlands in Mississippi ($r \sim 0.49^*$, $P < 0.001$). Micacchion (2004) found a modest correlation between ORAM and an Amphibian Quality Assessment Index (AQAI) based on amphibian CCs ($r \sim 0.58^*$, $P < 0.001$) among 53 vernal ponds in Ohio, and reported a stronger correlation between ORAM and a multi-metric amphibian IBI ($r \sim 0.71^*$, $P < 0.001$, $df = 52$). Stein et al. (2009) reported that the California Rapid Assessment Method (CRAM) correlated with a benthic macroinvertebrate IBI ($r_s = 0.64$, $P < 0.001$), percent cover of non-native plants ($r_s = -0.34$, $P = 0.04$), and species richness of birds ($r_s = 0.30$, $P = 0.06$), among riverine wetlands in California. And Sifneos et al. (2010) reported that (before its calibration to the latter) the Delaware Rapid Assessment Procedure (DERAP) strongly correlated with an L3 Index of Wetland Condition (IWC), which was based on numerous vegetation, hydrology, and buffer metrics derived from HGM monitoring data (Jacobs et al. 2009), among Flat ($r = 0.76$, $df = 123$), Riverine ($r = 0.82$, $df = 84$), and Depressional ($r = 0.73$, $df = 47$) wetlands in Delaware.

Although they are not often directly applied in RAM validations, landscape-level (L1) indicators can provide coarse but reliable measures of ecological condition. Indeed,

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[*] For comparison, relationships reported by determination coefficients (r^2) were converted to Pearson correlation coefficients (r) by taking the square root.

landscape data are widely used to determine preliminary and final gradients applied in the development of more highly-regarded L3 bioindicators, as they are applied in this study. The strong correlation of RIRAM and %ISA-1000 provides reliable supporting information on the functionality of RIRAM, particularly in producing a viable gradient of relative condition, which is valuable in establishing reference conditions for reference-based assessment.

This study also demonstrated the efficacy of RIRAM in establishing meaningful reference designations, based on *reference standard* (LD), intermediate (ID), and degraded (MD) condition. Here, RIRAM functioned as a central component of a three-level monitoring and assessment program, supplying high-resolution, quantitative information to evaluate the efficacy of, and refine, L1 and L3 data. The study found significant interactions among RIRAM, ISA, and OIWI in discriminating among index-derived reference designations. These interactions further validate RIRAM and indicate proper function all three indices. For example, similar functionality demonstrated by RIRAM and OIWI, in providing reference designations for analyzing % ISA disturbance-ranges (Fig. 14 and 15), clearly demonstrates their precision and utility through providing strongly concurring information.

Actual *P*-values generated in correlation analyses between RIRAM and OIWI and between RIRAM and %ISA-1000 indicate a nearly non-existent chance of error (less than one in one hundred billion) in concluding that these indicators similarly reflect variability in overall wetland condition as broadly represented by RIRAM v.2.10 (see datasheet, App. 1). OIWI was refined by bolstering the training data with study-site data to maximize the potential of the RIOA dataset in generating precise Odonata CCs; this was not done to improve correlation strength with RIRAM specifically. Stronger agreement (approaching $r = 1$) among these indices should not be expected or pursued because surrounding land use (e.g. ISA) cannot possibly account for all variability in wetland condition (e.g. RIRAM), and wetland condition cannot possibly account for all variability in wetland species composition (e.g. OIWI), due to other sources of variability. Further, no single index can fully represent wetland condition in all contexts of the various functions and values ascribed to wetlands; i.e. no "gold standard" of wetland condition is likely to exist (Stein et al. 2009).

Calibrating rapid assessment models can strengthen correlations with a specific (usually L3) assessment index. However, such direct calibration may have drawbacks, including a loss of scoring flexibility, the loss of function for underutilized metrics, and biases associated with the representativeness of the sample and the training index (Sifneos et al. 2010; Stein et al. 2010, respectively). Rather than working to maximize correlation with a single index, demonstrating correlation with multiple ecologically sound measures of wetland condition under varying circumstances may be a more sound and effective process of validation (Stein et al. 2009; personal opinion). Building on earlier findings (e.g. Kutcher 2010a, 2010b, and 2011), this study applies a *weight of evidence* approach to establish a case of concurring evidence based on RIRAM's relationship with independent indicators: here, a simple yet dependable physical landscape indicator (ISA) and an intensive biological response indicator (OIWI). The interactions among these data put each method in context with the others. Over time, this approach can transparently set each method in broad context against an array of methods and indicators that characterize wetland condition, thereby reducing uncertainties (Stein et al. 2009).

4.3 Odonata Index of Wetland Integrity

Through box and whisker analysis and strong correlations with RIRAM (r_s = 0.79 versus Working OIWI) and % ISA (r_s = -0.76 versus final OIWI), this study demonstrates the potential of OIWI as a single-metric bioindicator and suggests the utility of adult Odonata in the evaluation of freshwater wetland condition. Box and whisker analysis indicates excellent sensitivity of OIWI to the RIRAM designations of reference (LD) and degraded (MD) condition, as indicated by non-overlapping interquartile ranges. Indeed, the *entire* OIWI distributions for LD and MD wetunits were non-overlapping and OIWI interquartile ranges among all three designations (LD, ID, and MD) were non-overlapping; this strongly suggests excellent metric performance (Vaselka and Anderson 2010). The strength of inter-metric correlations are comparable to similar studies evaluating bioindicator efficacy against independent measures of ecological condition (refer to Sec. 4.2). Nearly identical operation of RIRAM and OIWI in %ISA-1000 box and whisker analyses further indicates the potential utility of OIWI in providing an adequately precise and reliable L3 measure.

Nearly-even, strong correlations among OIWI and the integrity ranks of four of five RIRAM wetland functional characteristics (Table 7) indicates that multiple environmental factors associated with wetland condition may affect habitat suitability for conservative Odonata species. This further suggests that multiple mechanisms may operate in determining habitat suitability among the diverse Odonata species. A stronger correlation between the OIWI and *Observed State* (i.e. the sum of the functional characteristics submetrics) suggests that cumulative wetland impacts may have the strongest overall effect on overall Odonata composition per OIWI. This essentially exemplifies the concepts behind species conservatism and bioindicator effectiveness in representing overall wetland condition, further supporting the validity of OIWI.

Because OIWI is a single-metric indicator of condition, it is straightforward and easily understood, and may thus be more effective than multi-metric indices in confidently representing wetland condition. OIWI is based on the simple premise that certain species show higher fidelity to undisturbed wetlands than others and that the species assemblage at a given site can therefore reflect the relative intensity of disturbance. Species were assigned coefficients of fidelity (CCs) based on a straightforward, empirical application of extensive data. Therefore, given its continued performance in comparative validation analyses, such as presented in this report, the soundness of OIWI as a bioindicator is nearly indisputable. Bioindicators, that employ numerous metrics calibrated to an often coarse or subjective gradient of condition (such as best professional judgment), can contain biases and hidden information that cannot easily be understood and rectified, thus they cannot be as confidently applied by the end user.

In this study, OIWI was based on Mean CC partly because an index based on the original FQAI formula was not possible under the constraints of the RIOA dataset. However, prior studies have suggested that Mean-CC may be a more effective indicator of ecological condition, in any case. For example, Rooney and Rogers (2002) presented a strong case asserting that Mean-CC is a more meaningful measure of ecological condition than FQAI, which they found to be largely affected by area-based sampling effort. And, Cohen et al. (2004) found that Mean CC of plant species was considerably more-strongly correlated with a Landscape Development Index than was FQAI among 75 isolated-depressional herbaceous wetlands in Florida

Although this study utilized Mean CC to evaluate wetland condition, other valuable and effective metrics could be derived from RIOA data. For example, in exploratory analysis, proportion of species with low conservatism (CC ≤ 5.0) was similar with working OIWI in correlating with RIRAM. And in a pilot analysis, proportion of rare species per site (< 20 site occurrences in the RIOA) was modestly correlated with surrounding land use intensity (as a pilot proxy for wetland condition).

This study utilized three training groups, representing LD, ID, and MD wetlands, to maximize CC precision. However, in applications collecting new Odonata training data, it may be more efficient and effective to employ two groups, at the expense of losing ID information. This study found that comparable results can be achieved utilizing LD and MD groups only, equaling one-third less monitoring effort at training sites and simpler CC computations, utilizing a single IndVal rather than averaging two. Such simplified CCs would not contain uncertainties that can result from incorporating a third group. For example, a CC of 7.5 for a given species, generated from two groups, clearly indicates that three times as many LD sites contain the species than MD sites; whereas if this same value is generated from three groups, the relative frequently the species occurs among LD, MD, and ID is less clear, although the general pattern is still evident. This project addressed this uncertainty by listing species occurrences per disturbance-class alongside species CCs in App. 5, but this may be cumbersome in some applications.

RIOA sampling effort was greater among LD sites than among ID and MD sites in both the training sample and the study sample. This raised some concern that the greater sampling effort among LD sites would artificially increase the CC values of species having low detectability—since they would be more likely to be found with greater sampling effort—and in turn artificially raise the OIWI among units with higher effort. However, OIWI was not correlated with any measure of sampling effort, indicating that sampling inequality did not influence its relative evaluation of wetland condition.

Although study findings may suggest that minimum thresholds applied to the study sample would constitute an adequate sampling protocol, effort should be considered for State implementation. The least rigorously-sampled wetunit in this study inventoried ten specimens in three site visits. Sixteen (31%) of the wetunits were visited five times or less (≤5) and < 20 specimens were identified at 21 (41%) of the units. Ideally, Odonata would be rigorously sampled over an entire season to ensure that a complete species inventory is collected. However, because sampling resources are often limited, it may be necessary to develop and test a streamlined standard protocol with enough sampling rigor to generate results similar to those presented in this study. For practical purposes, a sampling protocol requiring three or four standardized site visits spread across the breeding season and imposing a minimum specimen threshold (of perhaps 15 or 20), may provide CCs and IOWI values sufficiently precise for monitoring purposes; data from such a protocol would almost certainly be as sound as RIOA data applied to generate OIWI values for wetunits in this study.

Expert review concluded that refined Odonata CCs were overall accurate representations of species conservatism in Rhode Island with specific caveats (V. Brown, personal communication). Coefficient values of species that occur primarily in brackish waters may be influenced by circumstance since in Rhode Island, as elsewhere, coastal areas are more highly-developed than inland areas. Brackish species include *Enallagma durum*, *Erythrodiplax berenice*, *Ishnura ramburii*, and *Libellula needhami*. Next, species with low representation in the training sample (and low occurrence rate in Rhode Island) may not be accurately represented by the CC; examples include *Aeshna mutata*, *Anax longipes*, *Progomphus obscurus*, *Gomphaeschna antilope*, and *Nehalennia integricollis*. However, since these species are locally rare, the likelihood of any one or combination of these species strongly affecting an OIWI assessment at any given wetland in Rhode Island is low. Finally, the number of species documented at certain wetunits may be artificially low due to targeted early-season sampling during RIOA inventory efforts; such wetunits may include PRV-MAIL-FEN, SMA-ARC-MOON, and TNC-CRTR-WET1. It is unknown whether this may have affected the OIWI values at these units relative to the RIRAM, OIWI, or ISA gradients.

Finally, it should be made clear that the OIWI was designed to indicate overall wetland condition and is not intended indicate habitat suitability for Odonata, per se. Accordingly, effectively *any* use of a wetland by adult Odonata was counted in empirically generating species CCs and in generating OIWI per site. Otherwise important ecological factors, such as natality, sex ratios, obligate hydrology, structure, vegetation, etc., were not considered in OIWI assessment. Species occurrence was intended to indicate overall wetland condition by each species' relative affinity to LD, ID, and MD wetlands in the adult stage, disregarding the mechanisms of the relationship. Given the complexities of, and interactions among, the various landscape and in-wetland stresses, wetland integrity, and Odonata composition, specific mechanisms would likely need to be studied on a per-species basis, which was well beyond the scope of this study. An index indicating Odonata suitability, specifically, may need to consider species traits, such as ecological importance, niche width, and rareness; other species composition factors, such as richness or evenness; and habitat factors not considered in the OIWI. Further, *adult* Odonata may be an ineffective indicator of a wetland's suitability for successful Odonata reproduction, since adults may forage, mate, and oviposit in and around non-supporting pools (Raebel et al. 2010).

4.4 Impervious Surface Area

Karr and Chu (1997) propose that % ISA provides an effective surrogate for human influence because it can summarize and reflect multiple effects of stress; findings in this present study concur. Percent ISA-1000 was significantly correlated with seven of nine RIRAM Stress metrics and was negatively correlated with the integrity ranks of all five wetland functional characteristics evaluated in the RIRAM *Observed State* sub-index (Tables 12 and 11). This suggests the effectiveness of ISA as an indicator of overall wetland condition, reflecting associations with a broad spectrum of stresses and elements of wetland integrity. Overall, %ISA-1000 was strongly correlated with the RIRAM Index ($r_s = -0.88$) and with the OIWI ($r_s = -0.76$). After removing *Landscape Stress* scores from RIRAM (20% of RIRAM Index), RIRAM and %ISA-1000 were still strongly correlated ($r_s = -0.81$), indicating that the relationship was not solely driven by RIRAM's incorporation of landscape metrics.

Comparable studies directly comparing the relationship of ISA with wetland bioindicators could not be found. However the findings of this study support earlier findings that increased surrounding urbanization can affect wetland and surface-water suitability for certain biota. In a related wetland-based study, Richter and Azous (1995) found that amphibian species richness was correlated with % urbanization among 19 depressional wetlands in Washington State (r ~ 0.63[*], P < 0.01). In related stream-based studies, Ourso and Fresnel (2003) found that aquatic macroinvertebrate tolerance to pollution (a measure analogous to conservatism), according to the Hilsenhoff Biotic Index, was closely related to % ISA within the upstream subcatchments of 12 streams in Alaska ($r_s = 0.75$, P = 0.005); and similarly, DaSilva (2005) found that a related Family Biotic Index was closely related to % ISA among 41 subcatchments in Rhode Island ($r_s = 0.79$, P <0.001).

The correlation of %ISA-1000 with RIRAM was comparable or stronger than values found in studies applying more complex, weighted landscape models. Brown and Vivas (2005) reported a strong correlation between a Wetland Rapid Assessment Procedure and a complex land-use-based Landscape Development Intensity (LDI) index applied within 100m of depressional wetlands in Florida (r ~ 0.84[*], P = 0.05). And, Stein et al. (2009) reported that the California Rapid Assessment Method was modestly correlated with an LDI applied within 200m of 95 riverine wetlands in California ($r_s = -0.59$, $P < 0.01$). Earlier RIRAM demonstration and development studies found that RIRAM v.2.08 correlated with % cultural land cover within 300m ($r_s = -0.66$, $P < 0.01$, $df = 49$) across wetland types (Kutcher, unpublished data); and RIRAM v.2.09 correlated with % cultural land cover in a surrounding 500' to 1000' ($r_s = -0.74$, $P < 0.01$, $df = 49$) among Atlantic white cedar swamps (Kutcher 2011a). Findings of this present study suggest that %ISA-1000 may perform as well or better than simple and complex land-use-based models in indicating wetland condition, indicating its relative utility as an L1 indicator. Another advantage of ISA over such models is straightforward application, lending repeatability and objectivity.

Thresholds of ISA have been identified to help watershed and municipal managers and planners evaluate and predict the effects of urbanization on surface waters. However, no studies known to this author have previously evaluated thresholds of ISA in specific regard to wetland condition. In a summary of ISA literature and knowledge, Arnold (1996) first reported thresholds of impervious surface in relation to the degradation to

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[*] For comparison, relationships reported by determination coefficients (r^2) were converted to Pearson correlation coefficients (r) by taking the square root.

stream health as follows: <10% indicates protected condition; 10%-30% indicates impacted condition; and >30% indicates degraded condition. More recently, Ourso and Frenzel (2003) reported threshold responses to 8 physical and biological variables occurring at approximately 5% ISA. Findings of this present study identified ISA thresholds in relation to wetland condition through discrimination of ISA values among RIRAM and OIWI reference designations. Approximate thresholds could be represented as follows: <2% indicated least-disturbed condition; 2%-10% indicated intermediately-disturbed (i.e. degrading) condition; and >10% indicated most disturbed (i.e. degraded) condition.

These relatively low thresholds may result from factors that can be illustrated using OIWI as the more independent indicator of wetland condition. First, while stream condition is largely associated with water quality and hydrologic integrity, wetland condition (as evaluated by OIWI) was additionally associated with other functional ecological variables that were significantly negatively associated with %ISA-1000, including habitat structure, vegetation composition, and habitat connectivity (Tables 7 and 12, respectively). The synergy of multiple wetland impacts associated with ISA may have a relatively strong effect at these lower ISA levels. Further, by design, %ISA-1000 represents impervious cover out to only 1000’, whereas other studies have generally utilized subcatchments, potentially evaluating ISA from relatively distant areas. More proximate ISA may have a stronger affect on surface water systems at lower levels. And lastly, OIWI was strongly (and likely, directly) influenced by proximate surrounding landscape degradation (see Sections 3.2.4 and 4.5), which %ISA-1000, in part, directly reflects; again, such a direct impact may be effective at reported ISA levels.

4.5 Other Findings

While the mechanisms of the relationship between OIWI and RIRAM cannot be fully determined without further study, correlation outcomes between OIWI and RIRAM may provide some preliminary information. Strong correlations between OIWI and proximate landscape stresses indicate that the condition surrounding uplands may have a strong effect on the composition of Odonata at a given wetland. A strong correlation between OIWI and the RIRAM metric *Surrounding Land Use*, a weighted landscape model evaluating the condition of surrounding lands within 500’ (~150m) complements the work of Bried and Ervin (2006), who found near-even Odonata activity throughout a 160m-wide zone; Bried and Ervin’s work indicates essential use of surrounding upland habitat, while this present work indicates Odonata response to its degradation. Together, these findings clearly support prior assertions that surrounding uplands should be considered core Odonata habitat.

RIRAM *Observed State* was designed to represent the integrity of wetland characteristics that largely control many wetland functions and values; thus a strong negative correlation between *Observed State* and %ISA-1000 indicates that wetland functionality may decrease with increasing ISA. This may suggest that wetlands are not perpetually effective at buffering the impacts of increasing ISA; rather, their functionality may be exhausted by the process. Box plot analysis indicates that significant wetland degradation can occur at a fairly low level of impervious cover (i.e. 2%-7%; Figs. 15 and 16); this may partly account for the decline (threshold effect) in surface water condition at similarly low surrounding ISA (e.g. Ourso and Frenzel 2003).

Impacted hydrology is generally considered one of the strongest mechanisms linking ISA to the degradation of stream condition. Surprisingly, observed changes in *hydrologic integrity* were less strongly (although still highly significantly) related to OIWI than the other submetrics comprising RIRAM *Observed State*. This may stem from the numerous long-abandoned mill impoundments occurring throughout Rhode Island; many such impoundments were represented in the study sample, across the condition gradient. Impoundments located in presently developed areas among multiple other stresses would likely rate poorly by RIRAM and OIWI. However, many abandoned impoundments located in relatively undisturbed settings now function as minimally-disturbed lentic waters and wetlands; such wetlands may rate highly by both RIRAM and OIWI. The presence of such wetlands in the study sample could minimize the influence of impoundment on the indices.

4.6 Study Implications

This study used a *weight of evidence* approach to clearly demonstrate the precision and validity of RIRAM v.2.10 in evaluating relative freshwater wetland condition, establishing a reference gradient and reference-based condition bins, and refining and evaluating the efficacy of new assessment methods. Building on prior work, this effort further establishes RIRAM as an efficient, reliable, and effective tool that can be used in addressing multiple program objectives, reporting to federal agencies, and developing a long-term State-wide monitoring and assessment inventory.

The study also expands the freshwater wetland monitoring and assessment toolbox for the State, demonstrating the efficacy of a reliable and repeatable L1 assessment method and a meaningful L3 bioindicator of wetland condition. Specifically, study findings indicate that existing impervious surface and Odonata datasets could supply valuable information on wetland condition that could be broadly used to support the evaluation of wetland condition in the State. Further development and application of these new indicators will allow the State to further apply the tiered assessment approach to support various program needs.

The distinct assessment levels will provide information most appropriate for specific needs. For example, using automated GIS technology, %ISA-1000 (L1) could be applied to broadly characterize or predict changes in wetland condition across large areas, such as watersheds, municipalities, or Statewide. RIRAM (L2) data could be applied to more-precisely evaluate a sample representing a resource or area of concern, supplying valuable information on various components of condition that can be used for analysis, reporting, management, and affecting policy. Level 3 tools, such as OIWI, could be applied in evaluating wetland functional response to management actions. For example, L3 assessment may be particularly useful for evaluating the success of restoration or mitigation efforts, since it is an independent measure of biological response. Level 1 (e.g. %ISA-1000) and L2 (e.g. RIRAM) indices are largely measures of cause, thus they would essentially provide a scored tally of what has been mitigated; response to mitigation may be a stronger indicator of success in such cases. Combinations of the three levels of assessment could be employed to specific wetlands, areas, or resources in cases where a *weight of evidence* approach is desired to increase reliability or defensibility.

The successful functionality of OIWI broadens the utility of the RIOA. In its current form, the RIOA may be useful to a broad spectrum of stakeholders in applications ranging from recreational bug-watching to supporting State permitting and policy decisions. As an outcome of analysis, this effort has generated CCs for 135 Odonata species and an OIWI index for every (1090) RIOA inventory site. OIWI information added to the RIOA geospatial dataset will allow investigators to point to a wetland of concern and view or download Odonata species occurrences, the OIWI index score, the OIWI designation as LD, ID, or MD condition, and the number of species utilized in OIWI generation as an indication of index reliability. These data could be used to characterize wetland condition regarding an area or sample of concern, run analyses of cause and effect, or be combined with other information to assess the relative condition of specific wetlands. Likewise, thus study demonstrates the efficacy of the State's impervious surface dataset in indicating wetland condition, an application not previously recognized; this may add a great deal of utility to these data, as well.

Finally, this project may act as a rough template for future studies aimed toward developing and testing wetland monitoring and assessment tools, utilizing the EPA-endorsed *tiered* approach. The template can be summarized as follows:

1. Select a study sample (and an independent training sample, if applicable) across a preliminary gradient of surrounding land intensity. Utilizing a reference *gradient* enables the characterization of LD conditions and the verification or calibration of indicator response to disturbance, whereas simply identifying reference *standard* sites provides a characterization of LD conditions, but does not provide information to calibrate response to disturbances (U.S. EPA 2002b).
2. Establish a final reference gradient among the study units utilizing validated, high-resolution (L2) RAM data, such as RIRAM v.2.10. Only a high-resolution and dependable gradient should be used to calibrate or evaluate the efficacy of an indicator, since it acts as a standard against which the test data are measured. Utilizing a coarse or ineffective gradient would likely give imprecise or spurious results, since they can only be as reliable as the "weakest link". However, strong, highly significant correlations (i.e. $r \geq 0.70$ and $P < 0.01$) among ecologically-sound indicators indicate proper functionality of each.
3. Develop the new indicator by applying previously-tested ecological principles. Each metric should be based on the premise that it *should* indicate wetland condition. Indicators may vary considerably in content and complexity, ranging from single-metric indicators, such as those developed and tested in this study, to multi-metric IBIs incorporating biological and physical data in various proportions to maximize correlation to a specific gradient. Simple, understandable indices are generally more effective in communicating results (Sec. 4.3).
4. If the indicator metrics are to be derived strictly by applying ecological principles, no training sample is required. If metrics are to be derived empirically (as in this

study), develop them from an independent training sample and test them on the study sample. To further minimize circularity, reference gradients for the training and study samples should ideally be established by separate sound methods (e.g. by surrounding land use and a RAM, as in this study).

5. Utilizing data collected from the study sample, test the indicator against the RAM data and other available, tested gradients. Use non-parametric statistics for analyses involving any model containing prescribed metric values, such as those in a RAM or multi-metric IBI. Although more precise (and complex) methods certainly exist, correlation analysis and associated scatterplots provide straightforward information that is easily understood and interpreted because it contains minimal hidden information and allows visual interpretation of results (Karr and Chu 1997). Box and whisker plots can provide effective and practical means to evaluate the efficacy of an indicator to discriminate among independently-generated reference designations (Barbour et al. 1996, Vaselka et al. 2010). The ability of an indicator to discriminate among reference designations is often important for policy, management, and outreach in establishing, identifying, and communicating basic (e.g. pristine, intermediate, and disturbed) conditions.
6. Lastly, put the results in further context. Compare the results to similar studies and applications. Interpret the results in the context of environmental function. For example, condition can never account for *all* the variability in biological composition, so what amount can be expected? Determine whether the project results imply that the indicator is precise or otherwise useful enough support project objectives. If so, justify why this is the case and explain how and why the indicator should be applied.

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Appendix 1

Rhode Island Rapid Assessment Method version 2.10 Field Datasheet

RIRAM V.2.10 Investigators____________________________________ Site Code_____________ Date_________

A. Wetland Characteristics; apply to the *current* state of the wetland. Not Scored.

1) Assessment Unit Area; select one:

☐ <0.25 acres
☐ 0.25 to <1.0 acres
☐ 1.0 to <3.0 acres
☐ 3.0 to <10 acres
☐ 10 to <25 acres
☐ 25 to 50 acres
☐ >50 acres

2) Hydrologic Characteristics

Source of water; select main source:

☐ Precipitation
☐ Groundwater
☐ Surface water

Maximum water depth, today; select one:

☐ Dry
☐ Saturated
☐ <1 foot
☐ 1 to 3 feet
☐ >3 feet

Water Regime; select one or two dominant regimes:

☐ Permanently flooded
☐ Semi-permanently flooded
☐ Seasonally flooded
☐ Temporarily flooded
☐ Permanently saturated
☐ Seasonally saturated
☐ Regularly flooded (tidal)
☐ Irregularly flooded (tidal)

3) Habitat Characteristics

Habitat stratum diversity; estimate total cover of all habitat strata within unit using classes at right:

___ Trees
___ Shrubs
___ Emergent
___ Aquatic bed
___ Sphagnum
___ Surface water, today
___ Unvegetated substrate, today

Cover Classes:
0…..< 1%
1…..1-5%
2…..6-25%
3…..26-50%
4…..51-75%
5…..>75%

Microhabitat diversity; rate each present using the scale at right:

___ Vegetated hummocks or tussocks
___ Coarse woody debris
___ Standing dead trees
___ Amphibian breeding habitat

Ecological Significance Scale:
0…..None Noted
1…..Minor Feature
2…..Significant Feature
3…..Dominant Feature

4) Wetland Classification

Hydrogeomorphic Class; select main one:

☐ Isolated Depression
☐ Connected Depression
☐ Floodplain (riverine)
☐ Fringe
☐ Slope
☐ Flat

NWI Classes; select all comprising unit and indicate *Dominance Type*:

☐ Forested ____
☐ Scrub-shrub ____
☐ Emergent ____
☐ Aquatic Bed ____
☐ Unconsolidated Bottom or Shore
☐ Rock Bottom or Shore

RINHP natural community types; select all present within unit:

☐ Freshwater tidal marsh*
☐ Interdunal swale*
☐ Intermittent stream
☐ Eutrophic Pond
☐ Coastal plain pondshore*
☐ Coastal plain quagmire*
☐ Deep emergent marsh
☐ Shallow emergent marsh
☐ Emergent fen*
☐ Dwarf shrub bog / fen*
☐ Dwarf tree bog*
☐ Scrub-shrub wetland
☐ Floodplain Forest*
☐ Red Maple Swamp
☐ Vernal pool*
☐ Hemlock-hardwood swamp
☐ Atlantic white cedar swamp*
☐ Black Spruce Bog*
☐ Other Type: ___________________________

5) Wetland values; select all known or observed:

☐ Within 100 year flood plain
☐ Between stream or lake and human use
☐ Part of a habitat complex or corridor
☐ Falls in aquifer recharge zone
☐ Contains known T/E species
☐ Significant avian habitat
☐ Contains *GCN** habitat type
☐ Educational or historic significance

---

*Identified by DEM as habitat of *Greatest Conservation Need*

RIRAM V.2.10 Investigators______________________________________ Site Code______________ Date__________

B. Landscape Stresses. Sum metrics 1 and 2

1) Degradation of Buffers

Estimate % cultural cover within 100-foot buffer. Select one.

- ☐ <5% (10)
- ☐ 6 to 25% (7)
- ☐ 26-50% (4)
- ☐ 51-75% (1)
- ☐ >75% (0)

Associated Stressors: Check all that apply

- ☐ Commercial or industrial development
- ☐ Unsewered Residential development
- ☐ Sewered Residential development
- ☐ New construction
- ☐ Landfill or waste disposal
- ☐ Channelized streams or ditches
- ☐ Raised road beds
- ☐ Foot paths / trails
- ☐ Row crops, turf, or nursery plants
- ☐ Poultry or livestock operations
- ☐ Orchards, hay fields, or pasture
- ☐ Piers, docks, or boat ramps
- ☐ Golf courses / recreational development
- ☐ Sand and gravel operations
- ☐ Other ______________________________

2) Intensity of Surrounding Land Use

Land Use Intensity weighted average within 500-foot buffer.
Estimate proportion of each class to the nearest tenth and multiply.

	Proportion	Score	Weighted Value
Very Low	______	× 10 =	______
Low	______	× 7 =	______
Moderately High	______	× 4 =	______
High	______	× 1 =	______

Sum weighted values for score = ______

Very Low	Natural areas, open water
Low	Recovering natural lands, passive recreation, low trails/dirt roads
Mod High	Residential, pasture/hay, mowed areas, raised roads to 2-lane
High	Urban, impervious land cover, new construction, row crops, turf crops, mining operations, paved roads > 2-lane

Sum of Metrics 1 and 2 = **B. Landscape Stress Score**

C. Wetland Stresses. Sum metrics 3 to 9 and subtract from 70.

3) Impoundment.

Sum a and b (Max = 10)

a. Increase in depth or hydroperiod. Select one and multiply by the proportion of the unit affected to the nearest tenth. = _________

- ☐ None (0)
- ☐ Wetland was *created* by impoundment (1)
- ☐ Change in velocity only (2)
- ☐ Change of less than one water regime (4)
- ☐ Change of one water regime (6)
- ☐ Change of two or more water regimes (8)
- ☐ Change to deepwater (10)

Proportion of unit affected (circle one)
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

Evidence: check all that apply

- ☐ Physical barrier across flow downstream of wetland
- ☐ Abrupt and unnatural edge downstream of wetland
- ☐ Dam or restricting culvert downstream of wetland
- ☐ Deepening of wetland upstream of barrier
- ☐ Widening of wetland upstream of barrier
- ☐ Change in vegetation across barrier
- ☐ Dead or dying vegetation

Primary Associated Stressor; check one:

- ☐ Road
- ☐ Railway
- ☐ Weir / Dam
- ☐ Raised Trail
- ☐ Development Fill
- ☐ Other

b. Artificial barrier to movement of resources through water. Select all that apply and sum. = _________

- ☐ None (0)
- ☐ Barrier to upstream movement at low water (1)
- ☐ Barrier to downstream movement at low water (1)
- ☐ Barrier to upstream or downstream movement above low water (1)

Primary Source of Stress; indicate as current (C) or historic (H):

__ Private / Residential
__ Commercial
__ Agricultural
__ Public transportation
__ Public utilities
__ Public recreation
__ Undetermined

Water Regimes

(Upland)	Temporarily Flooded	Irregularly Flooded
Seasonally Saturated	Seasonally Flooded	Regularly Flooded
Permanently Saturated	Semi-permanently Flooded	
	Permanently Flooded	

RIRAM V.2.10 Investigators____________________________________ Site Code_____________ Date_________

4) Draining or diversion of water from wetland.

Decrease in depth or hydroperiod. Select one and multiply by the proportion of the unit affected to the nearest tenth.

- ☐ None (0)
- ☐ Change in velocity only (3)
- ☐ Change of less than one water regime (5)
- ☐ Change of one water regime (7)
- ☐ Change of two or more water regimes or to upland (10)

Water Regimes

(Upland)……………………………….Temporarily Flooded………….. Irregularly Flooded
Seasonally Saturated ……………Seasonally Flooded………………..Regularly Flooded
Permanently Saturated …………Semi-Permanently Flooded
Permanently Flooded

Proportion of unit affected (circle one)
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

Evidence: check all that apply

- ☐ Drainage ditches or tiles evident
- ☐ Evident impoundment upstream of wetland
- ☐ Severe root exposure
- ☐ Moderate root exposure
- ☐ Soil fissures
- ☐ Uncharacteristically dry groundcover
- ☐ Dead or dying vegetation
- ☐ Change in vegetation across barrier

Primary Associated Stressor; Check one:

- ☐ Road
- ☐ Railway
- ☐ Dike
- ☐ Fill
- ☐ Drainage ditch / tile
- ☐ Major well withdrawals
- ☐ Surface water pumps
- ☐ Other

Primary Source of Stress; indicate as current (C) or historic (H):

__ Private / Residential
__ Commercial
__ Agricultural
__ Public transportation
__ Public utilities
__ Public recreation
__ Undetermined

5) Anthropogenic fluvial inputs.

Rank the evidence of impact for each and sum (Max = 10).

_____ a. Nutrients

_____ b. Sediments / Solids

_____ c. Toxins / Salts

_____ d. Increased flashiness

Evidence-of-Impact Ranks

0…..No evidence
1…..Sources evident, only
3…..Slight impact evident
5…..Moderate to strong impact evident

Evidence: check all that apply

- ☐ Runoff sources evident
- ☐ Point sources evident
- ☐ Excessive algae or floating vegetation
- ☐ Excessive rooted submerged or emergent vegetation
- ☐ Uncharacteristic sediments
- ☐ Obvious plumes or suspended solids
- ☐ Chemical smell
- ☐ Strangely tinted water
- ☐ Dead, dying, or patchy vegetation
- ☐ Dead fauna or stark lack of life
- ☐ Root exposure or bank erosion due to scouring

Primary Associated Stressor; Check one:

- ☐ Point runoff
- ☐ Sheet runoff
- ☐ Effluent discharge
- ☐ Organic / yard waste
- ☐ Other point _________________
- ☐ Riverine (up-stream)
- ☐ Multiple / non-point
- ☐ Channelization

Primary Source of Stress; indicate as current (C) or historic (H):

__ Private / Residential
__ Commercial
__ Agricultural
__ Public transportation
__ Public utilities
__ Public recreation
__ Multiple / non-point
__ Undetermined

6) Filling and dumping within wetland. Select one and multiply by the proportion of the unit affected to the nearest tenth (Max = 10).

Intensity of filling

- ☐ None (0)
- ☐ Affects aesthetics only (2)
- ☐ Affects water regime, vegetation, or soil quality (6)
- ☐ Changes area to upland (10)
- ☐ Fill is above surrounding upland grade (12)

Proportion of unit (or perimeter) affected (circle one)
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

Evidence: check all that apply

- ☐ Unnaturally abrupt change in ground level
- ☐ Abrupt change in soil texture or content
- ☐ Unnaturally straight or abrupt wetland edge
- ☐ Unnatural items on or within the sediments

Primary Associated Stressor; Check one:

- ☐ Road
- ☐ Raised Trail
- ☐ Railway
- ☐ Trash
- ☐ Fill
- ☐ Organic / yard waste
- ☐ Dam
- ☐ Dike
- ☐ Other

Primary Source of Stress; indicate as current (C) or historic (H):

__ Private / Residential
__ Commercial
__ Agricultural
__ Public transportation
__ Public utilities
__ Public recreation
__ Undetermined

RIRAM V.2.10 Investigators____________________________________ Site Code_____________ Date_________

7) Excavation and other substrate disturbances within wetland. Select one and multiply by the proportion of the unit affected to the nearest tenth.

Intensity of disturbance
- ☐ None (0)
- ☐ Wetland unit was *created* by excavation (1)
- ☐ Soil quality or vegetation disturbed (4)
- ☐ Changes water regime (7)
- ☐ Excavated to deep water (10)

Proportion of unit (or perimeter) affected (circle one)
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

Evidence: check all that apply
- ☐ Unnaturally abrupt lowering in ground level
- ☐ Loss of vegetation
- ☐ Unnaturally straight and abrupt wetland edge
- ☐ Direct evidence of disturbance

Primary Associated Stressor; Check one:
- ☐ Vehicle disturbance
- ☐ Plowing / cultivation
- ☐ Excavation / Grading
- ☐ Channelization / Dredging
- ☐ Ditching
- ☐ Footpaths
- ☐ Trampling
- ☐ Other

Primary Source of Stress; indicate as current (C) or historic (H):
- __ Private / Residential
- __ Commercial
- __ Agricultural
- __ Public transportation
- __ Public utilities
- __ Public recreation
- __ Undetermined

8) Vegetation and detritus removal within wetland. Rank extent and multiply by the estimated proportion affected for each layer; then sum (Max = 10).

Layers affected	Extent		Proportion		
☐ Aquatic Bed	______	×	________	=	________
☐ Detritus	______	×	________	=	________
☐ Emergent	______	×	________	=	________
☐ Shrub	______	×	________	=	________
☐ Canopy	______	×	________	=	________

Sum =________

Proportion of unit affected
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

Evidence: check all that apply
- ☐ Cut stems or stumps
- ☐ Immature vegetation strata
- ☐ Missing vegetation strata
- ☐ Mowed areas
- ☐ Browsing or grazing

Extent of removal
0.....None
2.....Partial or recovering
3.....Complete

Primary Associated Stressor; Check one:
- ☐ Power lines
- ☐ Grazing
- ☐ Cultivation
- ☐ Timber Harvest
- ☐ Development clearing
- ☐ Trails / non-raised roads
- ☐ Excavation / ditching
- ☐ Other

Primary Source of Stress; indicate as current (C) or historic (H):
- __ Private / Residential
- __ Commercial
- __ Agricultural
- __ Public transportation
- __ Public utilities
- __ Public recreation
- __ Undetermined

9) Invasive species within wetland.

9a. Select one class for total coverage.
- ☐ None noted (0)
- ☐ Nearly absent <5% cover (2)............Cover Class 1
- ☐ Low 6-25% cover (4)..........................Cover Class 2
- ☐ Moderate 26-50% cover (6).............Cover Class 3
- ☐ High 51-75% cover (8).......................Cover Class 4
- ☐ Extensive >75% cover (10)................Cover Class 5

9b. List and select a cover class for each invasive plant species noted.

Cover Class	Species
_____	____
_____	____
_____	____
_____	____
_____	____

Primary Abutting Stressor; Check one:
- ☐ Road
- ☐ Railway
- ☐ Raised Trail
- ☐ Footpath
- ☐ Dam / Dike
- ☐ Organic / yard waste
- ☐ Other Fill
- ☐ Drainage ditch / tile
- ☐ Stormwater input
- ☐ Clearing
- ☐ Multiple
- ☐ Other

Primary Source of Stress; indicate as current (C) or historic (H):
- __ Private / Residential
- __ Commercial
- __ Agricultural
- __ Undetermined
- __ Public transportation
- __ Public utilities
- __ Public recreation

Sum of C3 to C9 Scores = ☐ **70 Minus Sum =** ☐ **C. Wetland Stress Score**

RIRAM V.2.10 Investigators________________________________ Site Code____________ Date_________

D. Observed State of Wetland Characteristics. Circle one score for each characteristic and sum.
Refer to Sections A through C to inform scores. Consider current wetland types.

Characteristics	Characteristic[*]		Degraded		Destroyed
Hydrologic Integrity……………………………………	2	1.5	1	0.5	0
Water and Soil Quality…………………………………	2	1.5	1	0.5	0
Vegetation/microhabitat Structure………………	2	1.5	1	0.5	0
Vegetation Composition………………………………	2	1.5	1	0.5	0
Habitat Connectivity……………………………………	2	1.5	1	0.5	0

SUM = ☐ **D. Observed State Score**

B. Landscape Stress Score (max 20) __________ +

C. Wetland Stress Score (max 70) __________ =

B+C. Total Stress Score (max 90) ☐

D. Observed State Score (max 10) __________ =

RIRAM V. 2.10 Condition Index ☐

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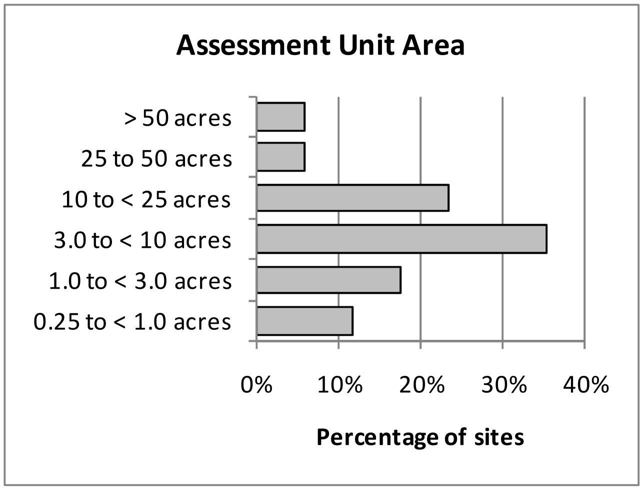
[*] Characteristic of wetland type in an unstressed setting

Appendix 2

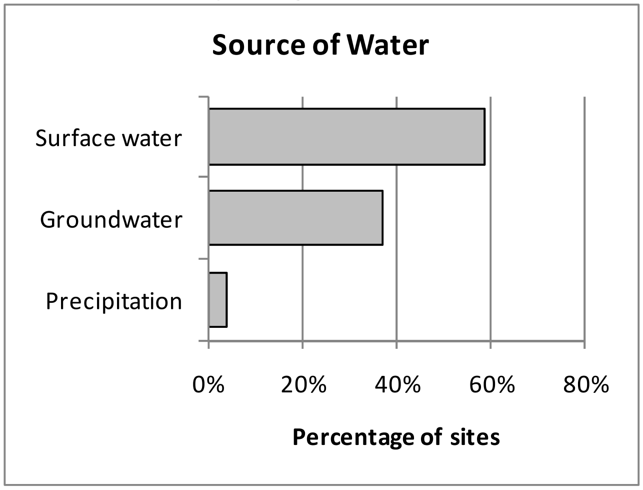
Graphical Summary of RIRAM Results from 51 Wetland Assessment Units in Rhode Island

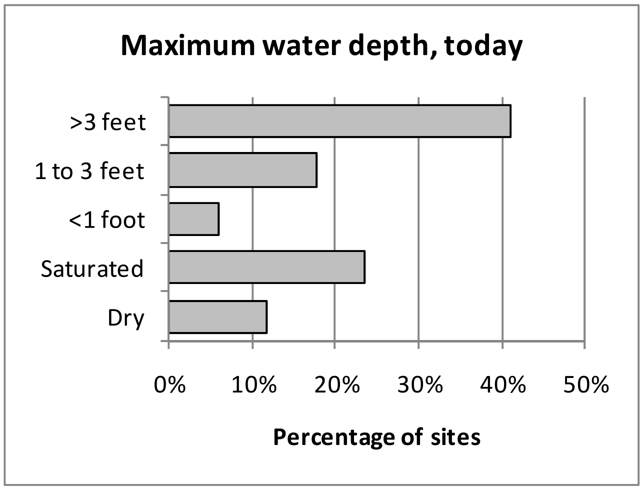
A. Wetland Characteristics

1. Assessment Unit Area

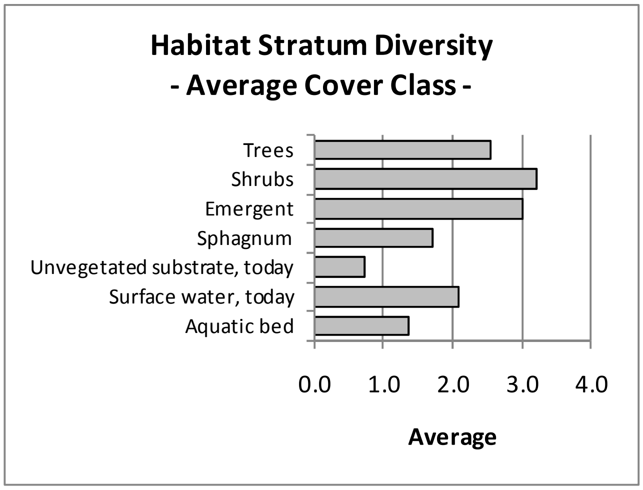


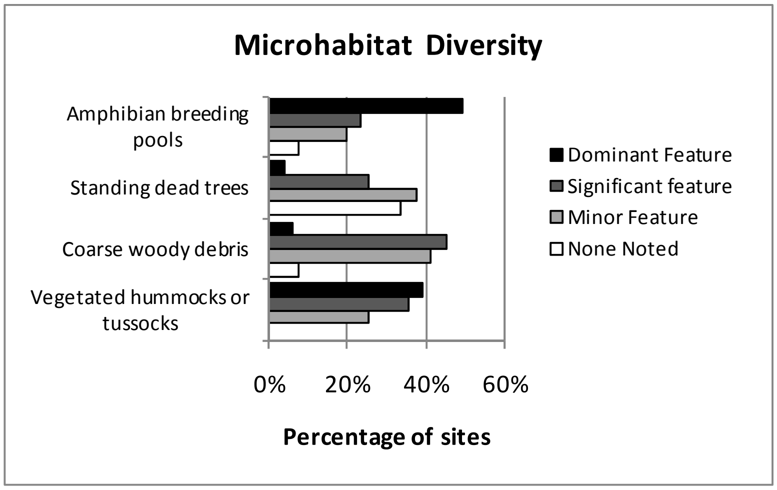
2. Hydrologic Characteristics



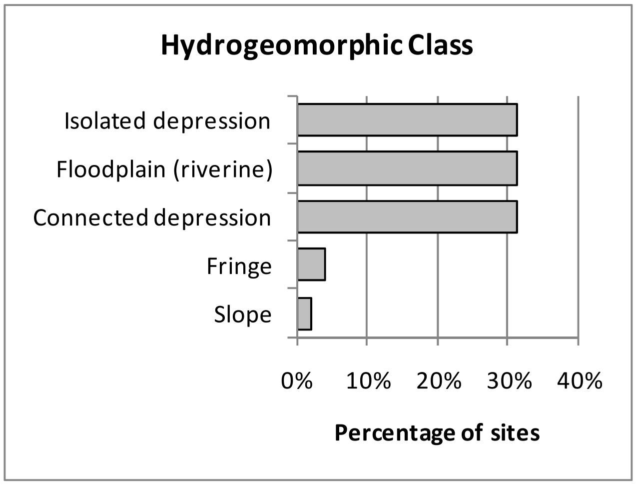


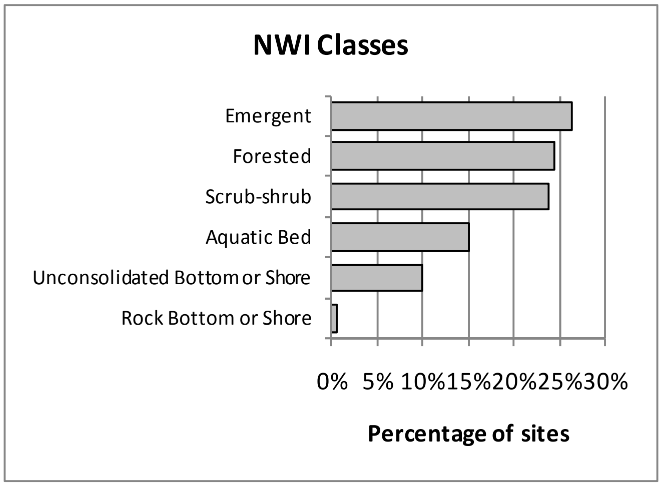
3. Habitat Characteristics

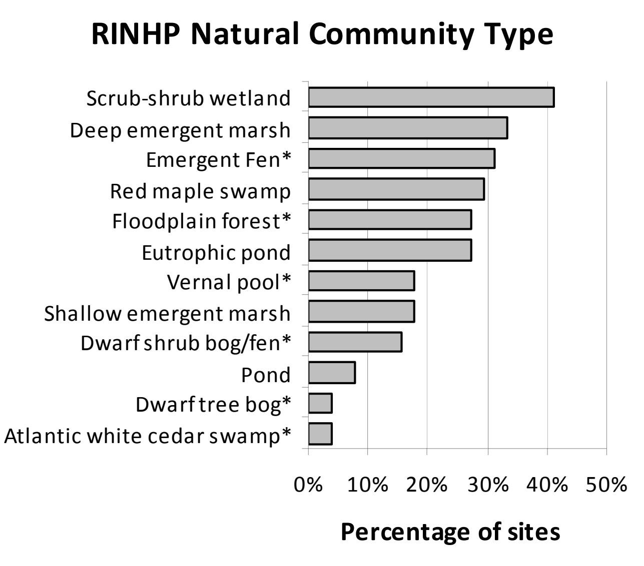




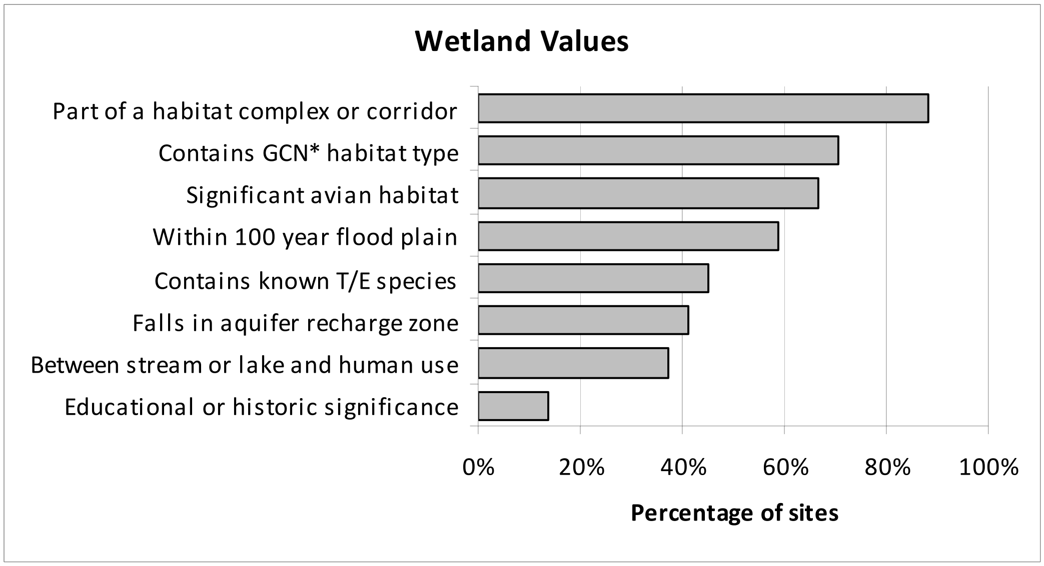
4. Wetland Classification





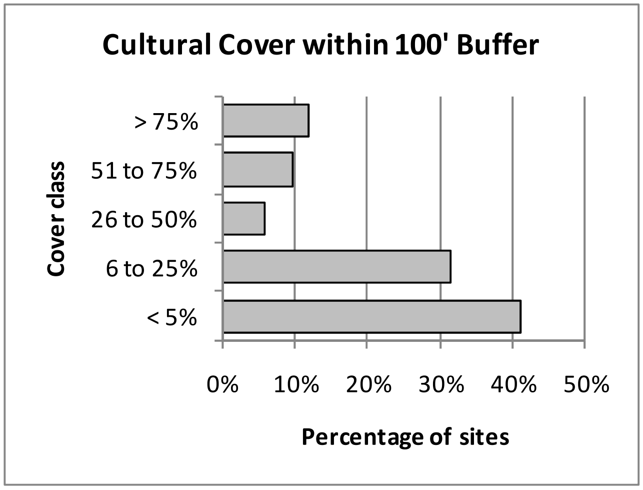


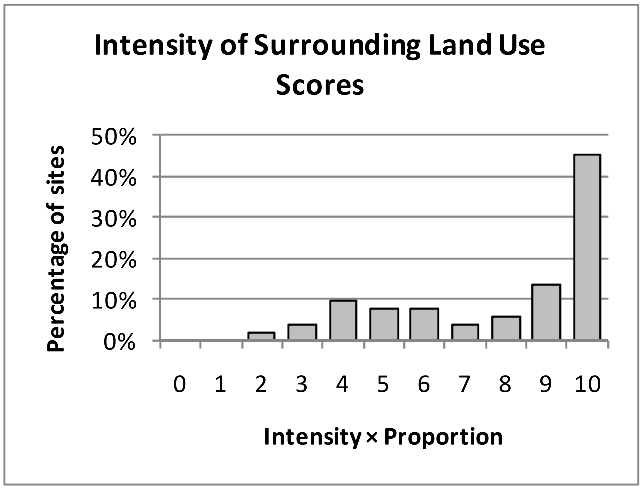
5. Wetland Values

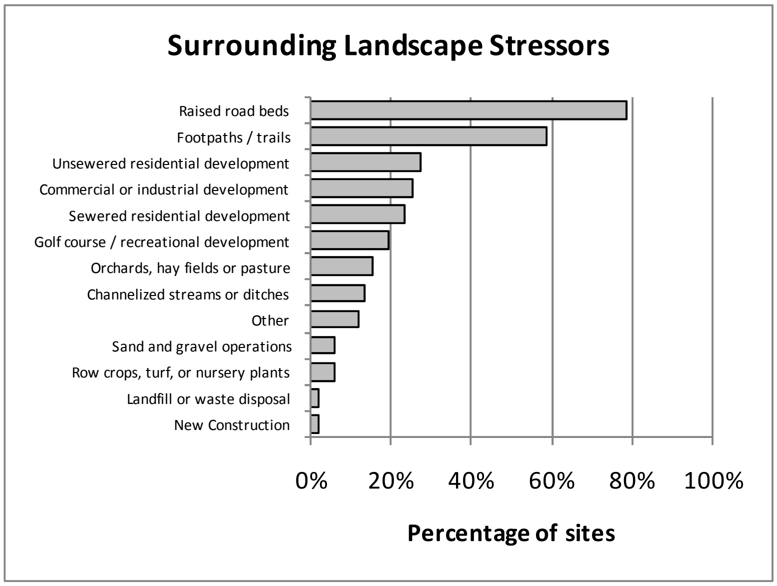


B. Landscape Stresses

1. Degradation of Buffers & 2. Intensity of Surrounding Land Use

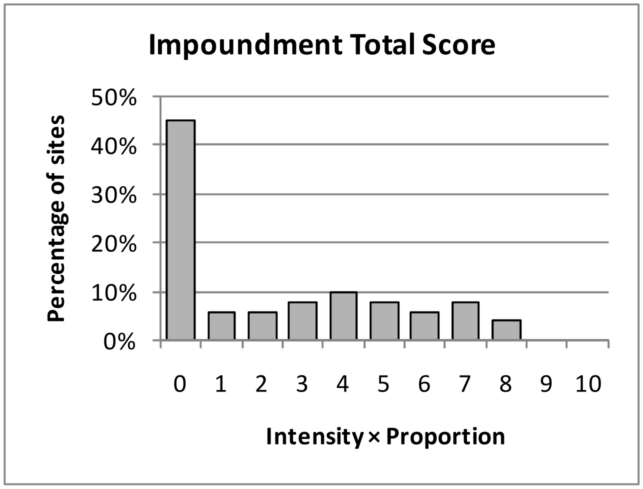


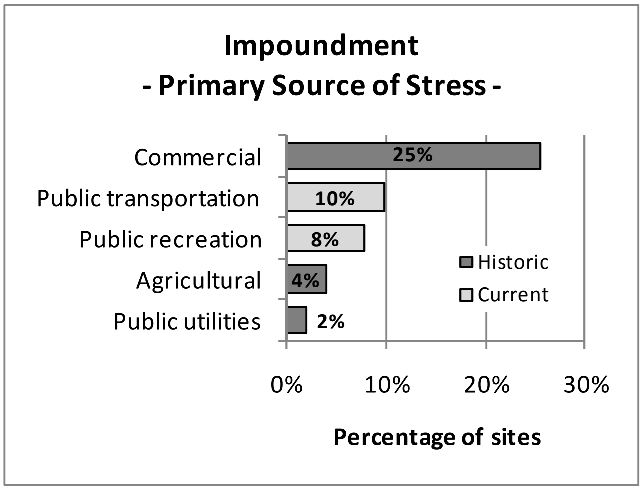


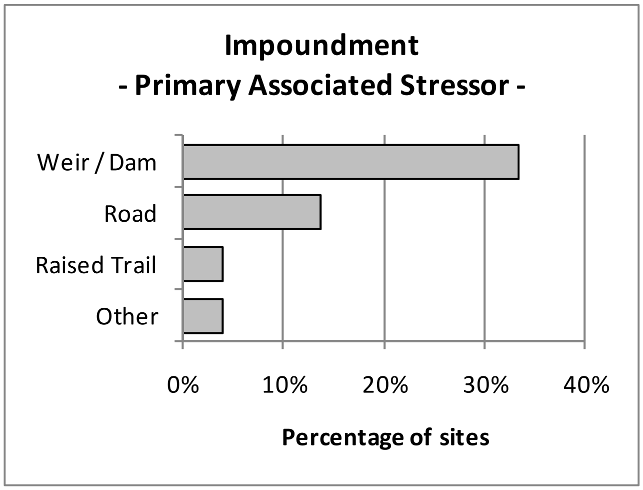


C. Wetland Stressors

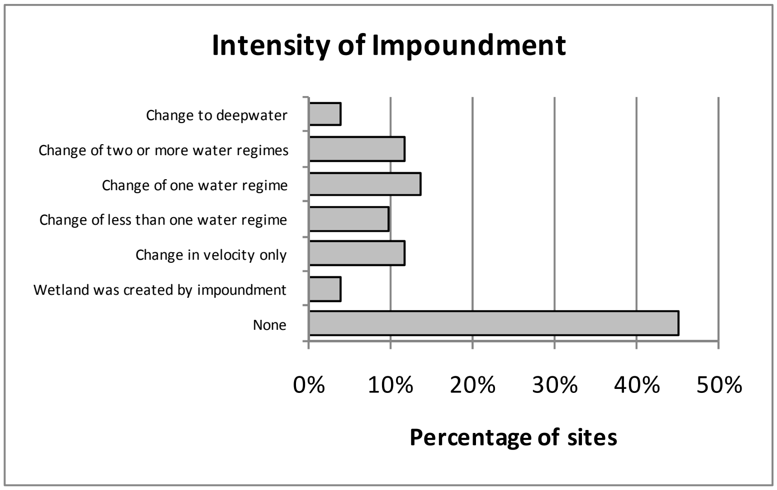
3. Impoundment



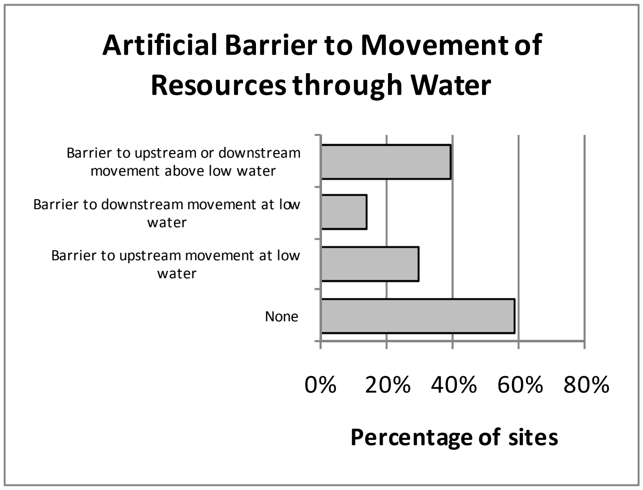




Impoundment
- Primary Associated Stressor -

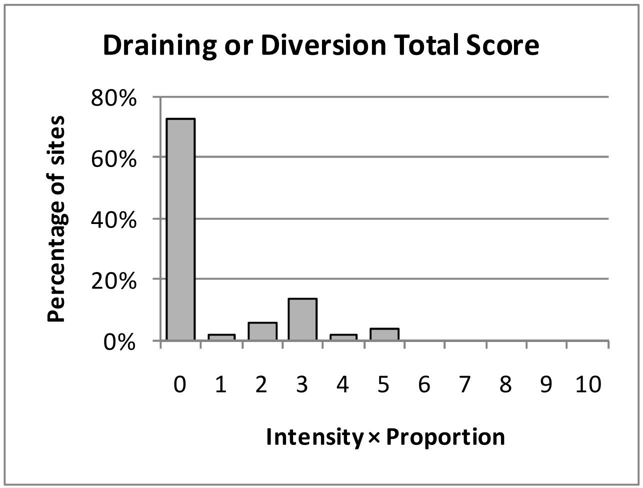


Intensity of Impoundment

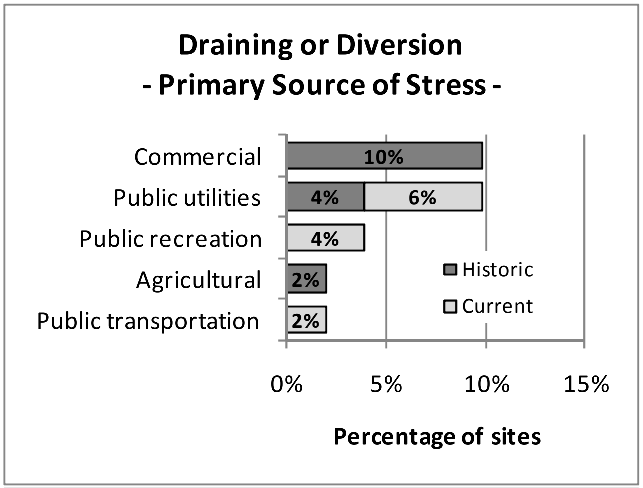


Artificial Barrier to Movement of Resources through Water

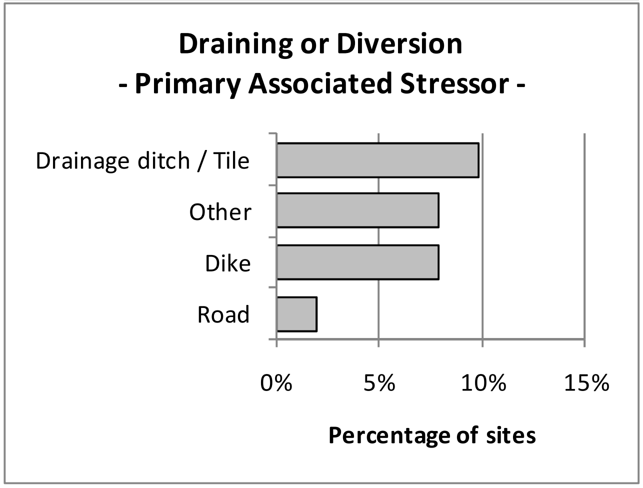
4. Draining or Diversion of Water from Wetland



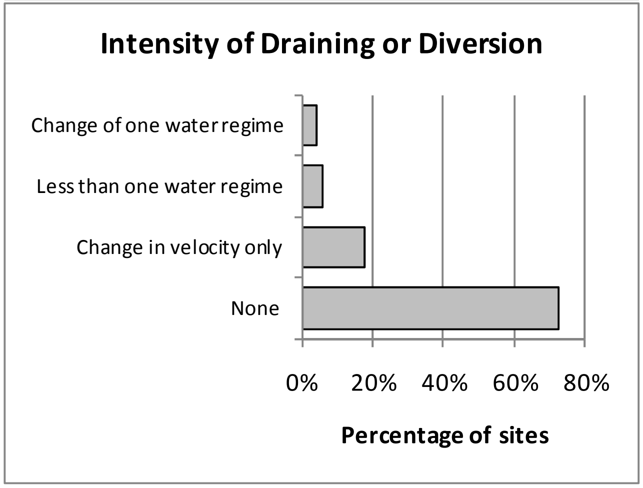
Draining or Diversion Total Score



Draining or Diversion
- Primary Source of Stress -

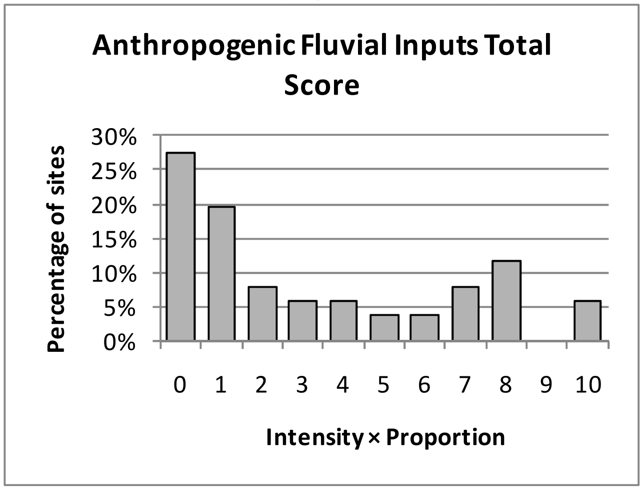


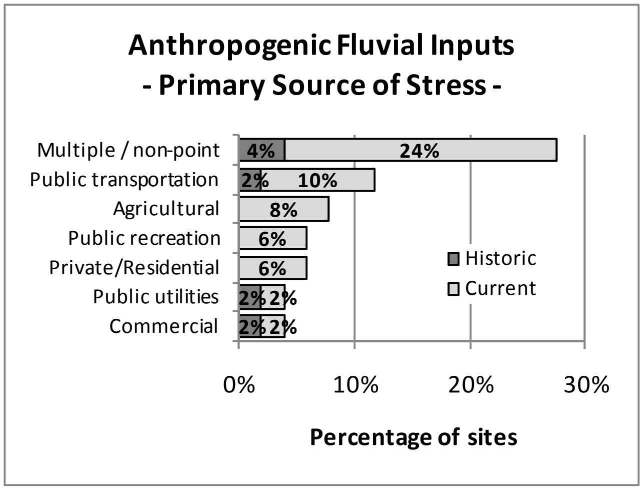
Draining or Diversion
- Primary Associated Stressor -

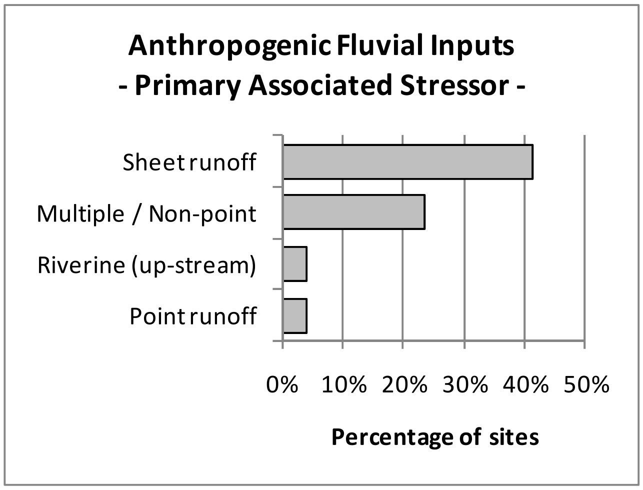


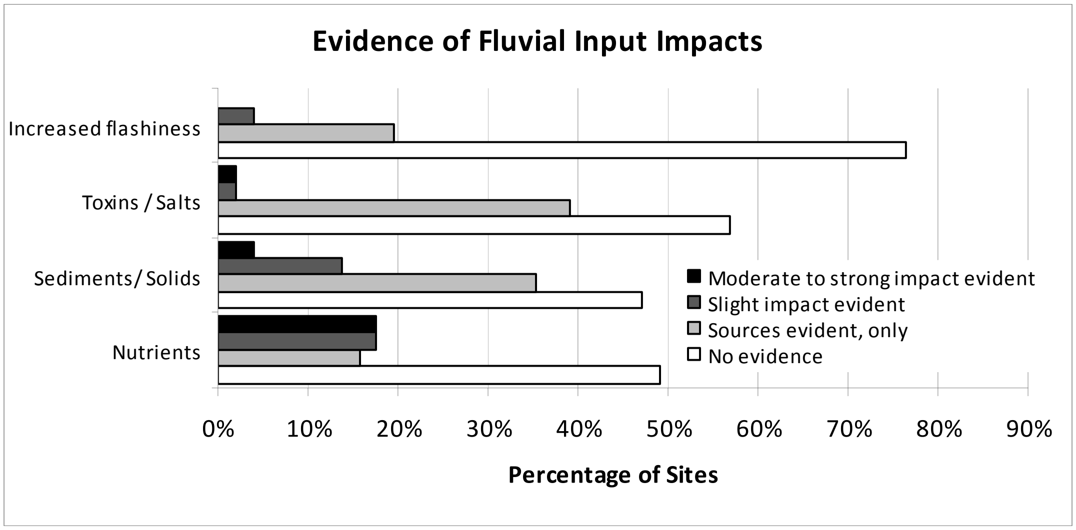
Intensity of Draining or Diversion

5. Anthropogenic Fluvial Inputs

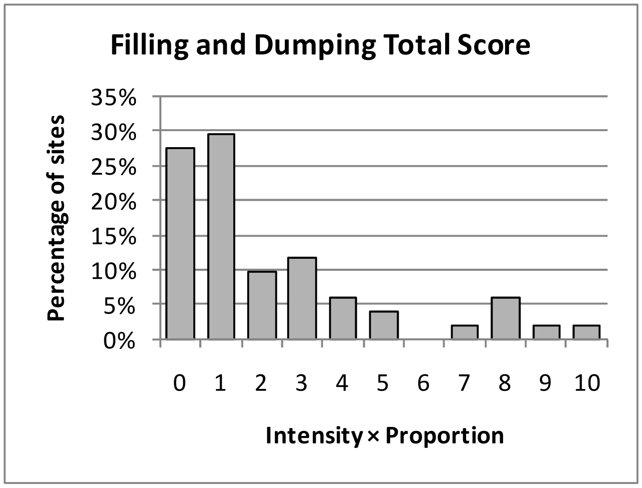


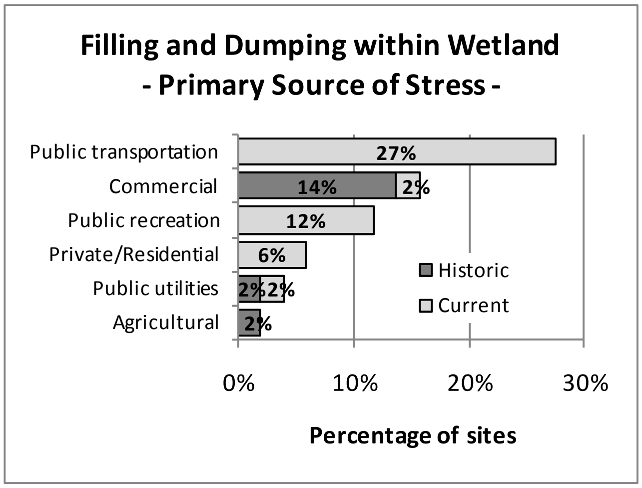


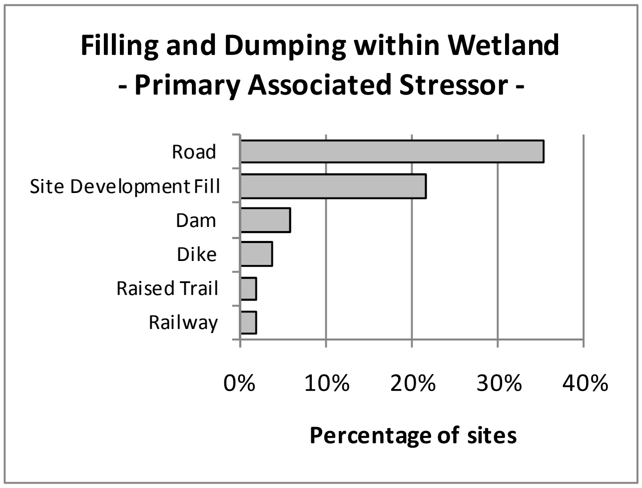


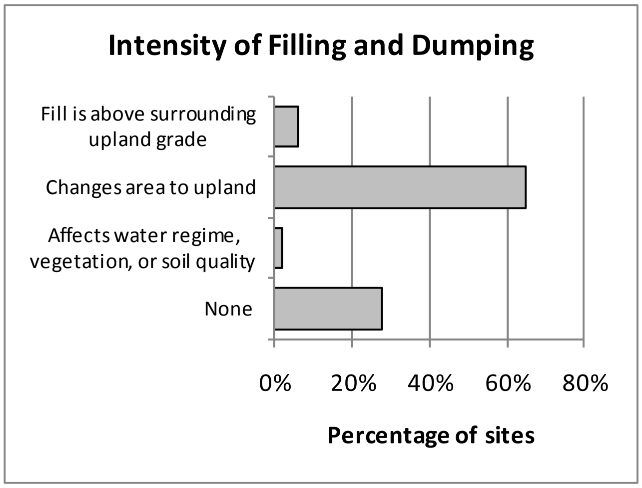


6. Filling and Dumping within Wetland

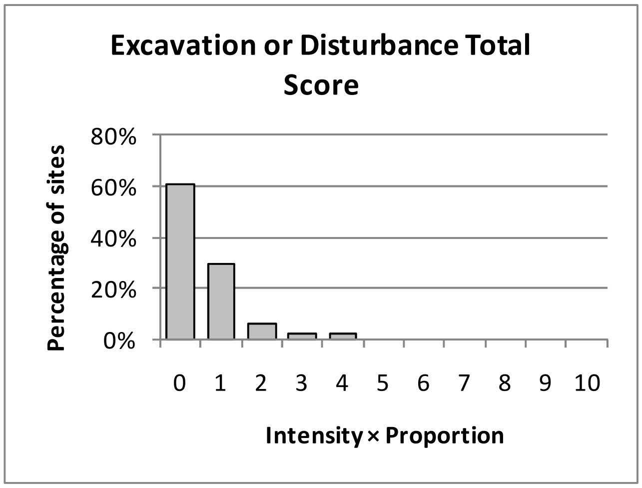


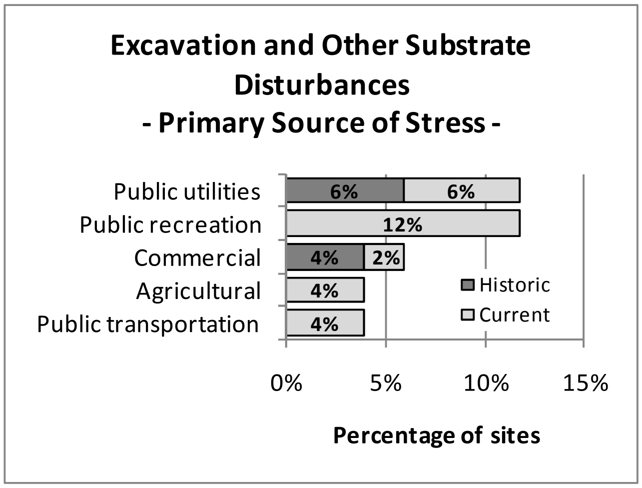


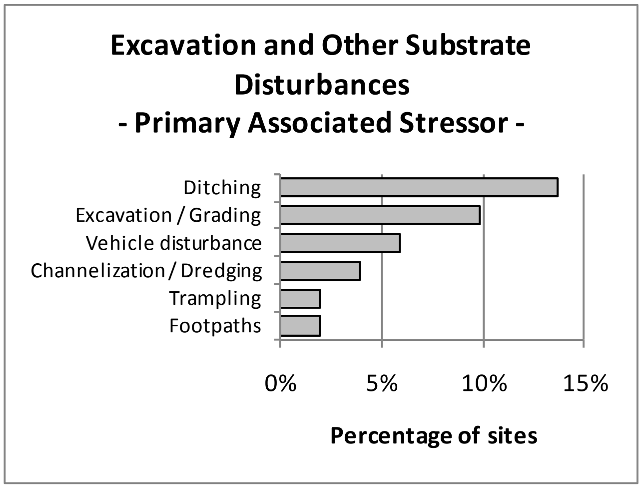


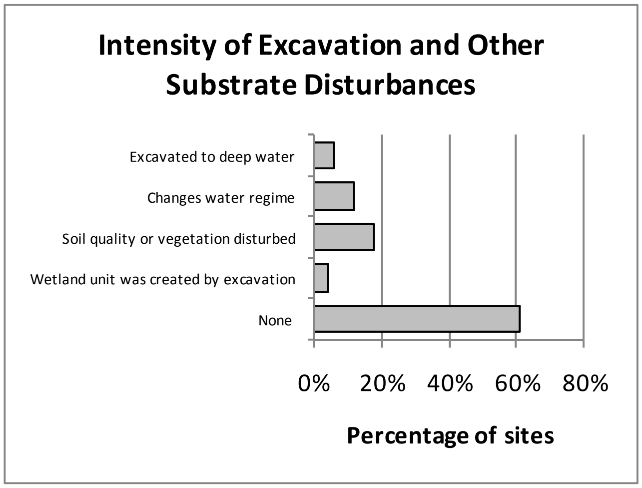


7. Excavation and other Substrate Disturbances within Wetland

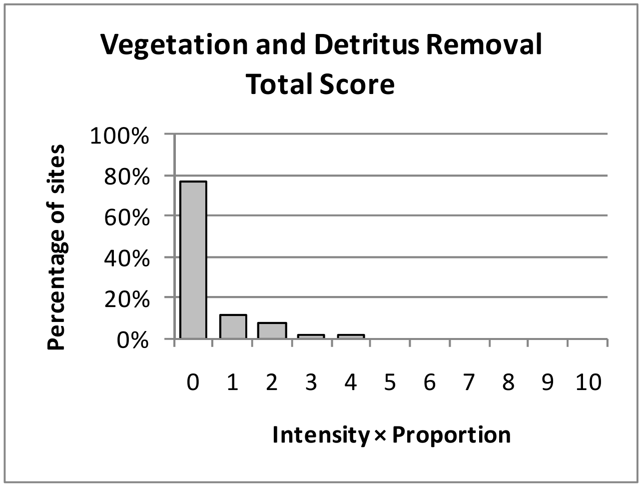


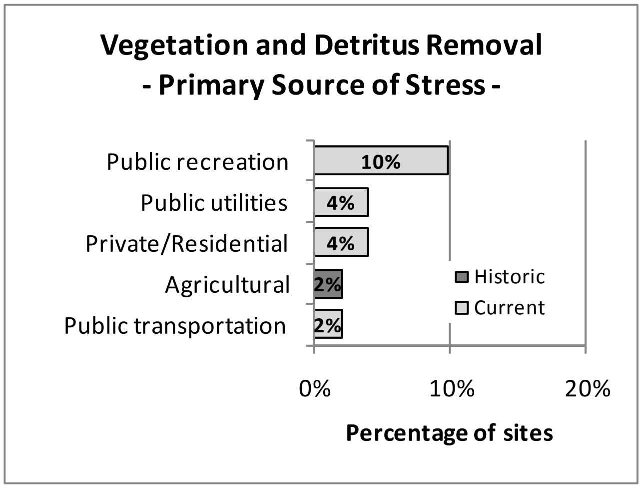


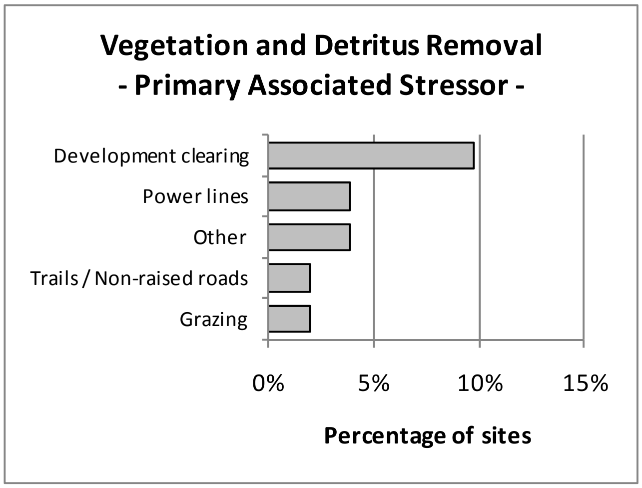


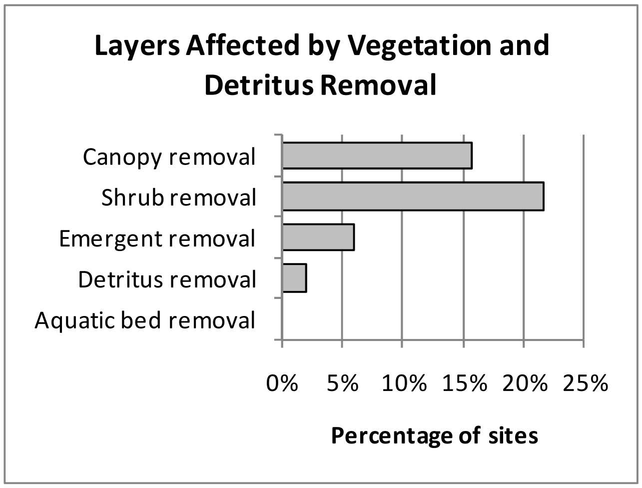


8. Vegetation and Detritus Removal within Wetland

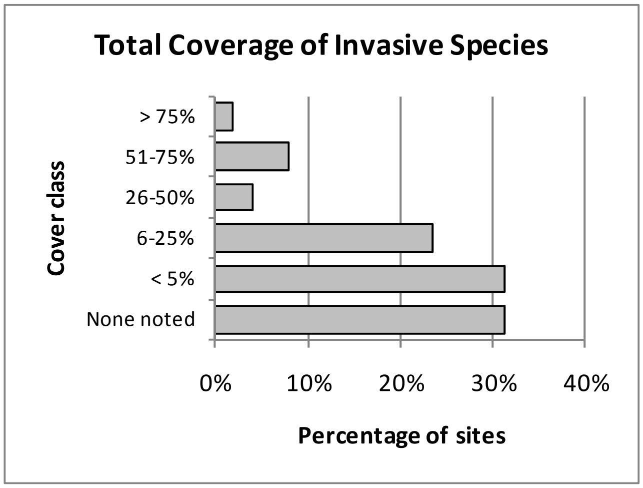


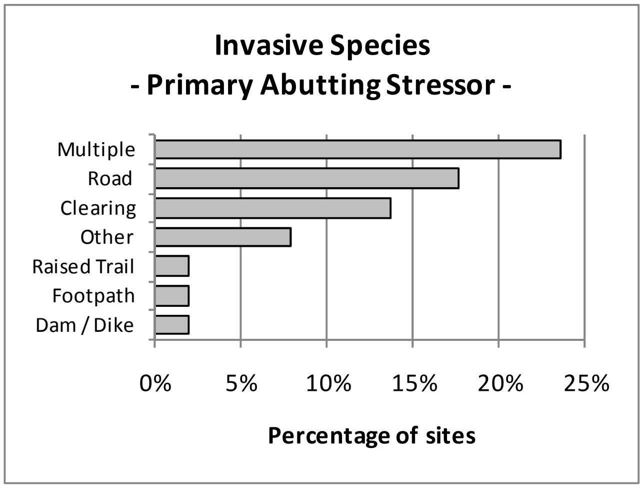


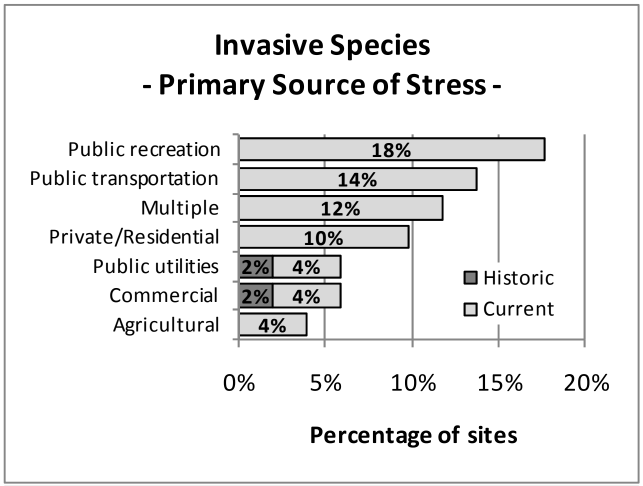


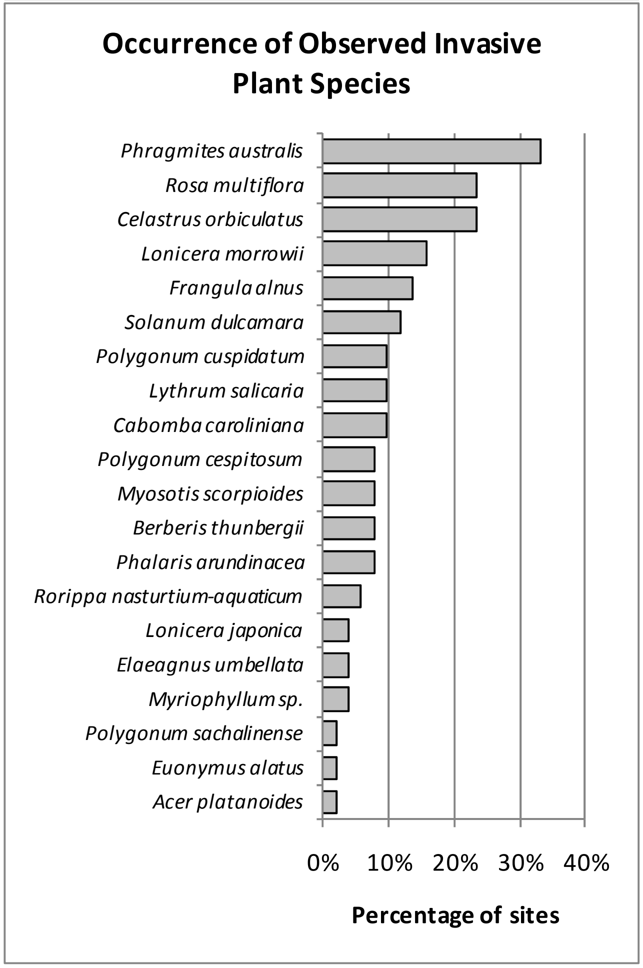


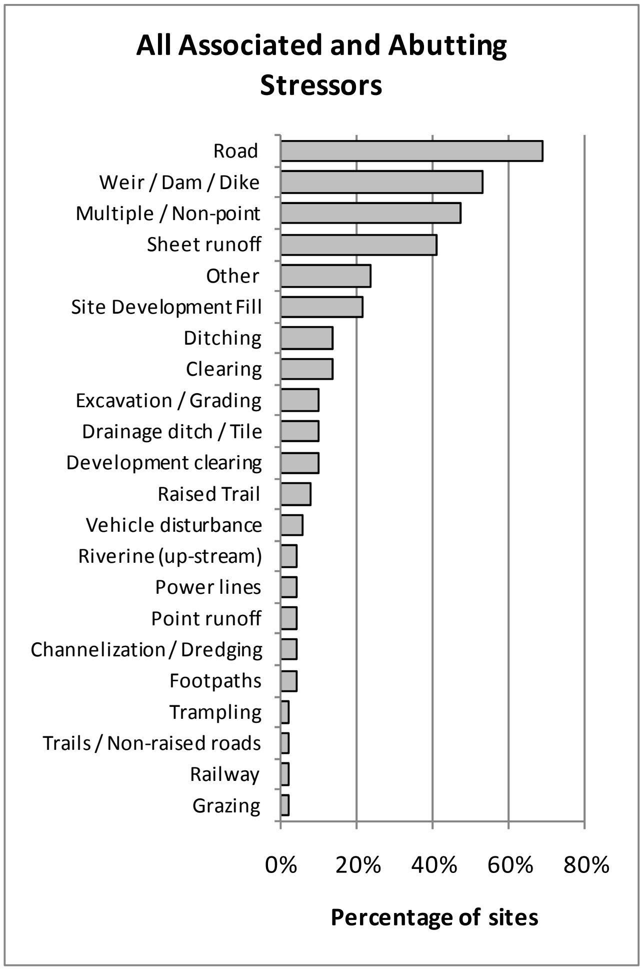
9. Invasive Species within Wetland

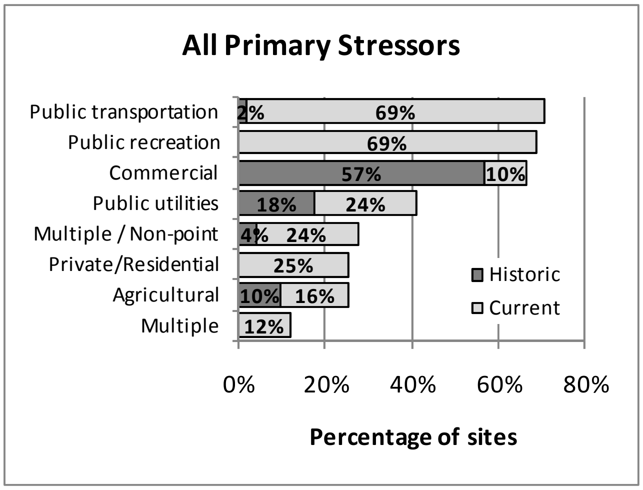




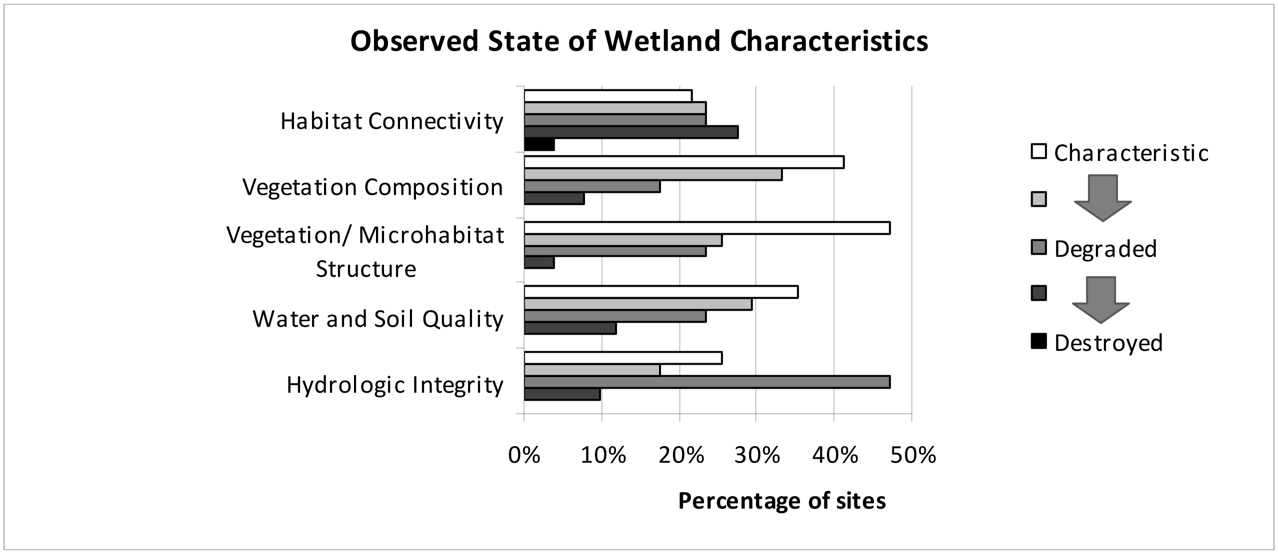








D. Observed State of Wetland Characteristics



Appendix 3

RIRAM Metric and Index Scores from 51 Wetland Assessment Units in Rhode Island

SITE CODE	B.1 DEGRADATION OF BUFFERS	B.2 SURROUNDING LAND USE	B. LANDSCAPE STRESS INDEX	C.3 IMPOUNDMENT	C.4 DRAINING OR DIVERSION OF WATER	C.5 ANTHROPOGENIC FLUVIAL INPUTS	C.6 FILLING AND DUMPING	C.7 EXCAVATION OR SUBSTRATE DISTURBANCE	C.8 VEGETATION & DETRITUS REMOVAL	C.9 INVASIVE SPECIES COVER	C. WETLAND STRESS INDEX	D. Hydrologic Integrity	D. Water and Soil Quality	D. Vegetation/ Microhabitat Structure	D. Vegetation Composition	D. Habitat Connectivity	D. OBSERVED INDICATORS INDEX	RIRAM V.2.10 CONDITION INDEX
AUD-CARD-SWP	10	9.4	19.4	2.0	0.0	0	0.0	1.0	0.0	2	65.0	1.5	2.0	2.0	2.0	2.0	9.5	93.9
AUD-EPP-QR4	10	9.4	19.4	0.0	0.0	1	1.0	0.4	0.0	2	65.6	2.0	2.0	1.5	2.0	1.5	9.0	94.0
AUD-FISH-BRK	10	9.4	19.4	0.0	0.0	1	1.0	0.0	0.0	0	68.0	2.0	1.5	2.0	2.0	1.5	9.0	96.4
AUD-NEW-PND	7	8.2	15.2	4.0	0.0	0	1.0	1.0	0.0	0	64.0	1.0	2.0	1.5	2.0	1.5	8.0	87.2
PRV-ASHA-RIV2	4	7.6	11.6	0.0	0.0	4	1.0	0.0	0.0	4	61.0	1.5	1.0	1.5	1.5	0.5	6.0	78.6
PRV-BLRD-PRK	1	7.0	8.0	0.0	0.0	6	7.0	1.0	1.6	4	50.4	1.5	1.0	1.0	1.0	1.0	5.5	63.9
PRV-BOTH-PND	10	9.7	19.7	4.0	0.0	0	1.0	0.0	0.0	0	65.0	1.0	2.0	2.0	2.0	2.0	9.0	93.7
PRV-BRCH-STA1	10	9.4	19.4	0.0	3.0	2	1.2	1.4	0.0	2	60.4	1.0	1.0	1.5	1.5	1.5	6.5	86.3
PRV-BUTT-PND	0	5.2	5.2	5.0	0.0	8	4.0	0.0	0.6	2	50.4	1.0	1.0	1.5	1.5	1.0	6.0	61.6
PRV-CARR-PND	7	9.1	16.1	1.0	0.0	3	0.0	0.0	0.0	4	62.0	1.0	1.5	2.0	1.5	1.5	7.5	85.6
PRV-DMCR-PLAY	1	3.7	4.7	0.0	3.5	2	4.0	0.4	0.6	2	57.5	0.5	1.0	1.0	1.5	0.5	4.5	66.7
PRV-EVAN-PND	0	3.4	3.4	5.4	1.5	8	10.0	2.1	0.0	2	41.0	0.5	1.0	1.5	1.5	0.5	5.0	49.4
PRV-FORG-GRN1	10	8.8	18.8	0.0	3.0	1	0.0	0.0	0.6	0	65.4	1.5	1.5	1.0	1.5	1.5	7.0	91.2
PRV-GLAC-PND	7	7.0	14.0	0.0	0.0	6	0.0	0.0	0.0	2	62.0	1.5	1.0	1.5	1.0	1.0	6.0	82.0
PRV-GRSY-PND	7	8.8	15.8	6.0	0.0	3	1.0	0.0	0.0	2	58.0	1.5	2.0	2.0	2.0	1.0	8.5	82.3
PRV-HART-BOG	7	5.2	12.2	5.0	0.0	1	2.0	0.0	0.0	2	60.0	1.0	1.5	1.5	1.5	1.0	6.5	78.7
PRV-HUNT-STA3	4	6.4	10.4	2.8	0.0	2	3.6	0.0	0.0	4	57.6	1.0	1.5	2.0	1.5	0.5	6.5	74.5
PRV-JACK-SCPD	10	9.4	19.4	8.0	0.0	2	2.0	0.0	0.0	0	58.0	1.0	1.5	2.0	2.0	1.0	7.5	84.9
PRV-LONS-MRSH	7	5.5	12.5	2.0	3.0	10	8.0	1.4	0.0	4	41.6	1.0	0.5	0.5	1.0	0.5	3.5	57.6
PRV-MAIL-FEN	10	9.4	19.4	3.4	0.0	4	1.0	0.7	0.0	2	58.9	1.0	1.5	2.0	2.0	1.0	7.5	85.8
PRV-MITC-PND	0	2.2	2.2	6.0	1.8	7	5.0	4.0	4.0	10	32.2	0.5	1.0	1.0	0.5	0.5	3.5	37.9
PRV-MOSH-PND	0	1.6	1.6	5.0	3.0	10	3.0	0.4	0.0	8	40.6	0.5	0.5	0.5	0.5	0.0	2.0	44.2
PRV-MOW-BRK2	7	8.2	15.2	2.2	0.6	3	1.0	0.4	0.2	2	60.6	1.5	1.5	2.0	2.0	1.0	8.0	83.8
PRV-NOTT-PD1	0	3.1	3.1	6.2	2.0	7	8.0	0.8	1.8	4	40.2	0.5	0.5	1.0	1.0	0.0	3.0	46.3
PRV-PED-PND	10	9.7	19.7	0.0	0.0	0	0.0	0.0	0.0	0	70.0	2.0	2.0	2.0	2.0	2.0	10.0	99.7
PRV-PYSZ-FEN	7	9.1	16.1	0.8	0.0	5	0.0	0.0	0.0	0	64.2	1.5	1.5	2.0	2.0	1.5	8.5	88.8
PRV-R216-POW	7	8.2	15.2	0.0	0.0	1	0.0	1.6	3.0	4	60.4	1.5	1.5	1.0	1.0	1.5	6.5	82.1
PRV-SLTR-PRK0	1	4.6	5.6	2.2	3.0	10	5.0	0.7	1.8	6	41.3	1.0	0.5	1.0	0.5	0.5	3.5	50.4
PRV-SNAKE-POW	7	8.5	15.5	1.0	0.0	1	3.0	0.4	2.0	0	62.6	1.0	1.5	1.5	1.5	1.0	6.5	84.6
PRV-TEN-RIV1	7	4.9	11.9	0.0	5.0	1	3.0	0.0	0.0	8	53.0	1.0	1.5	1.5	1.0	0.5	5.5	70.4
PRV-THIR-PND	7	2.8	9.8	0.0	0.0	7	1.2	0.0	0.0	8	53.8	2.0	1.5	1.0	1.0	0.5	6.0	69.6
PRV-WAR-RES	4	4.3	8.3	2.0	3.0	7	9.0	0.0	0.0	4	45.0	1.0	0.5	1.0	1.5	0.5	4.5	57.8
PRV-WOON-STA3	1	4.3	5.3	4.0	0.0	8	8.0	0.4	0.0	4	45.6	1.0	1.0	1.0	0.5	0.5	4.0	54.9
PRV-WOON-STA4	0	3.7	3.7	3.2	0.0	8	3.0	0.0	0.0	8	47.8	1.0	0.5	1.0	1.0	0.5	4.0	55.5
PRV-XXX-PWT17	1	3.7	4.7	0.0	4.2	8	3.0	0.7	0.6	4	49.5	1.0	1.0	1.0	1.0	0.5	4.5	58.7
PRV-XXX-PWT5	7	5.2	12.2	0.0	3.0	8	2.4	0.4	0.0	4	52.2	1.0	1.0	1.5	1.5	0.5	5.5	69.9
SMA-ARC-BFFEN	10	9.7	19.7	0.0	0.0	0	0.0	0.0	0.0	0	70.0	2.0	2.0	2.0	2.0	2.0	10.0	99.7
SMA-ARC-MOON	7	7.3	14.3	0.0	0.0	4	0.0	0.0	0.0	2	64.0	2.0	1.5	2.0	1.5	1.0	8.0	86.3
SMA-ARC-RBPD	10	9.7	19.7	7.0	0.0	0	1.0	0.0	0.0	2	60.0	1.0	2.0	2.0	2.0	1.0	8.0	87.7
SMA-ARC-WD3	10	9.7	19.7	0.0	0.0	0	0.0	0.0	0.0	2	68.0	2.0	2.0	2.0	2.0	2.0	10.0	97.7
SMA-BIG-CAP	10	9.7	19.7	7.0	0.0	0	1.0	0.0	0.0	2	60.0	1.0	2.0	2.0	1.5	1.0	7.5	87.2
SMA-BUCK-PD1	10	9.7	19.7	0.0	0.0	0	0.0	0.0	0.0	0	70.0	2.0	2.0	2.0	2.0	2.0	10.0	99.7
SMA-CAR-FISH	10	10.0	20.0	0.0	0.0	0	0.0	0.0	0.0	0	70.0	2.0	2.0	2.0	2.0	2.0	10.0	100.0
SMA-CAR-WLPD	10	10.0	20.0	0.0	0.0	0	0.0	0.0	0.0	0	70.0	2.0	2.0	2.0	2.0	2.0	10.0	100.0
SMA-DUR-TEPE	10	10.0	20.0	4.4	0.0	0	1.0	0.0	0.0	0	64.6	1.0	2.0	2.0	2.0	2.0	9.0	93.6
SMA-GSW-CHIP7	10	9.4	19.4	0.0	0.0	5	1.0	0.0	0.0	6	58.0	2.0	1.0	1.5	1.5	1.5	7.5	84.9
SMA-GWMA-OKPD	7	9.7	16.7	7.8	0.0	1	1.0	0.0	0.3	0	59.9	1.0	2.0	1.5	2.0	1.5	8.0	84.6
SMA-WOO-IMP	10	9.7	19.7	6.2	0.0	1	1.0	0.0	0.0	4	57.8	1.0	2.0	2.0	1.5	1.5	8.0	85.5
TNC-CRTR-WET1	7	8.8	15.8	3.0	0.0	1	2.0	0.0	0.0	0	64.0	1.0	1.5	2.0	2.0	1.5	8.0	87.8
TNC-ELL-PND	10	9.7	19.7	0.0	0.0	0	0.0	0.4	0.0	0	69.6	2.0	2.0	2.0	2.0	2.0	10.0	99.3
TNC-XXX-QR2	10	9.7	19.7	0.0	0.0	0	1.0	0.0	0.0	2	67.0	2.0	2.0	2.0	1.5	2.0	9.5	96.2

Appendix 4

Preliminary Coefficients of Conservatism for Rhode Island Odonata

		n Training Sites			
Species	**CC 510**	**LD**	**ID**	**MD**	**Total**
Aeshna canadensis	8.3	4	2	0	6
Aeshna clepsydra	8.3	16	3	2	21
Aeshna constricta	5.0	3	4	3	10
Aeshna mutata	7.5	1	1	0	2
Aeshna tuberculifera	8.2	12	7	0	19
Aeshna umbrosa	6.2	11	9	5	25
Aeshna verticalis	8.6	14	3	1	18
Amphiagrion saucium	6.4	6	2	3	11
Anax junius	5.1	20	21	19	60
Anax longipes	8.3	5	0	1	6
Argia apicalis	1.9	0	3	5	8
Argia fumipennis	4.6	23	31	29	83
Argia moesta	2.6	2	6	11	19
Argia translata	2.0	0	2	3	5
Arigomphus furcifer	6.7	5	2	2	9
Arigomphus villosipes	5.5	12	9	9	30
Basiaeschna janata	7.2	18	17	2	37
Boyeria vinosa	5.8	9	11	5	25
Calopteryx aequabilis	7.3	6	7	0	13
Calopteryx dimidiata	5.3	7	6	6	19
Calopteryx maculata	5.7	31	33	20	84
Celithemis elisa	5.7	22	18	14	54
Celithemis eponina	4.6	6	9	8	23
Celithemis fasciata	7.7	9	5	1	15
Celithemis martha	6.5	10	2	5	17
Chromagrion conditum	6.7	31	21	10	62
Cordulegaster diastatops	8.5	9	4	0	13
Cordulegaster maculata	7.5	7	4	1	12
Cordulegaster obliqua	10.0	2	0	0	2
Cordulia shurtleffi	8.3	2	1	0	3
Didymops transversa	7.5	6	6	0	12
Dorocordulia lepida	8.8	22	5	1	28
Dorocordulia libera	10.0	6	0	0	6
Dromogomphus spinosus	3.5	3	6	8	17
Enallagma aspersum	5.6	16	14	11	41
Enallagma boreale	7.9	8	3	1	12
Enallagma civile	4.0	17	23	32	72
Enallagma cyathigerum	7.5	3	3	0	6
Enallagma daeckii	6.9	8	2	3	13
Enallagma divagans	5.6	20	18	14	52
Enallagma doubledayi	5.9	8	3	5	16
Enallagma durum	1.3	0	1	3	4
Enallagma ebrium	5.7	4	8	2	14
Enallagma exsulans	2.1	1	7	13	21
Enallagma geminatum	4.7	28	30	33	91
Enallagma hageni	6.5	5	3	2	10
Enallagma laterale	6.4	14	8	6	28
Enallagma minusculum	6.1	3	5	1	9
Enallagma pictum	7.5	7	1	2	10
Enallagma recurvatum	8.2	10	3	1	14
Enallagma signatum	3.7	9	25	24	58
Enallagma traviatum	4.3	4	12	7	23
Enallagma vesperum	4.5	4	9	6	19
Enallagma weewa	7.1	5	0	2	7
Epiaeschna heros	6.7	5	2	2	9
Epitheca canis	8.8	3	1	0	4
Epitheca cynosura	6.3	32	31	12	75
Epitheca princeps	5.8	7	7	4	18
Epitheca spinigera	8.8	3	1	0	4
Erythemis simplicicollis	5.3	20	23	16	59
Erythrodiplax berenice	3.7	5	7	11	23
Gomphaeschna antilope	7.5	1	1	0	2
Gomphaeschna furcillata	8.5	16	7	0	23
Gomphus abbreviatus	5.0	1	2	1	4
Gomphus adelphus	8.0	3	2	0	5
Gomphus exilis	7.1	34	28	6	68
Gomphus lividus	7.8	6	2	1	9
Gomphus spicatus	10.0	2	0	0	2
Hagenius brevistylus	7.6	11	7	1	19
Helocordulia uhleri	7.7	9	5	1	15
Hetaerina americana	5.0	4	6	4	14
Ischnura hastata	5.4	8	9	6	23
Ischnura kellicotti	5.2	8	8	7	23
Ischnura posita	4.1	29	36	51	116
Ischnura ramburii	0.0	0	0	4	4
Ischnura verticalis	3.4	13	35	42	90
Lanthus vernalis	7.5	1	1	0	2
Lestes congener	5.7	10	6	7	23
Lestes disjunctus	6.7	18	15	5	38
Lestes dryas	3.3	0	2	1	3
Lestes eurinus	8.0	11	2	2	15
Lestes forcipatus	5.9	21	21	11	53
Lestes inaequalis	5.8	17	16	10	43
Lestes rectangularis	6.2	31	28	14	73
Lestes unguiculatus	0.0	0	0	2	2
Lestes vigilax	5.4	28	29	22	79
Leucorrhinia frigida	8.8	15	5	0	20
Leucorrhinia glacialis	10.0	1	0	0	1
Leucorrhinia hudsonica	7.8	6	2	1	9
Leucorrhinia intacta	6.3	20	19	8	47
Leucorrhinia proxima	8.8	3	1	0	4
Libellula auripennis	10.0	0	0	0	0
Libellula axilena	8.8	3	1	0	4
Libellula cyanea	6.4	20	15	8	43
Libellula deplanata	8.3	2	1	0	3
Libellula exusta	8.1	27	9	3	39
Libellula incesta	5.4	29	28	22	79
Libellula julia	10.0	5	0	0	5
Libellula luctuosa	4.0	10	26	22	58
Libellula lydia	6.0	26	19	14	59
Libellula needhami	1.0	0	1	4	5
Libellula pulchella	4.2	7	8	11	26
Libellula quadrimaculata	8.9	7	2	0	9
Libellula semifasciata	7.5	13	4	3	20
Libellula vibrans	5.0	2	3	2	7
Macromia illinoiensis	6.0	7	4	4	15
Nannothemis bella	7.5	6	6	0	12
Nasiaeschna pentacantha	7.1	5	7	0	12
Nehalennia gracilis	7.3	21	15	3	39
Nehalennia integricollis	10.0	1	0	0	1
Nehalennia irene	6.0	9	11	4	24
Neurocordulia obsoleta	7.5	1	1	0	2
Ophiogomphus aspersus	9.4	7	1	0	8
Ophiogomphus mainensis	8.8	3	1	0	4
Pachydiplax longipennis	4.1	21	22	36	79
Pantala flavescens	3.1	2	4	7	13
Pantala hymenaea	2.3	0	5	6	11
Perithemis tenera	3.9	11	19	23	53
Progomphus obscurus	8.8	3	1	0	4
Somatochlora georgiana	9.0	4	1	0	5
Somatochlora linearis	8.8	10	3	0	13
Somatochlora tenebrosa	8.8	24	8	0	32
Somatochlora walshii	9.0	4	1	0	5
Somatochlora williamsoni	10.0	3	0	0	3
Stylogomphus albistylus	6.4	8	7	3	18
Stylurus scudderi	6.7	1	2	0	3
Stylurus spiniceps	5.0	0	2	0	2
Sympetrum costiferum	4.5	4	2	5	11
Sympetrum internum	5.0	34	34	34	102
Sympetrum rubicundulum	4.2	2	6	4	12
Sympetrum semicinctum	7.0	13	9	3	25
Sympetrum vicinum	5.6	21	16	15	52
Tramea carolina	5.3	7	2	6	15
Tramea lacerata	5.0	8	8	8	24
Williamsonia lintneri	7.5	3	3	0	6

Appendix 5

Refined Coefficients of Conservatism for Rhode Island Odonata

		n Training Sites			
Species	**CC 561**	**LD**	**ID**	**MD**	**Total**
Aeshna canadensis	8.3	6	3	0	9
Aeshna clepsydra	7.9	21	7	3	31
Aeshna constricta	4.6	4	4	5	13
Aeshna mutata	8.3	2	1	0	3
Aeshna tuberculifera	8.3	16	8	0	24
Aeshna umbrosa	5.5	12	9	9	30
Aeshna verticalis	8.5	20	4	2	26
Amphiagrion saucium	6.5	9	4	4	17
Anax junius	4.9	25	27	26	78
Anax longipes	8.6	6	0	1	7
Argia apicalis	1.7	0	3	6	9
Argia fumipennis	4.4	25	38	37	100
Argia moesta	2.5	2	6	12	20
Argia translata	2.0	0	2	3	5
Arigomphus furcifer	6.8	6	3	2	11
Arigomphus villosipes	5.4	14	13	11	38
Basiaeschna janata	6.9	19	20	3	42
Boyeria vinosa	5.9	11	12	6	29
Calopteryx aequabilis	7.1	8	8	1	17
Calopteryx dimidiata	5.2	8	8	7	23
Calopteryx maculata	5.6	35	38	24	97
Celithemis elisa	6.0	29	20	16	65
Celithemis eponina	4.3	7	11	11	29
Celithemis fasciata	7.7	9	5	1	15
Celithemis martha	7.1	15	4	5	24
Chromagrion conditum	6.8	42	28	12	82
Cordulegaster diastatops	8.6	13	5	0	18
Cordulegaster maculata	7.7	9	5	1	15
Cordulegaster obliqua	8.3	2	1	0	3
Cordulia shurtleffi	8.8	3	1	0	4
Didymops transversa	7.9	10	7	0	17
Dorocordulia lepida	8.4	25	9	1	35
Dorocordulia libera	9.4	8	1	0	9
Dromogomphus spinosus	3.3	3	6	9	18
Enallagma aspersum	5.9	23	18	13	54
Enallagma boreale	8.2	10	3	1	14
Enallagma civile	3.8	20	25	41	86
Enallagma cyathigerum	7.9	8	6	0	14
Enallagma daeckii	6.3	8	3	4	15
Enallagma divagans	5.3	22	19	19	60
Enallagma doubledayi	6.3	10	5	5	20
Enallagma durum	1.3	0	1	3	4
Enallagma ebrium	5.3	4	10	3	17
Enallagma exsulans	1.9	1	7	16	24
Enallagma geminatum	4.5	32	35	43	110
Enallagma hageni	5.4	5	5	4	14
Enallagma laterale	6.6	16	10	6	32
Enallagma minusculum	6.5	4	5	1	10
Enallagma pictum	7.1	7	3	2	12
Enallagma recurvatum	8.1	12	5	1	18
Enallagma signatum	3.4	9	27	30	66
Enallagma traviatum	4.4	4	13	7	24
Enallagma vesperum	4.3	4	10	7	21
Enallagma weewa	6.9	5	1	2	8
Epiaeschna heros	6.9	7	4	2	13
Epitheca canis	8.8	3	1	0	4
Epitheca cynosura	6.2	39	36	17	92
Epitheca princeps	5.0	7	7	7	21
Epitheca spinigera	9.0	4	1	0	5
Erythemis simplicicollis	5.3	27	26	22	75
Erythrodiplax berenice	3.3	5	6	13	24
Gomphaeschna antilope	7.5	1	1	0	2
Gomphaeschna furcillata	8.5	18	8	0	26
Gomphus abbreviatus	5.0	1	2	1	4
Gomphus adelphus	8.0	3	2	0	5
Gomphus exilis	6.8	42	31	11	84
Gomphus lividus	7.8	6	2	1	9
Gomphus spicatus	10.0	2	0	0	2
Hagenius brevistylus	7.8	14	8	1	23
Helocordulia uhleri	7.9	11	5	1	17
Hetaerina americana	4.4	4	6	6	16
Ischnura hastata	6.1	13	13	6	32
Ischnura kellicotti	5.0	9	11	9	29
Ischnura posita	4.1	37	45	62	144
Ischnura ramburii	0.0	0	0	4	4
Ischnura verticalis	3.5	17	40	50	107
Lanthus vernalis	6.7	1	2	0	3
Lestes congener	6.5	15	10	6	31
Lestes disjunctus	6.7	25	20	7	52
Lestes dryas	3.3	0	2	1	3
Lestes eurinus	8.3	16	3	2	21
Lestes forcipatus	6.3	30	26	12	68
Lestes inaequalis	5.2	18	22	16	56
Lestes rectangularis	5.9	37	39	19	95
Lestes unguiculatus	0.0	0	0	2	2
Lestes vigilax	5.4	33	36	25	94
Leucorrhinia frigida	8.2	19	11	0	30
Leucorrhinia glacialis	10.0	1	0	0	1
Leucorrhinia hudsonica	7.9	8	3	1	12
Leucorrhinia intacta	6.7	28	23	8	59
Leucorrhinia proxima	9.0	4	1	0	5
Libellula auripennis	10.0	1	0	0	1
Libellula axilena	7.5	4	4	0	8
Libellula cyanea	6.4	27	21	11	59
Libellula deplanata	8.8	3	1	0	4
Libellula exusta	8.1	37	13	4	54
Libellula incesta	5.3	35	33	29	97
Libellula julia	8.3	7	1	1	9
Libellula luctuosa	3.9	13	27	28	68
Libellula lydia	5.7	31	23	20	74
Libellula needhami	0.8	0	1	5	6
Libellula pulchella	4.3	9	11	14	34
Libellula quadrimaculata	8.4	11	5	0	16
Libellula semifasciata	7.6	18	8	3	29
Libellula vibrans	5.0	2	3	2	7
Macromia illinoiensis	5.8	8	5	5	18
Nannothemis bella	7.5	8	8	0	16
Nasiaeschna pentacantha	6.3	7	10	2	19
Nehalennia gracilis	7.5	30	20	3	53
Nehalennia integricollis	10.0	1	0	0	1
Nehalennia irene	6.5	14	15	4	33
Neurocordulia obsoleta	7.5	1	1	0	2
Ophiogomphus aspersus	9.5	10	1	0	11
Ophiogomphus mainensis	9.3	6	1	0	7
Pachydiplax longipennis	4.2	29	26	45	100
Pantala flavescens	2.9	2	4	8	14
Pantala hymenaea	2.5	0	6	6	12
Perithemis tenera	3.5	12	19	30	61
Progomphus obscurus	8.8	3	1	0	4
Somatochlora georgiana	9.0	4	1	0	5
Somatochlora linearis	8.7	11	4	0	15
Somatochlora tenebrosa	8.6	26	10	0	36
Somatochlora walshii	9.3	6	1	0	7
Somatochlora williamsoni	10.0	3	0	0	3
Stylogomphus albistylus	7.2	13	7	3	23
Stylurus scudderi	7.0	2	3	0	5
Stylurus spiniceps	5.0	0	2	0	2
Sympetrum costiferum	4.5	4	2	5	11
Sympetrum internum	5.1	43	38	41	122
Sympetrum rubicundulum	4.6	3	7	4	14
Sympetrum semicinctum	6.8	14	10	4	28
Sympetrum vicinum	5.3	25	22	21	68
Tramea carolina	5.8	9	4	6	19
Tramea lacerata	4.3	8	10	12	30
Williamsonia lintneri	7.7	7	6	0	13